ARCHAEOLOGICAL RESIDUES AND RECIPES: EXPLORATORY TESTING FOR EVIDENCE OF MAIZE AND CACAO BEVERAGES IN POSTCLASSIC VESSELS FROM THE VALLEY OF OAXACA, MEXICO

Daniela Soleri, Marcus Winter, Steven R. Bozarth, and W. Jeffrey Hurst

As dates of earliest use of Theobroma cacao *in ancient Mesoamerica are established, interest is shifting to how cacao was used. One approach is to consider combinations of ingredients—the recipes for ancient cacao use. Beverages made from cacao seeds and maize have a long history in Mesoamerica. We began testing the hypothesis that there is qualitative evidence of this beverage type in the Postclassic archaeological record in a region where such a beverage,* tejate, *is a culturally significant food today. We looked for evidence of* tejate *ingredients in residue samples from eight Postclassic and one contemporary vessel from the Valley of Oaxaca, Mexico. Detection of morphologically specific maize phytoliths was accomplished by taxonomic analysis and comparison with a reference collection.* Tejate *ingredients* Pouteria sapota *and* Quararibea funebris *were also processed for phytolith detection. Testing for methylxanthines characteristic of* Theobroma *species used high-performance liquid chromatography-mass spectrometry. Four vessels were positive for maize phytoliths; three were positive for theobromine; two were positive for both maize and cacao. No diagnostic phytoliths were identified for the other* tejate *ingredients. Our hypothesis was supported; still, many challenges are present in the search for a deeper understanding of ancient cacao usage in this region of Mesoamerica.*

Estudios recientes han fechado el uso de Theobroma cacao *en varias regiones de Mesoamérica y ahora el interés en el cacao ha cambiado hacia cómo fue utilizado. Un enfoque es considerar las combinaciones de ingredientes, las recetas para el uso antiguo del cacao. Las bebidas hechas de semillas de cacao y maíz tienen una larga historia en Mesoamérica. Nosotros sometimos a prueba la hipótesis de que existe evidencia cualitativa de este tipo de bebida en el registro arqueológico del Postclásico, en una región donde hoy en día el tejate es un alimento culturalmente importante. Buscamos evidencia de los ingredientes del tejate en muestras de residuos tomadas de ocho vasijas postclásicas y una vasija contemporánea, todas procedentes del Valle de Oaxaca, México. Se detectaron fitolitos de maíz morfológicamente específicos por medio de análisis taxonómico y comparación con una colección de referencia. Los ingredientes del tejate,* Poutería sapota *(semillas de mamey) y* Quararibea funebris *(flor de rosita de cacao) también fueron procesados para detectar fitolitos. Se utilizó cromatografía líquida-espectometría de masas de alto rendimiento para la prueba de presencia de metilxantinas características de las especies de* Theobroma. *Cuatro vasijas resultaron positivas para fitolitos de maíz, tres positivas para teobromina y dos positivas tanto para maíz como para cacao. No se identificaron fitolitos diagnósticos para los otros ingredientes del tejate. Los resultados apoyan nuestra hipótesis. Sin embargo, quedan numerosos retos en la búsqueda de un mejor entendimiento sobre el uso antiguo del cacao en esta región de Mesoamérica.*

Many of the iconic traditional foods of contemporary Mesoamerica were described in the historical record by the Spaniards when they reached the New World (Hernández 2000:107-116; Sahagún 2000). For example, Sahagún describes cacao-based beverages (presumably *Theobroma cacao*) being sold and consumed in local markets (Sahagún 2000). Prehispanic codices and the archaeological record provide evidence of certain foods, either through their depiction or by the presence of particular tools or other implements specific to the preparation or con-

Daniela Soleri ■ Geography Department, University of California, Santa Barbara, Santa Barbara, CA 93106-4060 (soleri@geog.ucsb.edu)
Marcus Winter ■ Instituto Nacional de Antropología e Historia, Pino Suárez 715, 68000 Oaxaca, Oaxaca, Mexico (winteroax@prodigy.net.mx)
Steven R. Bozarth ■ University of Kansas Palynology Laboratory, Department of Geography, Lawrence, KA 66045-7613 (sbozarth@ku.edu)
W. Jeffrey Hurst ■ The Hershey Company Technical Center, Hershey, PA 17033 (whurst@hersheys.com)

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sumption of that food. The so-called *Zouche-Nuttall Codex*, dating to the Late Postclassic (A.D. 1200–1521) from the Mixtec area of what is now the state of Oaxaca, Mexico (Anders et al. 1992), includes images of foam-topped beverages being served in tripodal, vertical-necked *ollas*, held up with two hands, apparently as offerings, by seated nobles. Some of these images include representations of agave leaves, suggesting a *pulque*-like drink; others include flowers or what appear to be cacao pods.

The Valley of Oaxaca likely had access to cacao by the Late Postclassic, both through short (from the Pacific coast trade center of Tututepec for cacao grown by its tributaries [Levine 2011]) and long-distance trade (production from Soconusco that involved traveling long distances, including to central Mexico at the time [Gasco 2006]), although there were other sources as well. While not always on the scale of Soconusco cultivation, cacao appears to have been cultivated in appropriate environments, or improved ones (i.e., with irrigation), throughout precolonial Mesoamerica and including what is now northern Oaxaca, where diversity of remnant cacao populations suggests this was once an area of intense cultivation (Millon 1955; Ogata et al. 2006).

Research regarding ancient or historic diets has focused on the presence or absence of particular plant species and has found material evidence in the New World of maize (*Zea mays mays*), beans (*Phaseolus* spp), squash (*Cucurbita* spp), and chili (*Capsicum* spp) among many others (Bozarth 1987, 1990, 1993a; Piperno et al. 2009; Piperno and Stothert 2003). Recently, a number of studies have reported the early presence of *Theobroma* species, assumed to be *T. cacao*, detected in archaeological vessels or remains of vessels thought to have been used to serve or consume beverages in Early Preclassic Olmec Ojochi (from 1350 B.C.) and Mokaya (1900 B.C.) sites in Atlantic and Pacific coastal Mexico, respectively (Powis 2007); in a broad span of Early Preclassic Olmec (1800–1000 B.C.) occupation of their first capital San Lorenzo, in what is now Veracruz, Mexico (Powis et al. 2011); in Mayan Belize (600 B.C.–A.D. 250) (Hurst et al. 2002); in Ocotillo phase Puerto Escondido, northeastern Honduras (1400–1100 B.C.) (Henderson et al. 2007); and in what is today the southwestern United States (A.D. 1000–1125) (Crown and Hurst 2009) and (A.D. 900–1400) (Washburn et al. 2011). As we explain later, *T. bicolor* also may have been a source of these positive identifications (Kufer and McNeil 2006). For this reason, we use the term "cacao" as a gloss referring to both *T. cacao* and *T. bicolor*, unless otherwise indicated.

As an increasing number of studies are establishing dates of earliest use and distribution of prepared cacao in ancient Mesoamerica, a call to expand the research agenda to include "a more considered discussion of the richness of cacao cuisine" in the region (Joyce and Henderson 2010; see also Powis et al. 2002:101) has been made. One approach is to investigate not only the occurrence of cacao, but also its presence in combination with other ingredients—in a sense, the recipes for ancient cacao use. Vessel forms and imagery suggest this was often in the form of beverages. Contemporary preparation of traditional recipes is a useful starting place for insights into ancient recipes. Today, Mesoamerican cacao consumption in the form of traditional foods persists, including as a foam-topped beverage made from cacao seeds and maize, often with other plant-derived ingredients: a widespread family of recipes with many local variants, appreciated for their gastronomic qualities (Green 2010; especially regarding Maya Mesoamerica, see McNeil 2006:Table 17.11; Soleri and Cleveland 2007). Their ubiquity is also linked to the significance of those two plants in indigenous Mesoamerica: maize is widely considered the source of life and fertility, often embodied in a maize deity (e.g., Sellen 2011); cacao is frequently associated with the underworld (e.g., Prufer and Hurst 2007) and the cycle that proceeds from death back to life and spiritual meaning (e.g., Martin 2006). In addition, the foam in these beverages is in itself a coveted element, perhaps related to its spiritual interpretation; a central concept in Zapotec worldview is that of *pé*, a life force present in all animated objects, said to explicitly include the foam atop a cacao beverage (e.g., Marcus 1978:174).

The study discussed here is one part of an interdisciplinary project investigating the ethnographic, historical, and nutritional facets of such a beverage, as well as its relationship with agrobiodiversity. This research begins to test the hypothesis that there is evidence of this type of beverage in the Postclassic archaeological record in a region where

a maize and cacao beverage, *tejate*, is today an iconic food of substantial cultural significance. To do this, we looked for positive evidence of both cacao and maize, as well as two other plants typically used in *tejate's* contemporary preparation, *Pouteria sapota* and *Quararibea funebris*.

Tejate

In the family of cacao beverages made with maize, the manner in which the grain is processed can differ. For example, today in southern Mexico, households may boil their maize to prepare *atoles* containing cacao; in Oaxaca, an *atole*-like beverage called *pozontle* includes the petiole of the vine *cocolmécatl* (*Smilax* spp) as a flavoring and foaming agent (Kennedy 2010:327). Similarly, in the Isthmus of Tehuantepec, boiled maize, toasted cacao, cinnamon, and frangipani flowers (*Plumeria rubra* L.) are used to make *bu'pu* (Musálem 2002). To make *pinole,* toasted maize is ground with cacao and other spices (Popenoe 1919). Maize is nixtamalized using calcium carbonate (lime) before grinding for *pozol* (Javier 2000:35), and when making *chorote*, a fermented maize and cacao beverage in Tabasco (Castillo et al. 2005). Lime-nixtamalized maize is also used to make *tascalate* in Chiapas, which includes *achiote* (*Bixa orellana*) that also may be added as a foam-colorant for *atoles* as documented by Kennedy (2010:321). Other additives to maize and cacao beverages include chilis, vanilla, and honey and other ingredients such as those used in *tejate*.

Tejate is a traditional, foam-topped beverage made from cacao, other plant-based ingredients, and maize that has been nixtamalized using ashes, not lime. *Tejate* is prepared in many of the Zapotec communities in the Valley of Oaxaca (González 2006; Soleri et al. 2008), particularly in the Valley center and its Zimatlán and Tlacolula branches. Typical *tejate* ingredients include *T. cacao* and sometimes *T. bicolor*, *pixtle*—the seed of mamey (*Pouteria sapota*), and the aromatic blossoms of *rosita de cacao* (*Quararibea funebris*). There are variants of this recipe, including the ones with coconut, walnuts, and peanuts; but for *tejate* made with maize—cacao, *pixtle,* and *rosita de cacao* are the most typical. All of those ingredients are individually toasted and then ground together to create a paste. Similarly, the ash-nixtamalized maize is washed, then ground into a paste and combined with the cacao mixture. Water is then gradually incorporated to produce a milky, foam-topped liquid that may be served for special occasions, including some Christian religious holidays such as Easter; and it also is served as a daily staple (Soleri et al. 2008) and is a significant source of energy in some rural households (Sotelo et al. 2012). To produce the desirable surface froth, a portion of *tejate* is often poured into the rest from a height, precisely as shown in Mesoamerican archaeological (e.g., Kerr and Kerr 2005) (Figure 1) and historical depictions (e.g., Sahagún 2012).

Today in Oaxaca, *tejate* is served and consumed using decorated, hemispherical bowls or cups called *jícaras,* which are made from tree gourds (*Crescentia cujete* and *C. alata*) that are cut in half longitudinally. One *jícara* is used for serving and often left floating on the surface of the *tejate* in the large bowl in which it was mixed, while other *jícaras* are used for drinking. Some of highland Oaxaca's earliest pottery vessels have the same form, as if they were imitations of *jícaras* (see Flannery and Marcus 1994: Fig. 7.3). The historic and contemporary association of *jícara* vessels with maize beverages has been documented elsewhere in Mesoamerica (e.g., Ventura 1996). It is possible that *tejate*, or related beverages such as *pozol*, have been consumed since ancient times using *jícaras*, even before ceramics were made.

Archaeological Vessels in Oaxaca

Approximately 3,500 years ago, people in the Valley of Oaxaca started making pottery vessels and using them for cooking and serving food (Flannery and Marcus 1994; Winter 1984). Initially, only two vessel forms were made: jars (*ollas*) for cooking and perhaps storing food and water, and hemispherical bowls (*cajetes semiesféricos*), similar in form to *jícaras*, which were used for serving food and liquids. We know that people at that time ate some domesticated plants, including maize, squash (*Cucurbita pepo* and/or *argyrosperma*) (Piperno and Smith 2012), perhaps chili peppers (*Capsicum annum*) (Perry and Flannery 2007), and numerous other plants as well as animals obtained through gathering and hunting. Jars and bowls have persisted as the two basic vessel forms made and used in Oaxaca. Bowls have become elaborate, probably in relation to the types of food and drink peo-

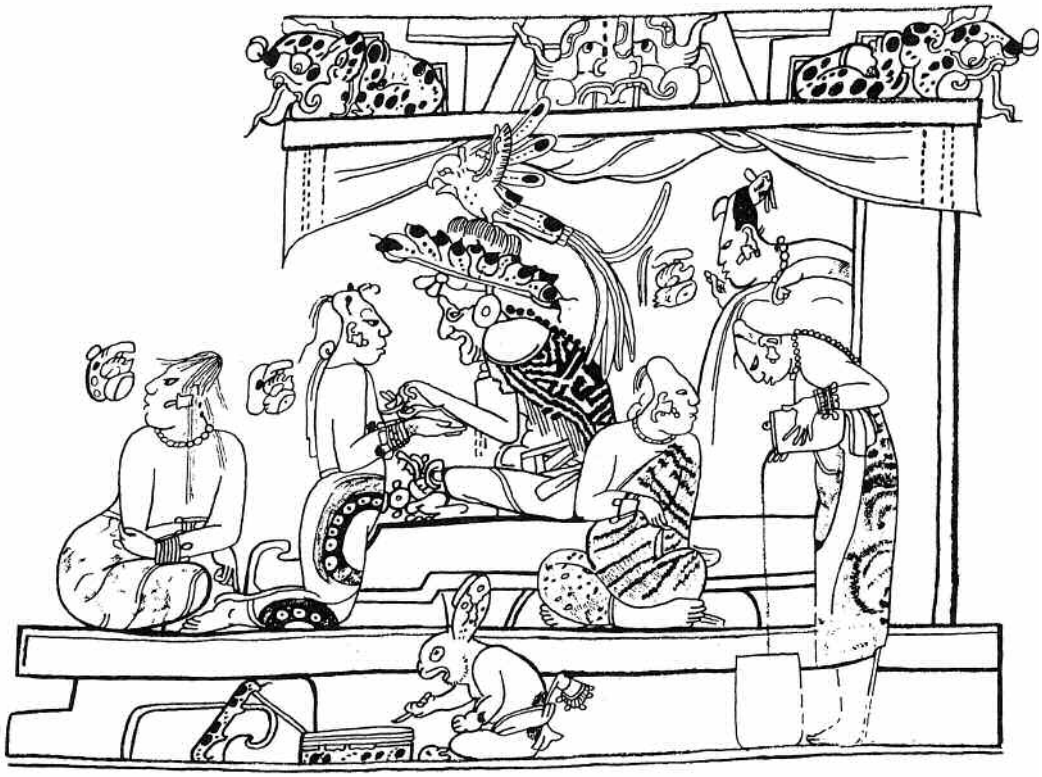

Figure 1. The "Princeton vase," a Classic period Mayan vessel decorated with a scene that includes the frothing of a cacao beverage by pouring the liquid into itself from a height (Kerr and Kerr 2005), in the same manner as *tejate* is frothed in the Valley of Oaxaca today (drawing copyright © 2000 by John Montgomery, after Kerr © K511; © Foundation for the Advancement of Mesoamerican Studies, Inc., www.famsi.org; item JM03214; reprinted by permission).

ple consumed, and also perhaps in relation to the context of use, whether as vessels for everyday domestic meals or special ceremonial occasions.

One of the first changes in bowl form evident in the archaeological record in Oaxaca is the appearance around 1300 B.C. of flat-based conical bowls (*cajetes cónicos*), probably used as serving vessels, followed by the appearance of cylindrical bowls or cups (*vasos*) around 1200 B.C. The cylinders may have been introduced to highland Oaxaca via direct or indirect contact with the Olmecs who flourished from 1800–400 B.C. in the Gulf coast region of modern Veracruz and Tabasco (Winter and Blomster 2008), an area that has produced evidence of early, continuous, and increasingly diversified use of liquid cacao at the first Olmec capital, San Lorenzo, in the Early Preclassic, starting in approximately 1800 B.C. (Powis et al. 2011). Some *vasos* from highland Oaxaca, decorated with Olmec style symbolic designs, may have been used in ritual settings for the consumption of a cacao drink, a hypothesis based on this history and on practices in the Gulf coast of modern Mexico (Winter and Blomster 2008).

Another vessel form, the spout-handled jar (*jarra con asa vertedera*), appeared in highland Oaxaca during Late Preclassic times, around 300 B.C. Residue analysis has shown that spout-handled vessels from the Maya area during this period were used for cacao (Powis et al. 2002). It seems likely that this vessel form served the same function in Oaxaca. Spout-handled jars may have been introduced into highland Oaxaca from Chiapas by way of the southern Isthmus, where they are found commonly in the Late Preclassic Goma (400–200 B.C.) and Kuak (200 B.C.–A.D. 1) phases. At Santo Domingo Tomaltepec in the Valley of Oaxaca, a high status Pe phase (300–100 B.C.) tomb contained 22 spout-handled jars (Whalen 1981), possibly contributed as burial offerings after being

used in the mortuary ceremony. *Vasos* and spout-handled vessels continued to be made and used in highland Oaxaca during the Classic period (A.D. 250–800), although they were not as common then as they were in earlier times.

During the Postclassic (A.D. 800–1521), various common forms of serving vessels—plates with wide everted rims, hemispherical bowls, vertical-necked jars, and composite-silhouette bowls—appeared with long tripod supports sometimes ending in zoomorphic effigy heads, typically of serpents and occasionally of eagles. They commonly occur in fine gray-paste ware and less frequently in elegant, highly decorated polychrome ware. Tripod, vertical-necked *ollas* are depicted in the codices containing frothy beverages. The Postclassic vessel forms common in the Valley of Oaxaca were the focus of our study.

As mentioned earlier, previous studies of archaeological food residues have focused on ascertaining the presence or absence of a single plant species to provide insights into past dietary practices and diversity and to determine the earliest use of a particular species. In contrast, this exploratory study starts with a nutritionally important and culturally iconic contemporary beverage and takes the first step of qualitatively investigating the presence or absence of the key components of that recipe (maize and cacao) in a sample of relatively recent (Postclassic) archaeological vessels.

Materials and Methods

Vessel Identification and Sampling

Postclassic vessels were selected for sampling for two reasons. First, it is not known when *tejate* was first made and consumed in Oaxaca; thus, the Postclassic is the archaeological period most likely to have continuity with the present day use of *tejate,* and so Postclassic vessels might offer a better chance for finding maize and cacao residues than vessels from earlier periods.

We sought evidence of a widespread Mesoamerican recipe in the Postclassic archaeological record within the spatial distribution of a contemporary local variant of that recipe. We sampled vessels from sites in the Tlacolula Valley (eastern branch of the Valley of Oaxaca, see Figure 3), one of the two branches in which *tejate* is most commonly made today (González 2006). San Andrés Huayapan, at the western edge of the Tlacolula Valley, is where *rosita de cacao* trees are cultivated today, a further contemporary association with *tejate*. As such, ours is a reverse chronological approach to investigating the presence of *tejate*, or a similar beverage in the Oaxacan archaeological record. This strategy is similar to the Direct Historical Approach advocated by Marcus and Flannery (1994), which uses contemporary ethnographic information in part to guide archaeological investigation and interpretation.

The second rationale for our sampling strategy is that Postclassic vessels presumably had been exposed to less post-depositional wear and weathering, and the vessels chosen, in particular, were excavated relatively recently and had not been too extensively cleaned.

Samples were taken from complete or reconstructable vessels of known form found in primary, clearly documented contexts. Vessel 1 is a Pilitas polychrome (Lind 1987), vessels 2-6 are G.3M (Caso et al. 1967), and vessels 7 and 8 are Xoxocotlán polychrome (Winter 2004) (Table 1, Figure 2). Six of the eight prehispanic vessels (numbers 1–6) sampled come from sites in the Tlacolula Valley; the other two (numbers 7 and 8) are from the central area of the Valley of Oaxaca (Figure 3).

All prehispanic vessels sampled are serving vessels, and, presumably, at least some were used to serve beverages, especially the vertical-necked tripod jars (vessels number 1 and 3) similar to those depicted in the codices. The contemporary vessel 9, a large bowl (*cazuela*), was used for five years to mix and serve *tejate* before it was acquired from a household in the Tlacolula area for this study.

The assumption underlying archaeological residue sampling is that repeated preparation of particular foods results in some food compounds permeating the vessel walls, some persisting over long periods. Interiors of the vessels that we sampled were completely burnished and hard-fired, and all had been rinsed to some extent after initial recovery and so required scraping with a pointed steel blade to loosen material for sampling. The scrapings, in the form of powder, were collected in individual plastic Ziploc bags and labeled with the vessel's provenience data and a sample number. Each vessel was sampled twice, with two exceptions: vessel 2 was inadvertently sampled three

Table 1. Sampled Vessels and Their Characteristics.

Vessel Number	Description	Branch of Valley of Oaxaca	Location and Context Where Found	Excavation Year	Residue Subsample Numbers in This Study	Dimensions (cm)		
						Diameter		
						Mouth	Body	Height
1	Tripod polychrome vertical-necked jar	Tlacolula	Macuilxóchitl; mound 35, feature 12 (Markens 2008; Winter, et al. 2007)	2002	1, 1B	16.0	16.5+	16.0
2	Tripod grayware periform jar	Tlacolula	Macuilxóchitl; mound 1, burial 18, object 7 (Markens 2008; Winter, et al. 2007)	2002	2, 2B, 2C	12.0	15.0+	16.0
3	Tripod grayware vertical-necked jar	Tlacolula	Macuilxóchitl; mound 1, feature 22, object 1 (Markens 2008; Winter, et al. 2007)	2002	3, 3B	13.0	15.5+	16.0
4	Tripod grayware jar with everted rim	Tlacolula	Macuilxóchitl; mound 1, feature 35, object 2 (Markens 2008; Winter, et al. 2007)	2002	4	13.0	15.5+	18.4
5	Tripod composite silhouette bowl; two-tone grayware	Tlacolula	Xaagá; área L, feature 1, object 4 (Martínez López and Markens 2008)	2003	5, 5B	16.5	11.2	-
6	Tripod composite silhouette bowl; two-tone grayware	Tlacolula	Macuilxóchitl; mound 1, feature 36, object 1 (Markens 2008; Winter, et al. 2007)	2002	6, 6B	17.5	10.7	-
7	Tripod bowl of red paste with white rim band and specular red slip (Xoxocotlán polychrome)	Zimatlán	Xoxocotlán; tomb 1 (Nieuwland 1990)	1987	7, 7B	9.7	12.8	-
8	Tripod bowl of red paste with white band, specular red slip, and painted decoration on the rim (Xoxocotlán polychrome)	Zimatlán	Xoxocotlán; tomb 1 (Nieuwland 1990)	1987	8, 8B	9.7	15.3	-
9	Contemporary bowl made in Atzompa, Oaxaca; green glaze on interior	Tlacolula	San Bartolomé Quialana household	2007	9	25.5	9.5	-

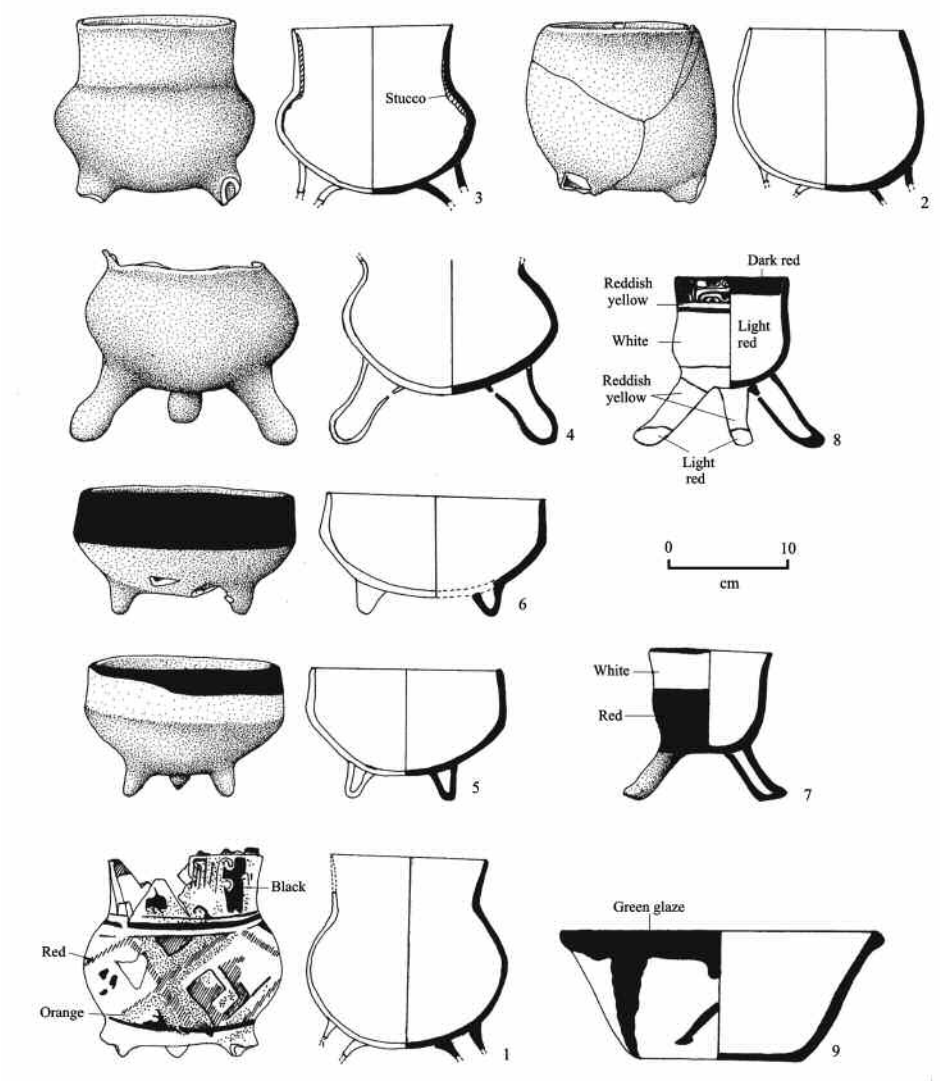

Figure 2. Drawings of vessels sampled for residue analysis. Vessel number next to each drawing is the same as in Table 1 (Juan Cruz Pascual, Artist).

times and vessel 4 only once. Samples for each vessel were then pooled and provided, first, to W. Jeffrey Hurst at the Hershey laboratory. After extracting a portion for methylxanthine detection, the remainder of each vessel's sample was sent to Steven R. Bozarth at the University of Kansas for phytolith analysis.

Methylxanthine Detection

Seeds and other parts of *Theobroma* species contain the methylxanthines theobromine (the most abundant in *T. cacao* and considered a marker for that species), caffeine and theophylline (Sotelo and Alvarez 1991). *Theobroma* species are the only known significant New World sources of theobromine and thus the species's presence in archaeological vessels is considered diagnostic of *Theobroma* usage. The samples were analyzed for the presence of these methylxanthines using the high-performance liquid chromatography-mass spectrometry (HPLC-MS) technique developed by Hurst et al. (2002; Hurst 2006). Where there was sufficient sample, minimal amounts consisting of 50–100 mg were withdrawn from sample contain-

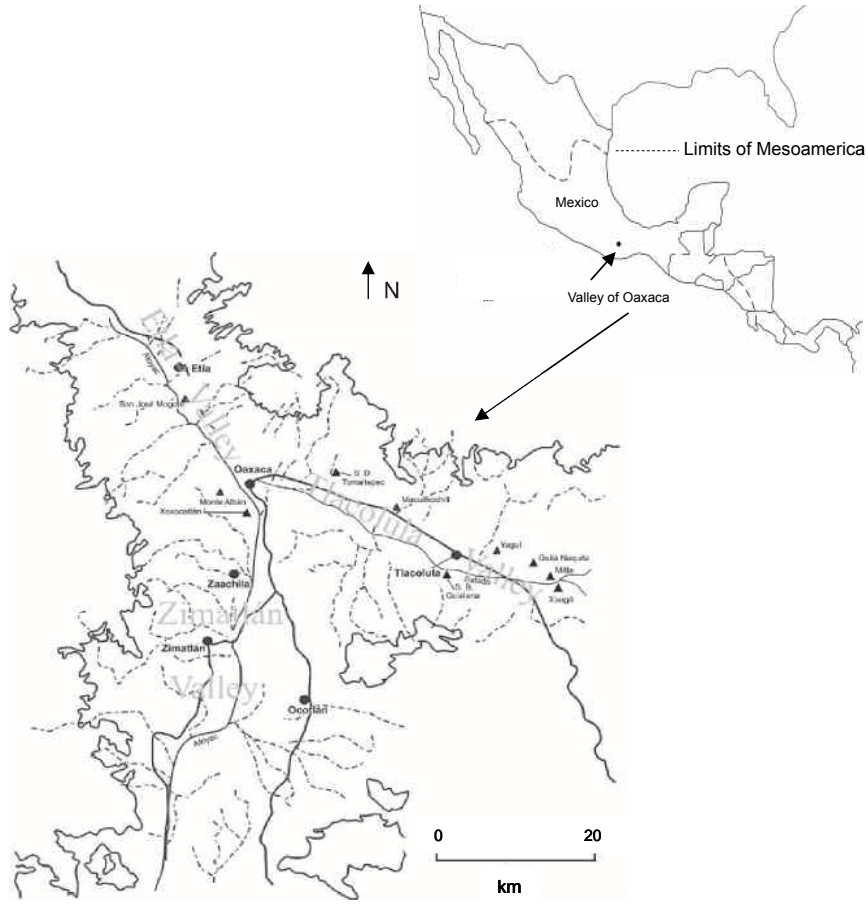

Figure 3. Mesoamerica with an enlarged view of the Valley of Oaxaca and the study sites identified.

ers and placed in 10-ml Erlenmeyer flasks. Approximately 2–3 ml of hot water (> 85 degrees C) was placed in each flask, which was then placed in a water bath for approximately 10 minutes. The samples were then allowed to cool to room temperature and filtered through 0.45 μm filter paper before analysis. An HPLC screening assay with UV detection was performed on all samples in the set prior to analysis by atmospheric pressure chemical-ionization mass spectrometry.

The total ion chromatogram and selected ion chromatograms were monitored for each sample. Selected ion chromatograms at mass to charge ratio (m/z) 181 and 195 were used to monitor the $(M+H)^+$ ion of the methylxanthines with m/z 181 used for theobromine and theophylline and m/z 195 used for caffeine. Although 181 is used for both theobromine and theophylline, these two compounds are separated chromatographically (the peaks are physically separated by time) to allow identification of each compound; the selected ion chromatogram at m/z 195 is unique for caffeine. Some have reported quantitative data in analyses of contemporary materials, but no quantitative data are provided in this study as the process of extracting methylxanthines from archaeological residues is affected by so many variables, and thus the most robust interpretation of those results is qualitative.

Phytolith Detection

Water taken up by plants contains dissolved silica, which then forms microscopic silica bodies by the partial or complete silicification of plant cells, cell walls, and intercellular spaces. In many species, the resulting silica bodies that have characteristic shapes and sizes are called opal phytoliths (Wilding and Drees 1971). Much of the early work on phytoliths was conducted by archaeologists work-

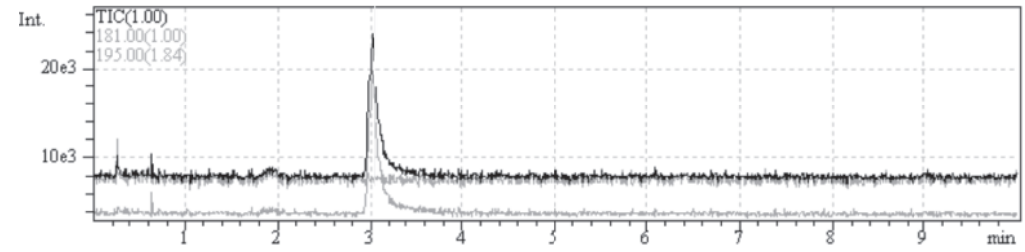

Figure 4a. Mass-spectroscopy total ion chromatogram (TIC) of theobromine standard with ion trace at m/z (mass to charge ratio) 181.

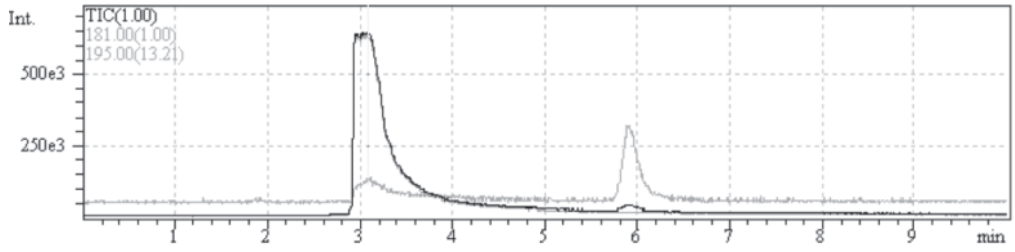

Figure 4b. Mass-spectroscopy total ion chromatogram (TIC) of extract from vessel 7, indicating theobromine peak at m/z 181 and caffeine peak at m/z 195.

ing in Latin America and focused on maize (e.g., Pearsall 1978) because of that plant's regional importance. This work identified taxonomically distinct phytoliths as well as morphologically specific phytoliths within some species such as *Z. mays* (Piperno 1984).

The extraction procedure for phytolith analysis consisted of seven steps: (1) removal of carbonates with dilute hydrochloric acid; (2) removal of colloidal organics, clays, and very fine silts by deflocculation with sodium pyrophosphate, centrifugation, and decantation through a 7-micron filter; (3) oxidation of the sample to remove organics; (4) heavy-liquid flotations of phytoliths from the heavier clastic mineral fraction using zinc bromide concentrated to specific gravity of 2.4; (5) washing and dehydration of phytoliths with butanol; and 6) dry storage in 1-dram vials.

After thorough mixing, all or part of the phytolith isolate was mounted on a microscope slide in immersion oil under a 24 x 40 mm or 18 mm circular cover glass (depending on the size of isolate) and sealed with clear nail lacquer. One complete slide per sample was scanned with a Zeiss microscope at a magnification of 625X for economic species.

Phytoliths were taxonomically classified based on phytolith systematics reported by Piperno (2006) and analysis of the University of Kansas phytolith reference collection of Central American flora, originally established for an archaeological study in Costa Rica (Bozarth 1993b). The phytolith reference collection currently consists of 47 arboreal species and 22 herbs for a total of 114 reference slides of leaves, fruits, and tubers.

In addition to the vessel residues, samples of a complete contemporary *Pouteria sapota* seed and *Quararibea funebris* flowers from Oaxaca were also processed for developing phytolith reference slides using a procedure based on oxidation in Schulze's reagent in a hot water bath (Bozarth 1997).

Results

Methylxanthines

Of the nine samples in this study, the results of the HPLC-MS analyses indicated the presence of both theobromine and caffeine visualized as MS chromatogram peaks at m/z 181 and 195, respectively, in extracts of residues from vessels 1 and 5, both from the Tlacolula branch of the Valley of Oaxaca, and vessel 7 from the central portion of the Valley of Oaxaca (Figure 4). Theophylline was not present in detectable levels in any of the samples.

Table 2. Scanning Phytolith Data for Residues from Postclassic Archaeological Vessels from the Valley of Oaxaca, Mexico.

Vessel Number*	1	2	3	4	5	6	7	8	9
Sample weight, gm	.17	.10	1.71	.11	.22	.01	.05	.06	.12
Number of phytoliths scanned	2,368	3,978	1,344	1,860	5,810	3	635	753	5
Plant phytoliths identified									
Zea mays mays									
Cob	1	1	-	-	1	-	-	-	-
Aerial portion: large Variant 1 cross	-	1	-	-	-	-	-	-	-
Aerial portion: bilobate	-	-	1	-	-	-	-	-	-
Bactris-type palms									
Hat-shaped phytoliths	-	-	-	-	2	-	-	-	-
Palms—other									
Spinulose spheres > 10 microns	-	1	-	-	1	-	-	-	-
Palms and bromeliads									
Spinulose spheres 5–10 microns	-	-	1	-	14	-	-	-	-

*See Table 1 and Figure 2.

Phytoliths

Phytoliths were well preserved in seven of the nine vessels sampled (Table 2). The exceptions were vessel 6, from which the smallest sample (.01 gm) was received, and the contemporary vessel. Neither the *Pouteria sapota* seed nor the *Quararibea funebris* flowers produced diagnostic phytoliths in this study.

Most of the phytoliths in the vessel samples were formed in native grasses that presumably found their way into the vessels during post-depositional processes. However, diagnostic maize cob phytoliths were identified in vessels 1, 2, and 5, strongly indicating that maize kernels in some form, along with some chaff, were repeatedly prepared or placed in the vessels (Figure 5). Moreover, the presence of one large Variant 1 cross in vessel 2 and one ridged bilobate with notched sides in vessel 3 indicate the use of maize husks/leaves, perhaps as cooking wrappers or to clean the vessels.

Two types of palm phytoliths were identified, including one spinulose sphere, each in vessels 2 and 5; and in vessel 5, two "hat-shaped" phytoliths, associated with the closely related *Bactris*- and *Acrocomia*-type palms. One possible scenario is that these vessels were used to serve palm wine, as well as other beverages. The carbohydrate-rich sap from *Acrocomia aculeata* fruit is fermented to produce a palm wine sold in Honduras (Henderson et al. 1995), and the presence of "hat-shaped" phytoliths in this type of palm wine has been experimentally established (Bozarth 2005).

Thus, this study found evidence of the presence of both maize and *Theobroma* species in the residues collected from the interior of two of the vessels in our sample, both from the Tlacolula branch of the Valley of Oaxaca: vessel 1—a tripod Pilitas polychrome vertical-necked jar from Macuilxóchitl, and vessel 5—a tripod composite, two-toned G.3M grayware bowl from Xaagá.

Discussion and Conclusions

To our knowledge, this study is the first investigation into the presence of markers for *Theobroma* species in residues from archaeological vessels in Oaxaca, Mexico. Maize cob phytoliths were found in abundance in a stratum dating to A.D. 620–740 of the Guilá Naquitz cave near Mitla, Oaxaca (Piperno and Flannery 2001), but we know of no other published research on maize phytoliths in archaeological vessels and other implements in that region. We are aware of only one other investigation into the presence of both *Theobroma* species and maize in archaeological vessels (Seinfeld 2007). In that study, residues from two of the 26 Olmec vessels sampled from the "Early Franco era (700–550/500 B.C.)" of the San Andrés site near La Venta in Tabasco, Mexico, tested positive for markers of both maize and cacao.

Our objective was to begin testing the hypothesis that there is evidence in the Postclassic archaeological record of the regionally and locally significant family of cacao and maize beverages. Analyses of residues from inside eight Postclassic and one contemporary vessel from the Valley of Oaxaca were positive for the presence of both theobromine and caffeine in three vessels, and for maize

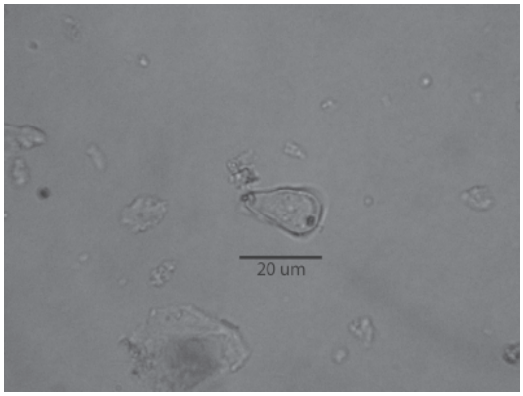

Figure 5a. Maize cob phytolith from vessel 2 (planar view) (slide and image courtesy of Steven R. Bozarth, University of Kansas).

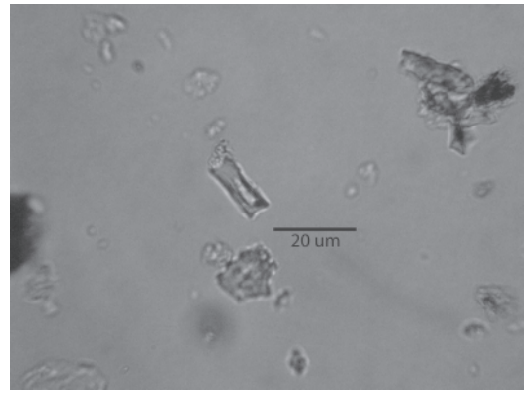

Figure 5b. Maize cob phytolith from vessel 2 (side view) (slide and image courtesy of Steven R. Bozarth, University of Kansas).

phytoliths in four (Tables 2 and 3). Residues from two vessels (numbers 1 and 5, see Table 1) were positive for markers of both of these important comestible plants consumed for millennia in Mesoamerica. Although used for frequent *tejate* preparation for five years immediately prior to being sampled for this study, it appears that the green, high-gloss glaze finish of the contemporary vessel (#9) prevented absorption of detectable evidence of either maize or *Theobroma* species.

Admittedly, one contemporary and eight archaeological vessels comprise a small sample, smaller than similar studies of vessel residues in Mesoamerica and what is now the U.S. southwest. However, a recent study of residues in archaeological vessels from the U.S. southeast had the same sample size—eight beakers (Crown et al. 2012). As an exploratory study and the first to report analyses of residues from archaeological vessels in Oaxaca for theobromine, we believe the findings of the present study are useful. While we cannot demonstrate clear patterns of vessel use, the associated materials and context of those vessels testing positive for both cacao and maize provide insights.

Vessel 1 is a Late Postclassic (Chila phase) Pilitas polychrome tripod *olla* found not far below the surface in association with a residence, probably a medium- to high-status palace, built on the top of Mound 35, a Late Classic (Xoo phase) structure at Macuilxóchitl. The vessel was found by itself (Feature 12), but other Chila phase vessels occurred within a general area of about 3 m^2 and may have formed part of a single offering in the residential patio.

Vessel 5 was found in association with a Late Postclassic (Chila phase) commoner residence at Xaagá near Mitla. It was part of Feature 1, a concentration of 23 ceramic vessels, one hammerstone,

Table 3. Maize Phytolith, Theobromine, and Caffeine Detection in Residues of Postclassic Archaeological Vessels from the Valley of Oaxaca, Mexico.

Vessel Number*	Maize Phytolith	Theobromine Marker Detected, m/z 181	Caffeine Marker Detected, m/z 195
1	Yes	Yes	Yes
2	Yes	No	No
3	Yes	No	No
4	No	No	No
5	Yes	Yes	Yes
6	No	No	No
7	No	Yes	Yes
8	No	No	No
9	No	No	No

*See Table 1 and Figure 2.

one chert bifacial (sacrificial) knife, and bones of a human child found in a residential patio. Vessel 5 is a two-tone gray tripod, composite-silhouette bowl about the same size as the large *jícaras* used today for *tejate* consumption. The vessel was found in an upright (normal) position with another similar vessel inverted and covering it, sometimes referred to as a lip-to-lip cache. Such caches have been found in a number of Mayan sites. Mathews and Garber (2004) describe an Early Classic cache from the Blackman Eddy site in Belize that consisted of lip-to-lip bowls, the lower one containing nine chert flakes, white marl, burned twigs, and a small rodent skeleton. They relate this cache to the vertical ordering of the universe in layers of underworld, earth (in the middle), and upper world (Mathews and Garber 2004:53). Cached vessels distributed on a single plane in a quadripartite arrangement symbolize the horizontal world. Vessels were cached by both commoners and elites and functioned to "sanctify the utilization of space" (Mathews and Garber 2004: 56). Such an ordering of the universe probably goes back to Olmec times and may be expressed differently by distinct ethnic and linguistic groups. Paired vessel caches from Oaxaca, known from sites in the Valley of Oaxaca and in the Mixteca Alta may have analogous meanings. Lind and Urcid (2010:275–277) have noted that during the Late Classic period, pairs of vessels in this position found in house patios may have been ritual burials of umbilical cords of babies born in the households. Feature 1 is from a later period and so may be a different kind of offering. Further research is required to determine the chronology and relationship, if any, between the presence of maize and cacao markers and other possible uses and significance of this vessel type and configuration.

Although no maize phytoliths were found in vessel 7, it did test positive for cacao. Vessels 7 and 8 are from the same Late Postclassic (Chila phase), relatively high-status tomb found at Xoxocotlán in the Valley center; vessel 8 was negative for both maize and cacao. Vessel 7 is a bichrome, small tripod bowl (more similar to vessel 8 in this study than to the other contemporaneous tripod vertical-necked *ollas*, vessels 1–4). The tomb contained many vessels, possibly produced specifically for the offering and so used for a limited time before deposition. Thus, while one of the two vessels testing positive for both cacao and maize in this study was from a commoner, non-elite context (#5), and the other from a high-status context (#1), as was another vessel testing positive solely for cacao (#7), still they all are thought to have been associated with ritual events.

This is the first study of its kind in Oaxaca; until now, the handling of archaeological artifacts has not been conducted specifically with residue analysis in mind, and so the possibility of contamination must be acknowledged. Vessels 1–6 were excavated and partly cleaned (leaving the inside basal part incompletely cleaned for future sampling) and stored in plastic bags inside boxes in the Centro Oaxaca of the Instituto Nacional de Antropología e Historia (INAH) laboratories in Cuilapan. Vessels 7 and 8 were excavated, then cleaned and restored and studied. They were also stored in bags and boxes in the same INAH laboratories, but had been examined by more people over the years and contamination is more likely with these than with the others. After acquisition from the family that used it for *tejate* preparation, vessel 9 was stored in a plastic bag to prevent contamination. Thus, while post-excavation contamination cannot be unequivocally ruled out, it is heartening to note that the vessels testing positive for both maize and cacao were among those least likely to have been exposed to contamination.

Investigation of recipes in the archaeological record requires the capacity to detect multiple ingredients and confirm their simultaneous deposition; our study was able to address only the first requirement. At this point, our presumption that detection of both maize and cacao represents contemporaneous use of those ingredients can only be tentatively supported, let alone the further hypothesis that they were ingredients in the same recipe. Still, our results provide the best available evidence of the presence of a cacao and maize beverage of the type found throughout Mesoamerica today, and it sets the stage for more extensive studies. However, the *Pouteria sapota* seed and *Quararibea funebris* blossom samples did not produce phytoliths in this study, and so further research will be required to determine whether phytoliths or other persistent, diagnostic markers for those characteristic ingredients of *tejate* can be identified. Thus, while our results suggest support for some form of cacao and maize beverage, there is no evidence for modern *tejate* per se, and the ubiquity of variants

of maize and cacao beverages in modern Mesoamerica, including Oaxaca, means there are a number of possible alternatives.

Detecting multiple ingredients in some cases requires the capacity to distinguish ingredients derived from closely related species. It is not yet possible to discern which *Theobroma* species was, or were, the source of the theobromine detected in this study, although contemporary, historical, and chemical data provide insights. Today, some communities use *Theobroma bicolor* in their *tejate* preparation, in addition to *T. cacao* (Soleri and Cleveland 2007; Soleri et al. 2008; Sotelo et al. 2012). The use of *T. bicolor* in Mesoamerica appears ancient, but at this time it is difficult to distinguish from *T. cacao* in the archaeological record (Kufer and McNeil 2006). In contrast, there is historical evidence that a beverage containing both *T. cacao* and *T. bicolor* was present in what is now Mexico in the late sixteenth century (Hernández 2000:109). While theobromine is diagnostic for all *Theobroma* species, in the future, quantitative studies of the ratio of theobromine to caffeine may provide further useful information for distinguishing it among those species. This ratio is often stated to be 10.0:1.0 in *T. cacao* (Hurst 2006; Hurst et al. 2002), although studies of contemporary samples of fermented seeds report substantially varying ratios: for two different varieties of *T. cacao* 1.6:1.0 and 11.2:1.0, *T. bicolor* 10.4:1.0, and *T. angustifolium* 8.3:1.0 (Sotelo and Alvarez 1991); for *T. cacao* 10.9:1.0 and *T. grandiflorum* 2.0:1.0 (Lo Coco et al. 2007). Another potential source of variation in the ratio of those methylxanthines in detection studies is the recent observation that caffeine may be preferentially extracted from archaeological vessel residues or washes, presumably because theobromine is bound more tightly to clay molecules in the vessel walls (Washburn et al. 2011). Development of precise, sensitive quantitative markers to determine this ratio in the small samples available from archaeological sources will be valuable for *Theobroma* species differentiation. However, work remains to be done to take into account the possible sources of variation in this ratio that cannot be attributed to consistent species differences.

Based on the positive results obtained here, we see three broad areas for future research to achieve a more profound and complex understanding of ancient cacao and maize foods in the Valley of Oaxaca. The first should be constructing a history of beverages containing cacao and other ingredients in the Valley of Oaxaca involving investigation of more diverse vessel forms, including those from earlier periods, especially those forms associated with cacao in other parts of Mesoamerica, such as *vasos* and spout-handled jars. Development of noninvasive, inexpensive, rapid methods will be important and may include sampling by washing vessel interiors as was recently done for methylxanthine detection (Washburn et al. 2011). One challenge is that until recently, standard protocol was to clean excavated artifacts as well as possible without being invasive.

Our second suggestion for future research is identification of durable, precise markers for ingredients characteristic of locally important variants of cacao and maize beverages, or for food processing that may distinguish some recipes. Examples include phytoliths or other markers for characteristic ingredients, such as *Pouteria sapota*, *Quararibea funebris, Bixa orellana*, *Plumeria rubra,* or *Smilax* spp; or for differential mineral content in ash versus lime nixtamalized maize (e.g., Pappa et al. 2010) and maize that has not been treated in either manner; or molecular markers for microorganisms associated with traditional fermentation (e.g., Cavalieri et al. 2003).

The third research area is investigating the archaeological and historical evidence for the relationship between diet, especially maize and cacao consumption and social class. Joyce and Henderson (2010: 171–2) noted that Mesoamerican societies following the Olmec have

> reshaped their heritage in ways that undoubtedly affected such fundamental daily practices as meals, and that must have changed the common experience of the meal as part of the structuring of social differences we now recognize as separating nobles and other villagers, farmers and urban citizens.

One window onto this social structuring may be the presence or absence of the maize and cacao combinations and variations of recipes in archaeological periods and contexts. Examples of possible approaches include qualitative studies of larger samples within a time period and geographic area, such as the Tlacolula branch of the Valley of

Table 4. Examples of Variation in Methylxanthine Content (mg/100 gm Dry Weight) in Contemporary *Tejate* Samples Made for Home Consumption versus Commercial Sale, and Cacao Tablet for Beverage Chocolate.

	T Test Results			*T* Test Results			*T* Test Results		
Group[a]	Caffeine	F	*p*<	Theobromine	F	*p*<	Total Methylxanthines	F	*p*<
Tejate for home consumption, $n = 11$	3.512y	50.31	.0001	29.329y	60.69	.0001	32.522y	60.46	.0001
Tejate for commercial sale, $n = 3$	9.754x			77.857x			87.611x		
Mexican chocolate[b, c]	200			1200					

Note: In columns, *tejate* averages followed by different letters are significantly different, Tukey's means separation, $p < 0.05$.
[a]Each sample was subsampled in triplicate for analysis; thus, 33 data points for home consumption *tejate*, 9 for commercial sale *tejate*. See Sotelo et al. 2012 for methods.
[b]Tablet cacao for making beverage chocolate.
[c]Bourges et al. 1996; Sotelo laboratory, UNAM.

Oaxaca, including both utilitarian, quotidian and elite ceremonial vessels. The primary methodological challenges involve the development of methods to determine (a) the probability that markers of recipe ingredients were deposited contemporaneously and (b) provide credible estimates of markers, and thus ingredient density, and so relative amounts of ingredients. Methods such as the "bulk stable carbon isotope analysis" for relative quantitative detection of C4 plant (i.e., maize) residues exist (e.g., Seinfeld 2007), although recent findings indicate that C isotopes may not be appropriate for accurate identification of past presence and density of maize (Warinner et al. 2013). The right methods could provide insights into whether these beverages were widely consumed by all classes, or evolved from (or occurred simultaneously as) a cacao-rich specialty of the elite to a maize-dominated staple of the laboring classes, flavored with cacao and other plant substances.

Association of cacao-rich beverages with the elite and powerful classes is indicated by early images representing the preparation and serving of these beverages in Mesoamerica. Sahagún (2000:919) supports this association, stating that "*cacao lindo"* was a beverage consumed only by the elite ("*solo los señores*") if made correctly, that is, without much added maize or water. He goes on to describe as poor and inferior the cacao beverages made with too much of these additives, including that their foam fails to mount and persist on the surface.

Contemporary use certainly suggests a social structuring, although a changing one. Variation can be observed in the type of cacao beverage present, as well as variants on a single recipe. Interestingly, the two common forms of cacao beverage in this part of the Valley of Oaxaca are prepared in the two oldest primary vessel forms in the area. Today, *T. cacao*—typically combined with water, sugar, almonds, and cinnamon and prepared in a ceramic *olla* as a hot morning beverage (*chocolate*)—is consumed widely in the Valley of Oaxaca and beyond, in urban and rural areas. In contrast, *tejate* plays a distinct role as a cool, refreshing, and fortifying beverage prepared in a bowl, most often consumed during the day and traditionally associated with those who perform hard physical labor in the countryside (Soleri et al. 2008). *Tejate* may indeed be a more palatable form of maize consumption than *tortillas* when daytime temperatures are high—for example, during maize harvest. However, both the loss of *tejate* in rural areas as traditions fade, and its increasing consumption in urban areas as a result of increasing cultural pride in traditional foods reflect social changes (Soleri et al. 2008).

Variations of *tejate* recipes for different consumers have been observed today. For example, recent data on the chemical and nutritional composition of 14 *tejate* samples (Sotelo et al. 2012) found variations in recipes and relative proportions of ingredients, and identified significant differences in methylxanthine content between *tejate* made for home consumption and *tejate* made for commercial sale (Table 4). It is not difficult to imagine that even small amounts of *Theobroma* species seeds would have been considered a desirable ingredient in simple maize-based beverages in the past for both cultural and gastronomic reasons, although their effect would depend significantly on the amount and

species used. The fat would have contributed to the production of highly valued foam, and the methylxanthines could have provided mild stimulation.

The story of how and why maize and cacao beverages such as *tejate* were transformed from a food of the elite, often associated with ceremonial circumstances, to a staple of rural farming communities has much to tell us. We believe that the three goals of constructing a history of cacao beverage recipes in the Valley of Oaxaca; identification of markers for other recipe ingredients and processes; investigation of the relationship between diet (especially recipes) and social class can build on this and other studies. In so doing, pursuit of these three research goals will contribute to a more nuanced understanding of cacao and maize consumption in the ancient Valley of Oaxaca in particular, and Mesoamerica in general, including insights into the significance of their variations across time and across social landscapes.

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