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Early Cultivation of Cacao (*Theobroma* [Malvaceae]) in Ancient Arenal, Costa Rica

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Abstract: Ethnohistoric sources document cacao (*Theobroma cacao*) as one of the most valued plant commodities produced in the Isthmo-Colombian Region following the Spanish Conquest, but there has been minimal archaeological evidence for the plant in this region in Prehispanic times despite its historical legacy of cacao production. Recent excavations in the Arenal region of Northwestern Costa Rica have recovered numerous fragments of wood charcoal identified to the *Theobroma* genus within residential contexts ranging from the Tronadora (2,000–500 BCE) to the Arenal (500 BCE–600 CE) cultural periods. Numerous taxa documented ethnohistorically as being used by native inhabitants in conjunction with cacao to prepare frothy beverages accompany the *Theobroma* wood charcoal, also in a macrobotanical form of preservation. These include *Bixa orellana*, *Bourreria*, *Ceiba*, *Curatella americana*, *Magnolia*, *Piper*, *Pouteria*, *Quararibea*, and *Zea mays*. Additionally, wood charcoal from *madre de cacao* (*Gliricidia sepium*) was also recovered, suggesting a deep history of cultivation of this shade tree alongside cacao trees in the Arenal region for the past several millennia.

Keywords: Archaeobotany, Anthracology, Cacao, Costa Rica, Agroforestry

Resumen: Las fuentes etnohistóricas documentan que el cacao (*Theobroma cacao*) fue una de las mercancías vegetales más valiosas producidas en la región Istmo-Colombiana después de la conquista española, pero ha habido evidencia arqueológica mínima del cultivo en esta región en tiempos prehispánicos a pesar de su legado histórico en la producción de cacao. Excavaciones recientes en la región de Arenal, al noroeste de Costa Rica, han recuperado numerosos fragmentos de carbón de madera identificados como del género *Theobroma* en contextos residenciales que abarcan desde el período cultural Tronadora (2,000–500 a.C.) hasta el período cultural Arenal (500 a.C.–600 d.C.). Numerosos taxones que han sido bien documentados etnohistóricamente como utilizados junto con el cacao en bebidas preparadas por los habitantes nativos acompañan el carbón de madera de *Theobroma*, también en una forma de preservación macrobotánica. Estos incluyen *Bixa orellana*, *Bourreria*, *Ceiba*, *Curatella americana*, *Magnolia*, *Piper*, *Pouteria*, *Quararibea* y *Zea mays*. Además, se recuperó carbón de madera de madre de cacao (*Gliricidia sepium*), lo que sugiere una larga historia de cultivo de este árbol de sombra junto con los cacaotales en la región de Arenal durante los últimos milenios.

Introduction

The cultivation of cacao (*Theobroma cacao* L., Malvaceae) represents one of the first agroforestry systems in tropical America with a

deep history of cultivation since at least 3,300 BCE (Zarrillo et al. 2018). The tree's origin lies in northwestern Amazonia, given that this is where the greatest intra-species variability is observed, along with linguistic and cultural diversity (Cornejo et al. 2018; Motamayor et al. 2008; Urban 2026). Ethnohistoric sources document that cacao was one of the most valued plant

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commodities produced in the Isthmo-Colombian Region following the Spanish Conquest, with many of the ethnohistoric accounts focusing on the area of Greater Nicoya, a region including Pacific Nicaragua and northwestern Costa Rica (Fig. 1) (Bergmann 1969; MacLeod 1973, 1996; Rosés Alvarado 1982; Steinbrenner 2006). It has been assumed by some scholars (Bergmann 1969; Fowler 1989a, 1989b) that cacao was introduced into this region during the Postclassic period (900–1,521 CE) by the Nicarao, a migrant group from Central Mexico that spoke Nahuatl. Bergmann (1969: 96) claims that Bagaces and Sigua colonies (Nicarao groups) introduced cacao into the Nicoya region. This assumption appears to be based in part on the group's cultivation practices being similar to Mesoamerican practices, their monopoly of the crop, and also the lack of archaeological evidence for cacao in the region at that time. However, Steinbrenner (2006: 255–258) notes some significant differences in cacao practices between these regions, suggesting greater antiquity for the crop in the Isthmo-Colombian region that may even have cultural influences from South America. Indeed, Steinbrenner argues that indigenous cacao in this area may have been what attracted the Nahuaspeaking colonists here in the first place, especially given that many other native territories-controlled cacao groves such as Quepo, Chira Island, Talamanca, Voto, and Guatuso (Fig. 1). Words for cacao within Central American languages in the Chibchan family further support Costa Rica as a pivotal isthmus where the plant and its associated terminology (for example *cajú*, *ko*, or *kuá*) spread northward from Amazonia (Urban 2026: 22).

Further supporting Steinbrenner's arguments are cacao remains recovered from recent archaeological excavations from Formative period household contexts in northwestern Costa Rica, along with numerous plant remains that were common additives in cacao beverages and recipes by native inhabitants of the Americas. Thus, this paper seeks to review and clarify the history of cacao cultivation in this region, and demonstrate that the native people of northwestern Costa Rica were in fact knowledgeable cultivators of cacao for several millennia before the arrival of the Nicarao migrants and the Spanish colonists. Furthermore, these people participated in various forms of cacao consumption in ways

that resemble both Mesoamerican and northern South American cultural practices, demonstrating strong intercontinental trade networks.

Accounts by Spanish Chroniclers document cacao's cultivation throughout the region by various indigenous groups. The chronicler Gonzalo Fernández de Oviedo y Valdés visited Greater Nicoya between 1527 and 1529 and suggested cacao was an “aboriginal cultivated plant in Nicaragua” (Oviedo 1851–55; Millon 1955: 73). The earliest historical documents that comment on cacao cultivation in Costa Rica come from letters written by the conquistador Juan Vázquez de Coronado who reported cacao cultivation in 1563 in Quepos on the Pacific slope of the Central Cordillera, within the Talamanca Cordillera, and by the Votos people in northeastern Costa Rica, all indigenous populations (Bergmann 1969: 95–96; MacLeod 1996: 84; MacLeod 1973: 330). In the late 1600 s, commercial cacao groves in the Mantina valley, the Nicoya Peninsula, and Guanacaste lowlands, managed through slave labor, are documented to have experienced yearly damage due to extreme rain (MacLeod 1973: 330–34). The Maleku in Llanuras de los Guatusos were reported to have cultivated cacao as well in 1783, with documents mentioning that cacao beverages were offered to their sun god (Bergmann 1969: 88–96). Another Spanish chronicler, Antonio Vazquez de Espinosa, suggested that the slopes of Mombacho Volcano (near Granada, Nicaragua) provided “the best and largest variety [of cacao]” (1942: 261), which is just 200 km northwest of Arenal. This latter account inspires possibilities of similar growing conditions near Arenal Volcano.

Unfortunately, there has been minimal archaeological evidence for cacao in this region despite its historical legacy of production. This is in part due to fewer archaeological investigations in the Isthmo-Colombian region overall compared to its northern and southern neighbors, in addition to the even greater paucity of paleoethnobotanical studies targeting the collection of preserved plant materials. The tropical setting leads to unfavorable conditions for long-term plant preservation, and the rich biodiversity of tropical regions can create a challenging framework for paleoethnobotanical investigations. For example, there are ca. 11,500 terrestrial plant species documented scientifically in Costa Rica, and it



Fig. 1. Map of Central America with relevant locations. Adapted from Steinbrenner (2006, Fig. 12.1)

is one of the countries with the highest number of species per unit area (Kappelle 2016; Obando 2002). More than 2000 of these documented plants are tree species (Kappelle 2016: 6), in contrast to the entire temperate zone of North America, with roughly 1,000 tree species (Condit et al. 2011: 11).

Recent archeological excavations in the Arenal region of Northwestern Costa Rica have recovered nearly 200 distinct plant taxa that were identified through macrobotanical analyses of preserved seeds, fruits, and wood charcoal at the sites La Chiripa and Sitio Bolívar (Slotten 2024: 127). This demonstrates the wide variety of plants in which these past peoples engaged during their day-to-day lives. Within this archaeobotanical assemblage were numerous fragments of wood charcoal identified to the *Theobroma* genus from residential contexts ranging from the Tronadora (2,000–500 BCE) to the Arenal (500 BCE–600 CE) cultural time periods. Additionally, accompanying the *Theobroma* wood charcoal are other macrobotanical remains from numerous taxa that native inhabitants consumed in conjunction with cacao within prepared beverages, as has been well documented ethnohistorically. I also identified wood from *madre de cacao* (*Gliricidia sepium* [Jacq.] Kunth), which is a shade tree commonly grown alongside cacao within orchards today. These archaeological revelations support Steinbrenner's (2006) assertion that cacao was known and used in the Isthmo-Colombian region long before the arrival of Mesoamerican groups such as the Nicaraos who colonized the area in the Postclassic period (900–1,521 CE).

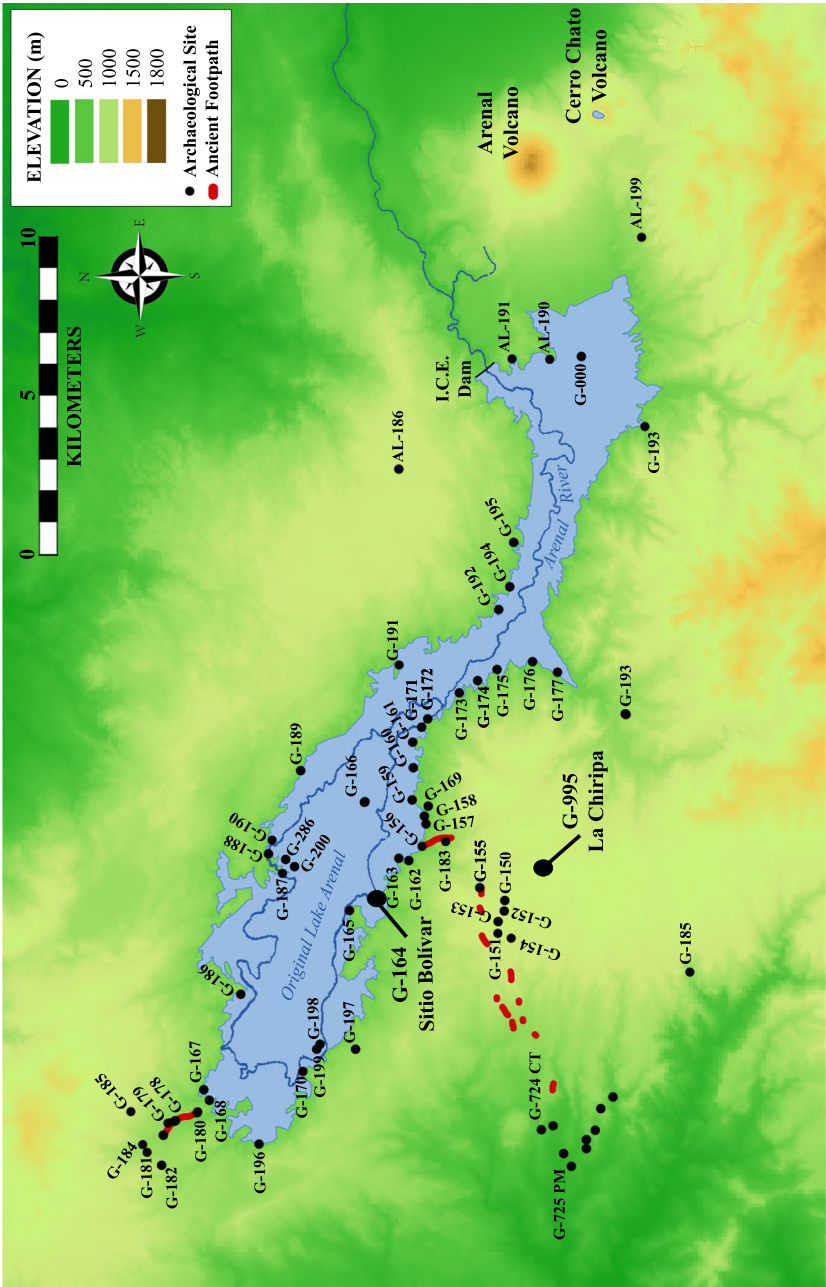
The Arenal Region

Located in northwestern Costa Rica within today's Guanacaste province, the Arenal region (Fig. 2) and the two study sites are situated along the Guanacaste Volcanic Mountain Range that forms part of the continental divide. Arenal has a lower average elevation (808 m.a.s.l.) compared to the rest of the mountain range, which has many peaks above 2000 m (Bergoeing 2017: 135). The lower elevation around Arenal provides a corridor between regions, making it a potentially significant trade route, since the isthmus of Central America

serves as the only land bridge between North and South America. Indeed, both the Greater Nicoya and Caribbean Lowlands culture areas had clear influence on Arenal traditions throughout the documented archeological record, as is evidenced through ceramic, lithic, and funerary practices (Sheets 1994b). Despite the clear interactions between Arenal and its surrounding regions, Sheets (1994a), Mueller (1994), and Hoopes (1994) point out that Arenal maintained its own political, economic, and cultural autonomy over time and therefore should be considered as a distinct cultural region. Throughout the majority of the periods in which Arenal was occupied, these communities appear to have been relatively self-sufficient and independent of outside groups when compared to other areas of Mesoamerica. Sheets (1992) suggests that the high species diversity in the tropical area allowed for communities to remain more stable than temperate areas where people specialize their subsistence on a smaller set of plant resources.

Because of Arenal's location along a volcanic cordillera, it tends to experience abundant rainfall, drizzle, cloud cover, and fog (Herrera 2016: 25), making it an ideal setting for cacao trees that thrive in moist forests. Cacao are shade-loving spindly trees that thrive in the understory of a forest. The trees depend upon fertile soils with sufficient moisture to maintain pools of lentic water that support larval development of dipterans (small flies and midges) which are the trees' primary pollinators (Bletter and Daly 2006: 35; Coe and Coe 2013). Populations of domesticated *Theobroma cacao* are dominant within wetlands, floodplains, and riverbanks; wild populations can also be distributed across dry valleys and ridges (González-Orozco et al. 2020: 2078). Once the cauliflorous flowers are pollinated, they result in a large pod that can vary in color from red to yellow or green. The pods contain 40 to 60 seeds surrounded by a sweet, white pulp. The seeds have a brief dormancy period and cannot survive low temperatures nor low humidity (Ogata et al. 2006: 70); these limitations are important because the seeds are the plant part used to produce chocolate.

Central to the region is Lake Arenal, which would have been a major source of freshwater in the past just as it is today. The lake in Prehispanic times would have been a bit smaller, since it rose from 512 to 545 m.a.s.l. after the construction of the Sangregado Dam in 1980. The Arenal



Volcano is a dominant feature on the landscape, just to the southeast of the lake, and would have been visible from most Prehispanic settlements in the region (Egan 2019). The Arenal region has tropical seasonality with a rainy season from May to September and a dry season from October to April (MacArthur 1972). The temperatures are relatively consistent year-round. A climatic gradient occurs across the lake. On the eastern end that is the closest to the volcano, there is minimal seasonal variation and a greater rate of precipitation (> 6,000 mm of rainfall per year) along with lower temperatures (22–23 °C). As one travels toward the western end of the lake, farther from the volcano, seasonality increases and there is less precipitation (< 2,000 mm of rain per year) along with a higher mean temperature (24 °C). Arenal contains a multitude of tropical zones or micro-environments, all located within relatively short distances of each other. This is due to the many valleys produced by the volcanic range that runs through the region, resulting in various slopes, elevations, and exposures (Holdridge et al. 1971).

The La Chiripa site, discovered in 2016 beneath a processional pathway, contains a Tronadora phase structure that represents one of the earliest known sedentary settlements in the country (1,616–1,426 BCE). Not only is this site early evidence of domestic life for the Arenal region, it also exemplifies the social memory perpetuated by descendant communities as they revisited this settlement along processions on a pathway many centuries after the structure was abandoned as a residence, a practice that has also been documented elsewhere in the region (Sheets 2011; Sheets and Sever 2007). La Chiripa is positioned directly along the continental divide at 950 m.a.s.l. within the Premontane Wet Forest. This is a mature evergreen rainforest with a wet season of 9 months. The life zone, as defined by Haber (2000), experiences moderate soil erosion and the soil has poor fertility, is quite saturated, anaerobic, and acidic.

Directly along the shore of Lake Arenal was the village settlement of Sitio Bolívar, which was inhabited much later in time than La Chiripa, during the Arenal Phase (500 BCE–600 CE). It is within the life zone deemed to be most ideal for agriculture in the region, the Premontane Transition zone of the Tropical Moist Forest (Bolaños and Watson 1993), due to its reliable dry season that can last up to 5 months annually. The soil

here is more fertile, maintains enough moisture to support crops, and has the lowest soil acidity in the region and the lowest risk of erosion (Holdridge 1967). These forests are also mostly evergreen with some epiphytes, but deciduous species are also prevalent (Lawton et al. 2016: 428). The moist forests are well known for their tall canopy trees such as *espavé* or wild cashew (*Anacardium excelsum* Skeels) and kapok (*Ceiba pentandra* [L.] Gaertn.) (Condit et al. 2011: 12), both of which were identified among the wood charcoal material in this investigation.

Together these two settlements provide a diachronic perspective of domestic life within the Arenal region and document the lifeways that persisted through time in the wake of frequent volcanic disruption to the region.

Methods

A total of 564 sediment samples were collected from the study sites during the 2018 and 2021 excavation field seasons (La Chiripa, 168 flotation, 70 screen, and 99 in situ hand-picked [1,760.5 L]; Sitio Bolívar, 137 flotation, all soil screened, 90 in situ [645 L]). Both projects employed a “blanket sampling” strategy (Pearsall 2015: 74–76) whereby samples designated for flotation and screening (ranging from 4 to 11 L) were taken as a composite from every square meter of excavation in each stratigraphic level. Excavations proceeded according to natural stratigraphic levels of sediment, and separate samples were taken from cultural features (e.g., concentrations of boiling stones, a hearth, and post holes). Prior to sampling, each area was scraped with a clean trowel to reduce exposure to modern contaminants that may have entered the excavation. Samples meant for screening were sieved through three mesh sizes (4 mm, 2 mm, 0.5 mm); these were taken from the same loci as flotation samples to assess the best method for plant recovery. Ultimately, water flotation was established as more productive and was prioritized. Water flotation eases the separation of plant materials from the soil samples because organic remains should float to the top when submerged in water due to their lighter specific gravity, allowing for the recovery of all size classes of macrobotanical remains without the bias of in situ recovery that relies on

the visibility of materials to the naked eye, and thus makes quantitative analysis of the results appropriate (Pearsall 2015: 44–46). A machine assisted flotation system (Siraf-style) was constructed for each project with the help of a local welder in Tilarán that used pressurized water flow (tap pressure) and collected organic material using a fine mesh fabric (0.2-mm opening). The poppy (*Papaver somniferum* L.) seed test, a common form of testing the efficiency of recovery of flotation systems in the Americas (Pearsall 2015; Wagner 1982), revealed a recovery rate of 94.7% at La Chiripa and 82.3% at Sitio Bolívar, demonstrating that the vast majority of plant remains within the samples was collected and analyzed.

All samples were analyzed at the UC Berkeley McCown Archaeobotany Laboratory. Due to space and time limitations at La Chiripa, only 1 L of each heavy fraction sample (roughly 20% of the total sediment) was retained and analyzed. This differs from Sitio Bolívar, where complete heavy fraction samples were analyzed. All macrobotanical samples were sorted using standard low-powered microscopy after being sieved through standard mesh sizes (4-mm, 2-mm, 1-mm, and 0.5-mm openings). Wood charcoal was only extracted from the larger fractions (4 mm and 2 mm). All plant remains were then divided into broad classifications (wood charcoal, seeds, fruits, and geophytes) and then identified to the lowest possible taxonomic category. Whenever possible, wood charcoal specimens were manually fractured into transverse, tangential, and radial cross-sections to observe diagnostic features on a fresh, flat surface. These specimens were recorded using a Hitachi TM-1000 Tabletop Scanning Electron Microscope in the Archaeological Research Facility at UC Berkeley at various magnifications ($\times 50$, $\times 100$, $\times 200$, and $\times 1,000$). Anatomical features used in identification include vessels per mm², the size and arrangement of vessels, rays per mm, the size and arrangement of rays, axial parenchyma patterning, porosity, and the presence of tyloses.

Taxonomic identifications were made with reference to the comparative archaeobotanical collection in the McCown Archaeobotany Laboratory at the University of California, Berkeley, in addition to the use of relevant identification manuals and field guides (Lentz and

Dickau 2005; Martin and Barkley 1961). To aid in wood charcoal specimen identifications, the author created a database of reference material based on: (1) a list of the most common trees of Costa Rica (Condit et al. 2011); and, (2) reference images (Gonçalves and Scheel-Ybert 2016; Roque et al. 2013; Wheeler 2011; Wheeler et al. 1989). Species-level identification was only determined if references were obtained for absolutely all possible species within the country, and they were distinguishable anatomically.

Results

One hundred and ninety-four distinct plants were identified through macrobotanical analyses of preserved seeds, fruits, and wood charcoal at La Chiripa and Sitio Bolívar (Slotten 2024: 127). Overall, 74 of the identified tree taxa from the two sites produce edible fruits, meaning cacao was just one of many tree fruits valued by the ancient inhabitants of Arenal. Because the focus of this paper is the cacao wood charcoal assemblage (Fig. 3), I also consider other recovered taxa commonly known to be related to cacao's cultivation and consumption (Table 1).

The vast majority of identified plant material at both settlements was in the form of wood charcoal, which is the most common plant material preserved in this region. The direct recovery of edible plant parts, such as seeds and fruits, is uncommon in tropical environments where mostly carbonized plant remains are what survive long-term. Many fruits are consumed raw, thus not given the opportunity to become charred. Ancient Mesoamerican style cacao drinks involved a complex series of preparation steps to the cacao seeds that included fermentation, drying, toasting, grinding, and then mixing with water prior to consumption (Henderson et al. 2007). These cooking techniques make the preservation of whole cacao seeds in the archeological record quite unlikely, since their ultimate form would be a powder incorporated into a beverage. Archeological studies have been able to directly document the use of liquid cacao within pottery vessels through the chemical markers of theobromine and caffeine (e.g., Powis et al. 2002). Such analyses have not yet been performed on

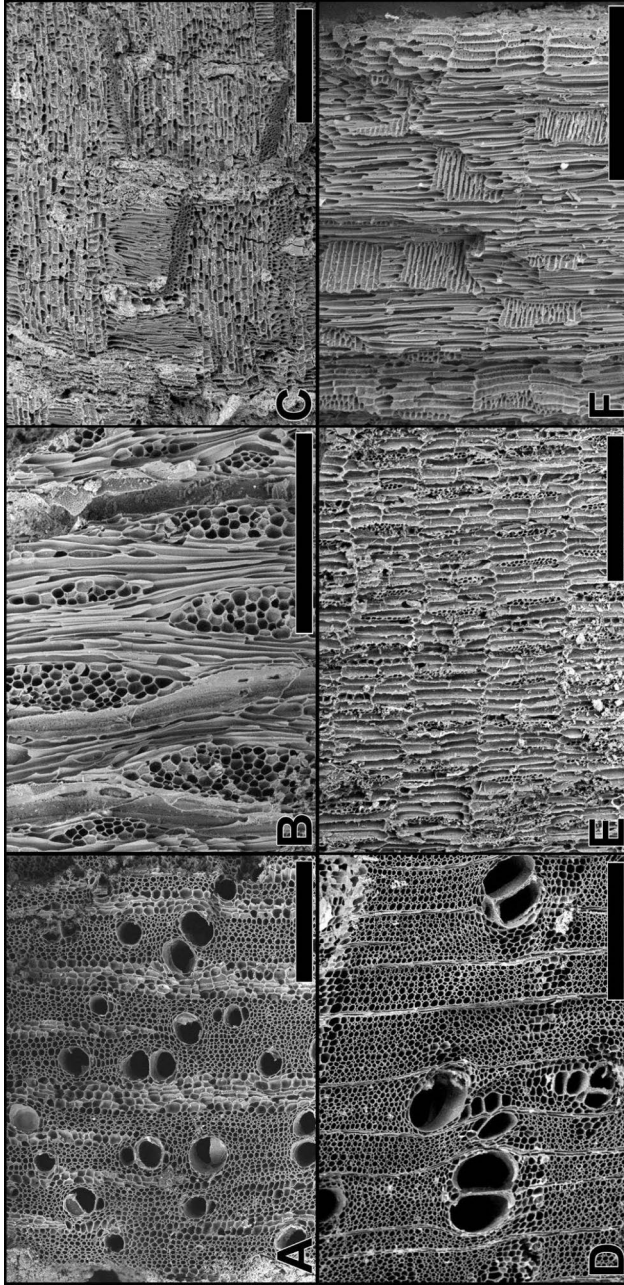


Fig. 3. Wood charcoals recovered from La Chiripa and Sitio Bolívar were identified as *Theobroma* sp. (A transverse view, B tangential view, and C radial view) and *Gliricidia sepium* (D transverse view, E tangential view, and F radial view). All scale bars are 300 µm in length

TABLE 1. MACROBOTANICAL REMAINS RECOVERED FROM LA CHIRIPA AND SITIO BOLIVAR RELATING TO THE CONSUMPTION OR CULTIVATION OF CACAO

Scientific name	Common name	La Chiripa					Total
		Sitio Bolivar	AR 16–15	Un. 54	AR 14–9	Hearth+post holes	
		Un. 53	AR 16–15	Un. 54	AR 14–9	Un. 60	Un. 61
<i>Bixa orellana</i> L.	Achiote	13 (0.346 g)		5 (0.032 g)		4 (0.056 g)	13 (0.313 g)
<i>Bourreria</i> sp.	Canalú	13 (0.408 g)				15 (0.137 g)	9 (0.182 g)
<i>Ceiba</i> sp.	Kapok						1 (0.008 g)
<i>Curatella americana</i> L.	Chumico						13 (0.199 g)
<i>Gliricidia sepium</i> [Jacq.] Kunth	Madre de cacao					2 (0.017 g)	2 (0.017 g)
<i>Magnolia</i> sp.	Baco					2 (0.006 g)	7 (0.027 g)
<i>Manihot</i> sp.	Manioc (wood, geophytes)					15 (0.123 g)	11 (0.167 g)
						1 (0.006 g)	3 (0.031 g)
<i>Piper</i> sp.	Hinojo (seeds)	205 (0.006 g)					205 (0.006 g)
<i>Pourouma</i> sp.	Uvito	1 (0.014 g)		1 (0.003 g)		2 (0.031 g)	4 (0.048 g)
<i>Pouteria</i> sp.	Mamey, sapote	34 (1.022 g)		1 (0.007 g)		18 (.143 g)	58 (1.191 g)
<i>Quararibea</i> sp.	Guayabillo						3 (0.033)
<i>Theobroma</i> sp.	Cacao	4 (.093 g)	2 (.012 g)	2 (0.066 g)	1 (0.003 g)	2 (0.010 g)	1 (0.014 g)
<i>Zea mays</i> L.	Maize (cupules)	58 (0.388 g)		1 (0.004 g)		16 (0.129 g)	15 (0.181 g)
						8 (0.126 g)	74 (0.561 g)
<i>Zea mays</i> L.	Maize (kernels)	45 (0.491 g)					45 (0.491 g)

All preserved plant material was wood charcoal unless noted otherwise. Data include raw counts; parentheses indicate weight in grams. The hearth and post holes are coeval (of the same time period) but post-date the house structure (units 60/61) and thus are treated as their own stratigraphic level. *N*, number of samples collected; *L*, total volume of samples collected in liters

Arenal pottery, but this present study suggests it could prove to be fruitful.

Neither of these settlements was directly buried by a volcanic eruption; therefore, all charcoal represents wood that was collected by the villagers and burned as a source of fuel. It is certainly curious to burn the wood from such useful species that are supplying important fruits, seeds, and flowers toward one's diet. An inspection on the quality of wood in the charcoal assemblage suggests that these people did not necessarily gather their fuel resources in an opportunistic fashion, searching for fallen trees and branches. Most of the charcoal represents wood of a high caliber, or of a large size such as mature trunks or large branches (76% at La Chiripa and 81% at Sitio Bolívar). Both sites exhibit charcoal that came primarily from seasoned wood that was adequately dried prior to combustion to prevent excessive smoke during the burning process (73% at La Chiripa, 68% at Sitio Bolívar). Analysis of the forest types reveals that trees from primary forests are dominant during the later time periods sampled (Slotten 2024: 175). This suggests that the forests of Arenal were healthy and thriving, and not over-exploited by these small village populations.

Identification of *Theobroma* wood charcoal was only possible to the genus level as there are no distinguishing characteristics of its wood anatomy at the species level when compared to all six species that are present in Costa Rica today (*T. angustifolium* DC., *T. bernoullii* Pittier, *T. bicolor* Bonpl., *T. cacao*, *T. mammosum* Cuatrec. & J.León, and *T. simiarum* Donn.Sm. [<https://biodiversidad.museocostarica.go.cr/>]). The majority of these species have seeds that are known to be fermented and roasted to produce a chocolate or have edible pulp, so it is not necessarily pertinent to determine which particular species was present in order to know if it was an edible variety (Bletter and Daly 2006; Cuatrecasas 1964). For example, *T. bicolor* pulp was used to produce a beverage called *pinolillo* in Nicaragua; while more commonly consumed farther south in Ecuador, Colombia, and Peru, it is rarer in Mesoamerica (Bletter and Daly 2006; Cuatrecasas 1964; Young 1994). The only documented *Theobroma* growing in recent times near Arenal includes *T. simiarum* and *T. mammosum* (Fig. 4). Cuatrecasas (1964) noted that *Theobroma simiarum* seeds provided a cacao of good quality in

Costa Rica, suggesting that perhaps this was a local specialty. Even though *Theobroma cacao* has not been documented in Arenal in recent times, the area is suitable for its cultivation both today and in the ancient past. It is also important to acknowledge that modern distribution of the species is not prescriptive of its exact distribution in the distant past.

A sample from the floor of the La Chiripa structure was identifiable to *Herrania*, which was formerly considered its own genus, but phylogenetics now show it as a section included within *Theobroma* (Colli-Silva et al. 2024). The native Bribrí of the Talamanca region, Costa Rica were documented using *T. purpureum* Pittier (recorded as the formerly named *Herrania purpurea* [Pittier] R.E.Schult.) to produce a bitter cacao drink (Pittier 1908). The use of the *Herrania* section of *Theobroma* is more closely associated with northern South American groups who commonly consume the seeds and pulp in a manner similar to cacao (Bletter and Daly 2006), but also use the leaves, bark, and fruit husks as an anesthetic to treat snakebites (Schultes and Raffauf 2004).

Wood charcoal from *Theobroma* was present in every stratum sampled at La Chiripa, including from both cultural layers and ash deposits (Fig. 5; Slotten 2024: 472). This evidence attests to the tree's strong and continual presence on the Arenal landscape through time and suggests that past people encouraged and maintained its growth for many centuries directly near this settlement. Within this study, *Theobroma* is the most prevalent during the Formative period; it is the sixth most ubiquitous fruit tree identified from the Tronadora phase domestic structure (with a ubiquity measure of 36% from the Un. 60 stratum). It is notable that wood charcoal from a companion species, *Gliricidia sepium*, was also found from the floor of the structure and within the fill of the post holes. Commonly referred to as *madre de cacao*, this tree is typically used to provide shade in cacao orchards in contemporary Guatemala and Nicaragua (Millon 1955) in addition to aiding nitrogen fixation which supports soil fertility in cacao's area of growth (Kaba et al. 2019). Cacao wood was also present at the Arenal phase village at Sitio Bolívar. Cacao's continual presence within every sampled stratum in this study indicates that these trees grew all around these settlements.

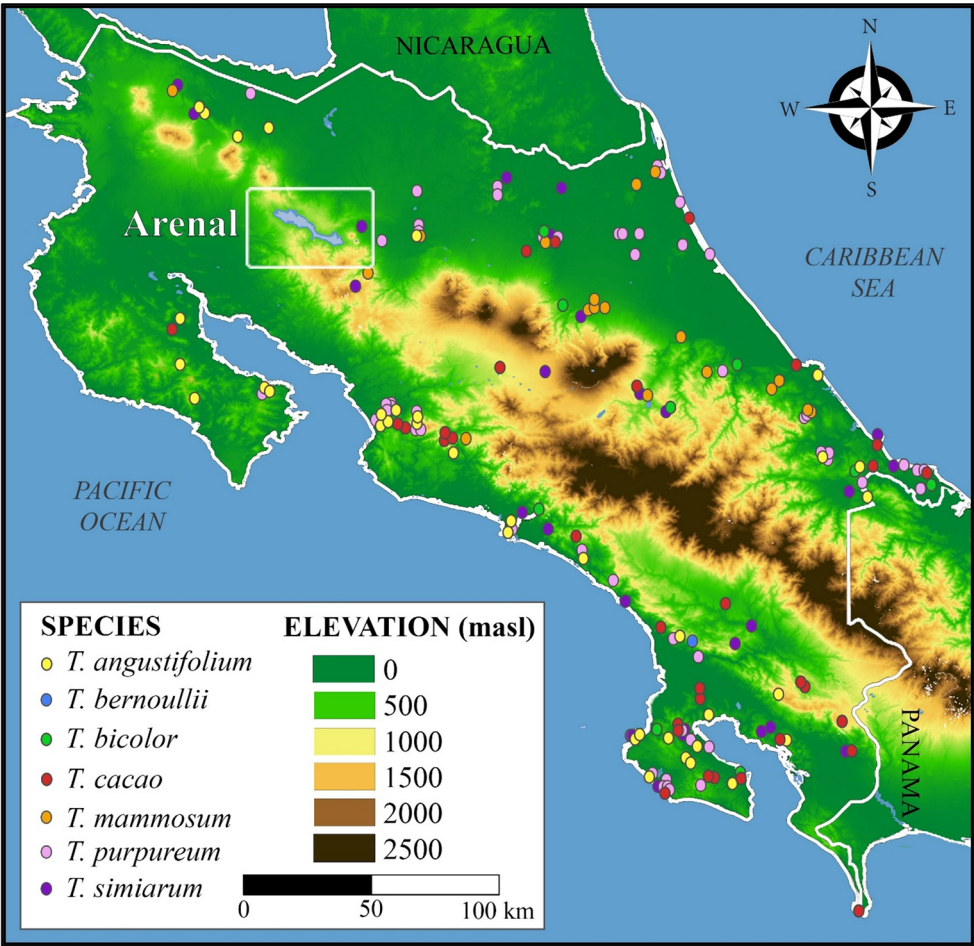


Fig. 4. Distribution of the origin of *Theobroma* collections at the Herbario Nacional de Costa Rica (<https://biodiversidad.museocostarica.go.cr/>). The map was created by the author

The inhabitants were likely exploiting the fruits from the trees as well, but it is unlikely for the seeds and pods to survive in carbonized assemblages. Thus, the wood is a proxy for reconstructing the presence of the plant and indicates that the past inhabitants of Arenal were likely producing cacao-based beverages and serving them during social gatherings.

The inference that local residents were consuming cacao beverages is supported by the presence of companion species (known to be cultivated or consumed in conjunction with cacao) in the assemblages. Ten companion species were present within the samples from ancient

Arenal, all of which have been documented as additives used in cacao beverages throughout Central America (see Fig. 6). Unfortunately, we cannot definitively prove their use in conjunction with cacao in ancient Arenal since the majority of plant material from these species was identified in the form of wood charcoal as opposed to consumable plant parts. In tropical environments like those found in Central America, most plant preservation occurs through carbonization, which biases assemblages toward the woody parts of these plants. Future research on the microbotanical and chemical residue remains from artifacts at these sites could aid such a conclusion, such as

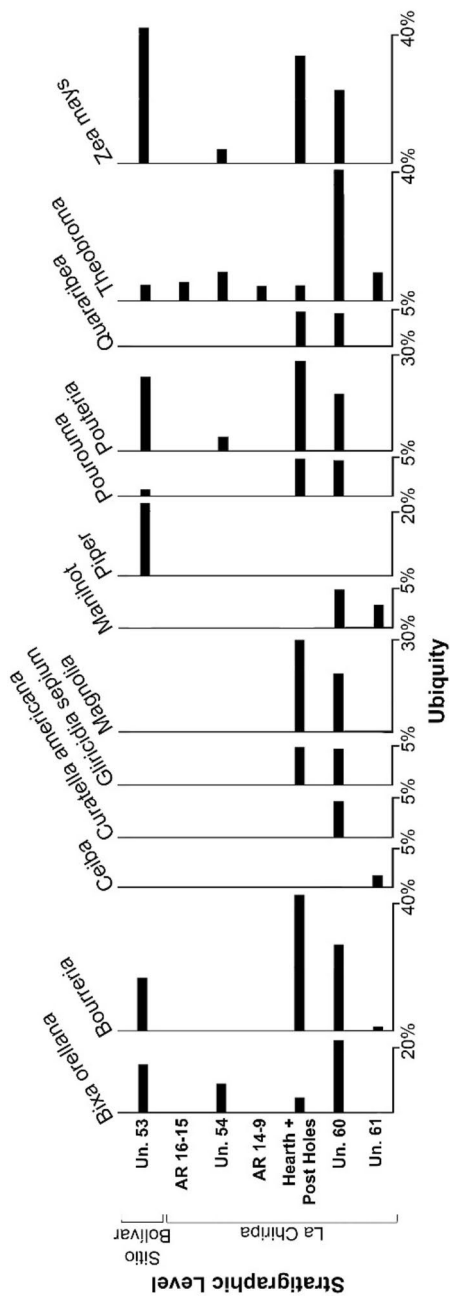


Fig. 5. Ubiquity measures for cacao-associated plants recovered from La Chiripa and Sitio Bolívar. Time periods for each stratigraphic level based on calibrated AMS radiocarbon dates (Slotten 2024 Appendix J) are as follows: Un. 53 430–540 CE, AR 16–15 100 BCE–100 CE, Un. 54 372–176 BCE, AR 14–9 1276–553 BCE, hearth and post holes 1384–1108 BCE, Un. 60 1544–1426 BCE, and Un. 61 1616–1442 BCE

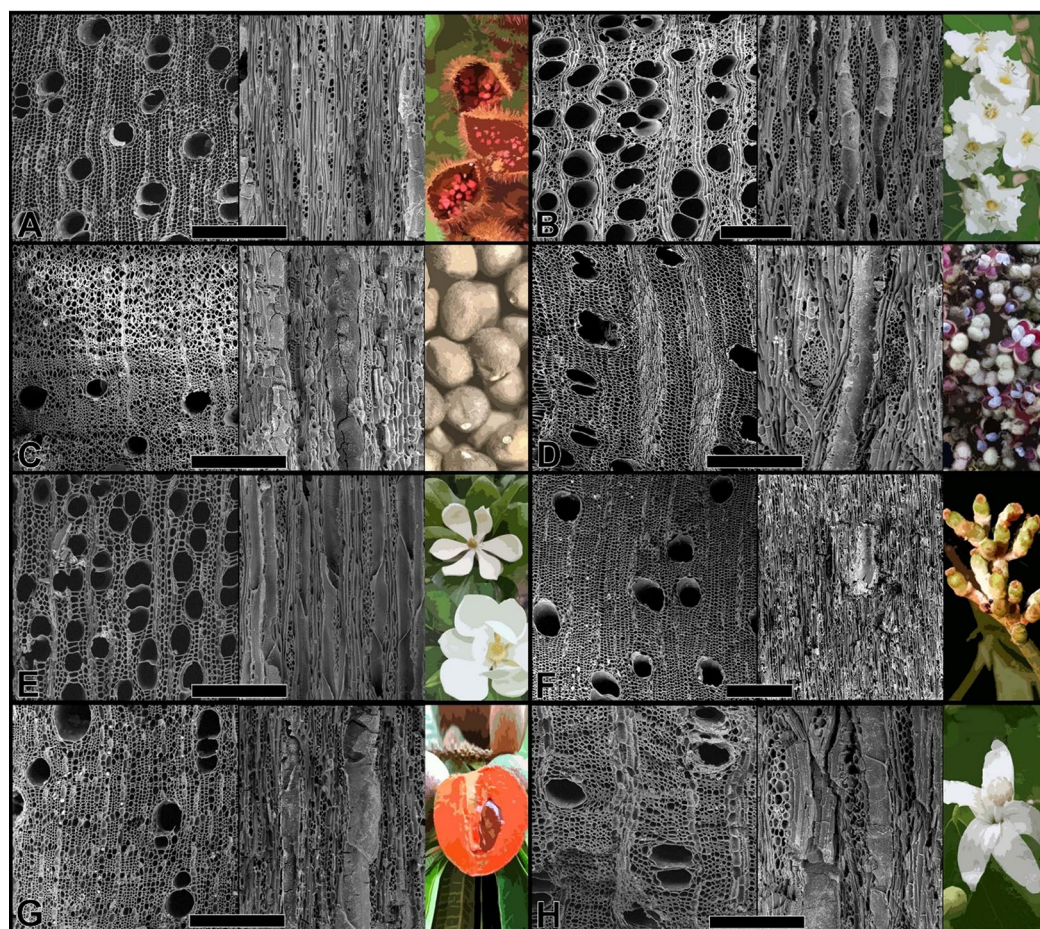


Fig. 6. Transverse and tangential views of wood charcoal recovered from La Chiripa and Sitio Bolívar known as common additives in cacao beverages: **A** *Bixa orellana*, **B** *Bourreria*, **C** *Ceiba*, **D** *Curatella americana*, **E** *Magnolia*, **F** *Pourouma*, **G** *Pouteria*, and **H** *Quararibea*. All scale bars are 300 μ m in length

sampling from ceramic vessels or ground stone tools used to process food materials.

The data presented here suggests that ancient inhabitants of Arenal were engaged in cacao consumption. The recipe and methods for producing cacao beverages varied widely in the past, with many additives used by the Zapotec, Aztec, and Maya populations to impart flavor. One of the most detailed historical written accounts detailing the many varieties of cacao comes from Sahagún's (1950–59: v.8, 40) description on the food of the *tlatoque* which includes a list of the fine chocolate beverages offered to the lords: "Then, by himself in his house, his chocolate was served: green cacao

Pods, honeyed chocolate, flowered chocolate, flavored with green vanilla, bright red chocolate, *huitzecolli*-flower chocolate, flower-colored chocolate, black chocolate, white chocolate." This account demonstrates the assortment of cacao recipes that existed in Central America at least during the Postclassic period. Archaeological finds suggest that these dishes may have great antiquity, since nine of the cacao additives identified in this study were found in residential contexts from the Initial through the Early Formative periods.

One of the ingredients most often consumed with cacao was maize (*Zea mays* L.). Indeed, maize and cacao were an important ritual pairing

in Mesoamerican cosmology and iconography, often combined in ritual beverages and even prepared for consumption in similar manners (Kufer and Heinrich 2006; Meskell and Joyce 2003: 139). Maize may have been mixed with cacao to create a beverage such as *tejate*, as was practiced farther north in Mesoamerica by later Maya, Aztec, and Zapotec people (Sotelo et al. 2012). The Aztecs would remove the foam from the cacao beverage, then add ground maize, before later replacing the foam (Coe and Coe 2013: 86). Although maize appears to be a minor food source at both study sites compared to elsewhere in the Americas, it is present and increases in ubiquity through time. Perhaps one of the most well-known artifact types from Costa Rica is the elaborate metates (Fig. 7) made from volcanic stone and decorated with intricate geometric and zoomorphic designs (Graham 1992). The elaborate metates show little use wear, but household varieties were well used (Chenault 1994). These metates may have been used to process a range of materials including maize, roots, tubers, bones, as well as medicinal and psychotropic plants (Hoopes 2007), and perhaps even cacao. Maize may have served a more ritualistic purpose in the study region and may not have been considered a staple food, as evidenced by the paleoethnobotanical (Table 1) and isotopic evidence from the region, the latter showing it only comprised 12% of the overall diet (Norr 1991). Maize is also less ubiquitous in the La Chiripa structure than the cacao wood charcoal. Perhaps the extravagant metates are further evidence that maize was viewed primarily as a component of ritual activities in this region rather than a source of daily sustenance. I suggest cacao was processed on these tools as well. Unfortunately, there has been a lack of microbotanical investigations on these artifacts.

Aromatic flowers were a common admixture to cacao beverages since pre-Columbian times, and the wood charcoal from many trees that produce these flowers was recovered in this archaeological assemblage, including “flor de cacao” (*Quararibea*), *uvito* (*Pourouma*), *baco* (*Magnolia*), *hinojo* (*Piper*), and the white “popcorn” flower (*Bourreria*), which would both strengthen the flavor and add a pleasant fragrance to the drinks (Coe and Coe 2013). *Piper* is possibly considered to be the flavoring mentioned by Sahagún (1950–1959) that created the “black chocolate” offered to the Aztec



Fig. 7. Elaborate metates on display at the Museo Nacional de Costa Rica in San José, Costa Rica. Photographs by the author. Scale bar is an estimation

lords. *Hinojo* only appears in this study during the later time period of 430–540 CE, suggesting a later incorporation into cacao recipes was introduced later in time compared to the other ingredients. *Magnolia* was considered the “heart flowers” by the Aztec due to the petal’s shape and was mixed into cacao beverages to supposedly regularize a patient’s heartbeat (Coe and Coe 2013: 93). The *Bourreria* flowers are used to treat fevers and coughs (Dreiss and Greenhill 2008: 108; McNeil 2012), and this tree was one of the most common at the La Chiripa site. The addition of *Quararibea* flowers into cacao-based alcohol or vinegar has been practiced by various native groups from Bolivia, Colombia, Ecuador, Panama, and Venezuela who mainly use the pulp of cacao rather than the seeds (Bletter and Daly 2006; Duke 1986; Friede 1953; Glenboski 1983; Vickers and Plowman 1984). Many of these groups also incorporate manioc (*Manihot*) into such recipes, which is a root crop that was identified with the La Chiripa hearth feature. The Arenal residents may have appreciated the strong fragrances of these various flowers so much so that they encouraged groves of these trees near the settlement to be able to incorporate the petals into drinks.

Achiote wood (*Bixa* sp.) is present at both of the Arenal settlements, which is unsurprising given the tree flourishes in tropical humid areas and montane cloud forests such as Arenal. It is well documented as a key ingredient within cacao beverages. Spanish chroniclers observed Nicaraguans adding achiote seeds to their cacao beverages to color it red and add a spicy flavor (Benzoni and Smyth 1857: 148; Millon 1955: 163). Mesoamerican iconography of “bleeding cacao” (likely *T. cacao* mixed with *Bixa orellana* L.) appears in Mixtec codices and Classic Maya ceramics, suggesting that cacao pods with achiote were included as offerings in ceremonies and that cacao was a sacred tree linked to blood (Dreiss and Greenhill 2008; McGee 1990: 46; McNeil 2006: 15). Achiote is likely the additive that led to the bright red chocolate documented by Sahagún (1950–1959).

Ground seeds from *Curatella americana* L., *Ceiba*, and *Pouteria* (Coe and Coe 2013: 86–94; Standley and Steyermark 1946) would also have been used to create different flavor profiles and have also been identified in the form of wood charcoal in Arenal. In fact, *chocolatl*, the word from which chocolate is derived, refers to a sixteenth-century recipe that incorporates either the heart of

a sapote seed (*Pouteria sapota* [Jacq.] H.E. Moore & Stearn) or a *pochotl* seed (*Ceiba*) along with ground maize and cacao (Coe and Coe 2013: 94, 117; Hernández 1959: 305).

Discussion

Cacao is most well known for the chocolate produced from its seeds. In Prehispanic Mesoamerica, the seeds would have been fermented and incorporated into beverages or even sauces (McNeil 2006). People used cacao to produce ritual beverages as early as 3,300 BCE during the Early Formative Period in southeastern Ecuador, where it was identified using a variety of methodologies, including starch grain analysis, ancient DNA (aDNA), and chemical residue analysis (Zarrillo and Blake 2022; Zarrillo et al. 2018). Macrobotanical evidence of cacao seeds shows that cacao was grown by 1,300 BCE in Gran Coclé, Panama at the sites Rio Bermejito and Los Santanas (Dickau 2005). The archaeological finds geographically closest to Arenal include possible cacao seed remains from the Nicoya area of Pacific Nicaragua at the Santa Isabel site (McCafferty 2021: 135–136; McCafferty and Steinbrenner 2003) and the Ayala site dating to the Bagaces period (300–800 CE) (Salgado Gonzalez 1996: 179). *Theobroma* has also been identified in the Maya area in the form of wood charcoal at sites such as Tikal (Lentz et al. 2014a), Aguateca (Lentz et al. 2014b), Dos Pilas (Cavallaro 2013), and San Bartolo (Santini 2016), and in the form of cacao seeds at Copán (McNeil 2006) and Cerén (Lentz et al. 1996). However, archaeological recovery of cacao is more well known via residue analysis (Hall et al. 1990; Henderson et al. 2007; Joyce and Henderson 2007, 2010). Targeted chemical analyses have revealed theobromine and caffeine compounds (which are both prevalent in cacao and rare in other plants indigenous to the Americas) in ancient pots and other artifacts from Belize (Ford et al. 2022; Powis et al. 2002), the Soconusco region of Mexico (Powis et al. 2008), and from the Puerto Escondido village in northern Honduras (Henderson et al. 2007; Joyce and Henderson 2007).

Oviedo mentions a particular method for preparing cacao used in “la provincia de Nicoya” (modern Guanacaste) (1851–1955: 317–318),



Fig. 8. Artistic rendering of the La Chiripa structure surrounded by the plants identified in this study related to the cultivation and consumption of cacao: (1) *Zea mays*, (2) *Piper*, (3) *Magnolia*, (4) *Ceiba*, (5) *Curatella americana*, (6) *Pourouma*, (7) *Pouteria*, (8) *Quararibea*, (9) *Bourreria*, (10) *Gliricidia sepium*, (11) *Theobroma cacao*, (12) *Theobroma purpureum*, and (13) *Bixa orellana*

detailing how local people prevent the sun from scalding the cacao trees by planting companion trees called *Yaquaquyt* or *madre negro* in between them. These companion trees are double the height of cacao, providing shade with their branches and leaves. Oviedo also notes the presence of irrigation systems in regions with more seasonal rainfall patterns. *Madre de cacao* is another shade tree referenced by Oviedo (Incer Barquero 2000: 207). Since wood from this tree was recovered alongside cacao from the La Chiripa house structure, it is probable that orchards containing both were growing nearby. These findings demonstrate the antiquity of this practice of inter-planting these two trees together.

Oviedo (1851–55: 318–319) details how cacao was prepared for consumption. The seeds were ground into a thick paste, formed into small cakes that were left to stand before incorporation into beverages (with longer rest times associated with higher-quality beverages, 5 or 6 days ideally). Dye from achiote was added to the cacao paste to produce a blood-red color. The paste was then mixed with water (and optionally spices) and served as a beverage (Benzoni and Smyth 1857: 148–150). Oviedo mentions that natives would consume the pulp and uncooked seeds (1851–55: 321), a practice common to many native groups of the Americas (Bletter and Daly 2006). Oviedo confirms that cacao seeds were used as a form of currency, just as it was across Mesoamerica, to purchase goods such as cotton, other fruits, rabbits, and even maize (Benzoni and Smyth 1857: 149; Oviedo 1851–55: 316).

Henderson and Joyce (2006: 152) assert that the preparation sequence of cacao beverages, including the creation of a froth and adding condiments like flowers or ground seeds, would have been a performative and social spectacle for those to whom these beverages were served. Many senses would have been invigorated by the presentation of such cacao beverages. The red paste of achiote would have created vibrant red drinks that were a stark contrast to the various bright white and showy flowers of *Bourreria*, *Magnolia*, and *Quararibea* added for strong and pleasant fragrance. The grinding and preparation of the ingredients, as imagined within the artistic reconstruction in Fig. 8, on intricately decorated metates would have created a scene for guests to consume prior to a cacao feast.

Conclusion

The presence of cacao, its relatives, and so many of the common additives to beverages prepared from its pulp and seeds within residential spaces in ancient Arenal for several millennia situates the region as a crossroads for social connections between South and Central America. The consumption of cacao is intricately tied to social gatherings, and the additives incorporated into beverages in this region would have amplified the performative and memorable nature of its consumption. With Arenal situated conveniently at the low point of the continental divide, it would have been a welcoming spot for travelers as they traded with people across the two continents and a great avenue for the exchange of ritualistic cacao consumption. Ingredients that are common admixtures into cacao beverages from both regions were recovered from these settlements. Arenal's biodiverse setting would have allowed for the incorporation of a variety of admixtures to cacao recipes where La Chiripa or Sitio Bolívar residents may have been managing or cultivating these ingredients close to their homes.

As more macrobotanical, anthracological, microbotanical, genetic, and chemical residue investigations are more regularly incorporated into archaeological excavations within the Isthmo-Colombian region, I believe that cacao will present as a key fruit tree that was cultivated through agroforestry practices, just as has been demonstrated in neighboring regions to the north and south. The suite of associated ingredients that accompany cacao within these archaeobotanical results shows that Arenal villagers likely incorporated the same recipes and perhaps even cultural beliefs associated with this beverage that have been well documented elsewhere as they participated within networks of cultural exchange. The residents of Arenal continually encouraged the growth of cacao trees and multiple other plants closely tied to its consumption for thousands of years within their surrounding forests and perhaps even managed them as fruit orchards. The continuity of cacao and the various ingredients associated with its consumption through time in such a dynamic volcanic landscape demonstrates the great cultural significance that it held within these ancient Central American communities.

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Author Contribution

V. S. wrote and prepared the manuscript.

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Data Availability

No datasets were generated or analyzed during the current study.

Declarations

Conflict of interest The author declares no competing interests.

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References

- Benzoni, G., and W. H. Smyth. 1857 [1565]. History of the new world. Translated by W. Smyth. London: Hakluyt Society.
- Bergmann, J. 1969. The distribution of cacao cultivation in Pre-Columbian America. *Annals of the Association of American Geographers* 59(1): 85–96. <https://doi.org/10.1111/j.1467-8306.1969.tb00659.x>
- Bergoeing, J. 2017. Geomorphology and volcanology of Costa Rica. Boston, Massachusetts: Elsevier.
- Bletter, N., and D. Daly. 2006. Cacao and its relatives in South America. In: *Chocolate in Mesoamerica: a cultural history of cacao*, ed. C. L. McNeil, 31–68. Gainesville: University Press of Florida.
- Bolaños, R., and V. Watson. 1993. Mapa ecológico de Costa Rica, según el sistema de clasificación de Zonas de Vida del mundo de L. R. Holdridge. 1:200 000. San José, Costa Rica: Centro Científico Tropical.
- Cavallaro, D. 2013. Reconstructing the past: paleoethnobotanical evidence for ancient Maya plant use practices at the Dos Pilas site, Guatemala. Masters Thesis. Cincinnati: University of Cincinnati.
- Chenault, M. 1994. Precolumbian ground, polished, and incised stone artifacts from the cordillera de Tilarán. In: *Archaeology, volcanism and remote sensing in the Arenal region, Costa Rica*, eds. P. D. Sheets, and B. McKee, 255–277. Austin: University of Texas Press.
- Coe, S., and M. Coe. 2013. The true history of chocolate. London: Thames and Hudson.
- Colli-Silva, M., J. E. Richardson, A. M. Bossa-Castro, and J. R. Pirani. 2024. Phylogenetic evidence reshapes the taxonomy of Cacao and its allies (*Theobroma* and *Herrania*; Malvaceae, Byttnerioideae). *Brittonia* 76: 53–61. <https://doi.org/10.1007/s12228-024-09783-1>
- Condit, R., R. Perez, and N. Daguerre. 2011. Trees of Panama and Costa Rica. Princeton, New Jersey: Princeton University Press.
- Cornejo, O. E., M. Ch. Yee, V. Dominguez, M. Andrews, A. Sockell, E. Strandberg, D. Livingstone, C. Stack, A. Romero, P. Umaharan, S. Royaert, N. R. Tawari, P. Ng, O. Gutierrez, W. Phillips, K. Mockaitis, C. D. Bustamante, and J. C. Motamayor. 2018. Population genomic analyses of the chocolate tree, *Theobroma cacao* L., provide insights into its domestication process. *Communications Biology* 1: 167. <https://doi.org/10.1038/s42003-018-0168-6>
- Cuatrecasas, J. 1964. Cacao and its allies: a taxonomic revision of the genus *Theobroma*. *Contributions from the U.S. National Herbarium* 35(6): 379–614.

- Dickau, R. 2005. Resource use, crop dispersals, and the transition to agriculture in prehistoric Panama: evidence from starch grains and macroremains. Doctoral dissertation. Philadelphia: Temple University.
- Dreiss, L., and S. E. Greenhill. 2008. Chocolate: pathway to the gods. Tucson, Arizona: The University of Arizona Press.
- Duke, J. A. 1986. Isthmian ethnobotanical dictionary. Jodhpur, India: Scientific Publishers.
- Egan, R. 2019. When the volcano erupts: lessons from the archaeological record on human adaptation to hazardous environments, Tilarán-Arenal, Costa Rica. Doctoral dissertation. Boulder: University of Colorado, Boulder.
- Ford, A., A. Williams, and M. S. de Vries 2022. New light on the use of *Theobroma cacao* by Late Classic Maya. Proceedings of the National Academy of Sciences 119(40): e2121821119. <https://doi.org/10.1073/pnas.2121821111>
- Fowler, W. 1989a. The cultural evolution of ancient Nahua Civilization: the Pipil-Nicarao of Central America. Norman, Oklahoma: University of Oklahoma Press.
- Fowler, W. 1989b. The Pipil of Pacific Guatemala and El Salvador. In: New frontiers in the archaeology of the Pacific coast of southern Mesoamerica, eds. F. Bové and L. Heller, 229–243. Anthropological Research Papers No. 39. Tempe: Arizona State University.
- Friede, J. 1953. Los Andaki: Historia de la aculturación de una tribu selvática. Mexico City: Fondo de Cultura Económica.
- Glenboski, L. 1983. The ethnobotany of the Tukuna Indians, Amazonas, Colombia. Bogotá: Universidad Nacional de Colombia.
- Gonçalves, T., and R. Scheel-Ybert. 2016. Charcoal anatomy of Brazilian species. I. Anacardiaceae. Anais da Academia Brasileira de Ciências 88(3 Suppl.): 1711–1725. <https://doi.org/10.1590/0001-3765201620150433>
- González-Orozco, C., A. A. S., Galán, P., Ramos, and R., Yockteng. 2020. Exploring the diversity and distribution of crop wild relatives of cacao (*Theobroma cacao* L.) in Colombia. Genetic Resources and Crop Evolution 67(8): 2071–2085. <https://doi.org/10.1007/s10722-020-00960-1>
- Graham, M. 1992. Art-tools and the language of power in the early art of the Caribbean lowlands of Costa Rica. In: Wealth and hierarchy in the intermediate area, ed. F. W. Lange, 165–206. Washington, DC: Dumbarton Oaks Research Library and Collections.
- Haber, W. 2000. Plants and vegetation. In: Monteverde: Ecology and conservation of a tropical cloud forest, eds. N. M. Nadkarni and N. T. Wheelwright, 39–94. New York: Oxford University Press.
- Hall, G., S. Tarka, W. Hurst, D. Stuart, D., and R. Adams. 1990. Cacao residues in ancient Maya vessels from Rio Azul, Guatemala. American Antiquity 55(1): 138–143. <https://doi.org/10.2307/281499>
- Henderson, J., and R. Joyce 2006. Brewing distinction: the development of cacao beverages in formative Mesoamerica. In: Chocolate in Mesoamerica: a cultural history of cacao, ed. C. L. McNeil, 140–153. Gainesville: University Press of Florida.
- Henderson, J., R. Joyce, G. Hall, J. Hurst, and P. McGovern. 2007. Chemical and archaeological evidence for the earliest cacao beverages. Proceedings of the National Academy of Sciences 104: 18937–18940. <https://doi.org/10.1073/pnas.0708815104>
- Hernández, F. 1959. Obras completas. 5 vols. Mexico City: Universidad Nacional Autónoma de México.
- Herrera, W. 2016. Climate of Costa Rica. In: Costa Rican ecosystems, ed. M. Kapelle, 19–29. Chicago: University of Chicago Press.
- Holdridge, L. R. 1967. Life zone ecology. San José, Costa Rica: Tropical Science Center.
- Holdridge, L. R., W. Grenke, W. Hatheway, T. Liang, and J. Tosi. 1971. Forest environments in tropical life zones: a pilot study. Oxford: Pergamon.
- Hoopes, J. W. 1994. Proyecto prehistórico Arenal excavations in the Santa Rosa river valley. In: Archaeology, volcanism and remote sensing in the Arenal region, Costa Rica, eds. P. D. Sheets, and B. McKee, 122–134. Austin: University of Texas Press.
- Hoopes, J. W. 2007. Sorcery and the taking of trophy heads in ancient Costa Rica. In: The taking and displaying of human body parts as trophies by Amerindians, eds. R. J. Chacon, and D. H. Dye, 444–480. New York: Springer.
- Incer Barquero, J. 2000. Geografía dinámica de Nicaragua. Managua, Nicaragua: Hispamer.

- Joyce, R., and J. Henderson. 2007. From feasting to cuisine: implications of archaeological research in an early Honduran village. *American Anthropologist* 109(4): 642–653. <https://doi.org/10.1525/aa.2007.109.4.642>
- Joyce, R., and J. Henderson. 2010. Forming Mesoamerican taste: cacao consumption in formative period contexts. In: *Pre-Columbian foodways: Interdisciplinary approaches to food, culture, and markets in ancient Mesoamerica*, eds. by J. Staller and M. Carrasco, 157–173. New York: Springer.
- Kaba, J. S., S., Zerbe, M., Agnolucci, F., Scandellari, A. A., Abunyewa, M. Giovannetti, and M. Tagliavini. 2019. Atmospheric nitrogen fixation by *Gliricidia* trees (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) intercropped with cocoa (*Theobroma cacao* L.). *Plant and Soil* 435(1): 323–336. <https://doi.org/10.1007/s11104-018-3897-x>
- Kappelle, M. 2016. Costa Rica's ecosystems: setting the stage. In: *Costa Rican ecosystems*, ed. M. Kapelle, 3–16. Chicago: University of Chicago Press.
- Kufer, J., and M. Heinrich 2006. Food for the rain gods: cacao in Ch'orti' ritual. In: *Chocolate in Mesoamerica: a cultural history of cacao*, ed. C. L. McNeil, 31–68. Gainesville: University Press of Florida.
- Lawton, R., M. Lawton, R. Lawton, and J. Daniels. 2016. The montane cloud forests of the volcanic cordilleras. In: *Costa Rican ecosystems*, ed. M. Kapelle, 415–450. Chicago: University of Chicago Press.
- Lentz, D., and R. Dickau. 2005. *Seeds of Central America and southern Mexico: the economic species*. New York, NY: The New York Botanical Garden Press.
- Lentz, D., M. Beaudry-Corbett, M. De Aguiar, and L. Kaplan. 1996. Foodstuffs, forests, fields, and shelter: a paleoethnobotanical analysis of vessel contents from the Cerén site, El Salvador. *Latin American Antiquity* 7(3): 247–262. <https://doi.org/10.2307/971577>
- Lentz, D., N. Dunning, V. Scarborough, K. Magee, K. Thompson, E. Weaver, E., C. Carr, R. Terry, G. Islebe, K. Tankersley, L. Grazioso Sierra, J. Jones, P. Buttles, F. Valdez, and C. Ramos Hernandez. 2014a. Forests, fields, and the edge of sustainability at the ancient Maya city of Tikal. *Proceedings of the National Academy of Sciences* 111(52): 18513–18518. <https://doi.org/10.1073/pnas.1408631111>
- Lentz, D. L., B. Lane, and K. Thompson. 2014b. Food, farming and forest management practices of the late classic Maya at Aguateca. In: *Life and politics at the royal court of Aguateca: artifacts, analytical data, and synthesis, monographs of the Aguateca archaeological project first phase*, vol. 3. eds. T. Inomata, and D. Triadan, 230–262. Salt Lake City: University of Utah Press.
- MacArthur, R. 1972. *Geographical ecology: patterns in the distribution of species*. New York, NY: Harper and Row.
- MacLeod, M. 1973. *Spanish Central America: a socioeconomic history, 1520–1720*. Berkeley, CA: University of California Press.
- MacLeod, P. 1996. Auge y estancamiento de la producción de cacao en Costa Rica 1660–95. *Anuario de Estudios Centroamericanos* 22: 83–107.
- Martin, A., and W. Barkley. 1961. *Seed identification manual*. Berkeley, CA: Regents of the University of California.
- McCafferty, G. 2021. Twenty years of Nicaraguan archaeology: results of the University of Calgary projects. In: *The archaeology of greater Nicoya: two decades of research in Nicaragua and Costa Rica*, eds. L. Steinbrenner, A. Geurds, G. McCafferty, and S. Salgado, 125–161. Louisville: University Press of Colorado.
- McCafferty, G. and L. Steinbrenner. 2003. Informe N-RI-44-00, Santa Isabel, Rivas. Report submitted to the Dirección de Patrimonio Cultural, Managua, Nicaragua.
- McGee, R. 1990. *Life, ritual, and religion among the Lacandón Maya*. Belmont, CA: Wadsworth.
- McNeil, C. 2006. *Chocolate in Mesoamerica: a cultural history of cacao*. Gainesville, Florida: University Press of Florida.
- McNeil, C. 2012. Recovering the color of ancient Maya floral offerings at Copan, Honduras. *RES: Anthropology and Aesthetics* 61: 300–314. <https://doi.org/10.1086/RESvnlms23647837>
- Meskill, L., and R. Joyce. 2003. *Embodied lives: figuring ancient Maya and Egyptian experience*. London: Routledge.

- Millon, R.F. 1955. When money grew on trees: A study of cacao in ancient Mesoamerica. Ph.D. dissertation, Columbia University, Department of Political Science, New York.
- Motamayor, J. C., P. Lachenaud, J. W. da Silva e Mota, R. Loor, D. N. Kuhn, J. S. Brown, and R. J. Schnell. 2008. Geographic and genetic population differentiation of the Amazonian Chocolate Tree (*Theobroma cacao* L). *PloS One* 3(10): e3311. <https://doi.org/10.1371/journal.pone.0003311>
- Mueller, M. 1994. Archaeological survey in the Arenal basin. In: *Archaeology, volcanism and remote sensing in the Arenal region, Costa Rica*, eds. P. D. Sheets and B. McKee, 48–72. Austin: University of Texas Press.
- Norr, L. 1991. Nutritional consequences of prehistoric subsistence in lower Central America. Doctoral Dissertation. Champaign: University of Illinois at Urbana-Champaign.
- Obando, V. 2002. Biodiversidad en Costa Rica: estado del conocimiento y gestión. Santo Domingo DeHeredia, Costa Rica: Instituto Nacional de Biodiversidad.
- Ogata, N., A. Gómez-Pompa, and K. Taube. 2006. The domestication and distribution of *Theobroma cacao* L. in the Neotropics. In: *Chocolate in Mesoamerica: a cultural history of cacao*, ed. C. L. McNeil, 69–89. Gainesville: University Press of Florida.
- Oviedo y Valdes, G. F. de. 1851–55. *Historia general y natural de las Indias, islas y tierra-firme del mar Océano* 4. V. 1. Madrid: Impr. de la Real academia de la historia.
- Pearsall, D. 2015. *Paleoethnobotany: a handbook of procedures*. 3rd edition. New York, NY: Routledge.
- Pittier, H. 1908. *Plantas usuales de Costa Rica*. San José: Editorial Costa Rica.
- Powis, T. G., F. Valdez Jr, T. R. Hester, W. J. Hurst, and S. M. Tarka Jr. 2002. Spouted vessels and cacao use among the Preclassic Maya. *Latin American Antiquity* 13: 85–106. <https://doi.org/10.2307/971742>
- Powis, T. G., W. J. Hurst, M. del Carmen Rodríguez, O. C. Ponciano, M. Blake, D. Cheetham, M. D. Coe, and J. G. Hodgson. 2008. The origins of cacao use in Mesoamerica. *Mexicon* 30: 35–38.
- Roque, R., M. Wiemann, and C. Olivares. 2013. Identification of endangered or threatened Costa Rican tree species by wood anatomy and fluorescence activity. *Revista de biología tropical* 61: 1133–1156.
- Rosés Alvarado, C. 1982. El ciclo del cacao en la economía colonial de Costa Rica, 1650–1794. *Mesoamérica* 4: 247–278.
- Sahagún, F.B. de, 1950–59. *General history of the things of New Spain: Florentine Codex*. Translated from Nahuatl by A. J. O. Anderson and C. E. Dibble. Volume 8. Santa Fe, NM: School of American Research.
- Salgado Gonzalez, S. 1996. Social change in a region of Granada, Pacific Nicaragua (1000 BC–1522 AD). Doctoral dissertation. Albany: State University of New York.
- Santini, L. 2016. *The fabricated forest*. Doctoral dissertation. Cambridge: Harvard University.
- Schultes, R. E., and R. F. Raffauf. 2004. *Vine of the soul: medicine men, their plants and rituals in the Colombian Amazonia*. Santa Fe, NM: Synergetic Press.
- Sheets, P. 1992. The pervasive pejorative in intermediate area studies. In: *Wealth and hierarchy in the intermediate area*, ed. F. Lange, 15–42. Washington DC: Dumbarton Oaks.
- Sheets, P. 1994a. The proyecto prehistórico Arenal: an introduction. In: *Archaeology, volcanism and remote sensing in the Arenal region, Costa Rica*, eds. P. D. Sheets, and B. McKee, 1–23. Austin: University of Texas Press.
- Sheets, P. 1994b. Summary and conclusions. In: *Archaeology, volcanism and remote sensing in the Arenal region, Costa Rica*, eds. P. D. Sheets, and B. McKee, 312–325. Austin: University of Texas Press.
- Sheets, P. 2011. Pilgrimages and persistent social memory in spite of volcanic disasters in the Arenal area, Costa Rica. *Ancient Mesoamerica* 22: 425–435.
- Sheets, P. and T. Sever. 2007. Creating and Perpetuating Social Memory Across the Ancient Costa Rican Landscape. In: *Remote Sensing in Archaeology*, eds. J. Wiseman and E. B. Farouk, 161–183. New York: Springer.

- Slotten, V. 2024. Forests, foodways, and households of the Arenal region, Costa Rica: an archaeological and paleoethnobotanical investigation of resilient practices in a volcanically active landscape. Doctoral dissertation. Berkeley: University of California, Berkeley.
- Sotelo, A., D. Soleri, C. Wachter, A. Sánchez-Chinchillas, and R. Argote. 2012. Chemical and nutritional composition of tejate, a traditional maize and cacao beverage from the central valleys of Oaxaca, Mexico. *Plant Foods for Human Nutrition* 67: 148–155. <https://doi.org/10.1007/s11130-012-0281-5>
- Standley, P. C., and J. A. Steyermark. 1946. *Flora of Guatemala*. Fieldiana: Botany. Chicago Natural History Museum.
- Steinbrenner, L. 2006. Cacao in Greater Nicoya: ethnohistory and a unique tradition. In: *Chocolate in Mesoamerica: a cultural history of cacao*, ed. C. L. McNeil, 253–270. Gainesville: University Press of Florida.
- Urban, M. 2026. Indigenous nomenclature reveals prehistoric interaction related to cacao in Amazonia and diffusion to Mesoamerica. *Ethnobotany and Economic Botany* 80(1): 19–37.
- Vazquez de Espinosa, A. 1942. *Compendium and description of the West Indies*. Translated by C.U. Clark. Smithsonian Miscellaneous Collections Vol. 102. Washington, DC: Smithsonian Institution.
- Vickers, W. T., and T. Plowman. 1984. Useful plants of the Siona and Secoya Indians of eastern Ecuador. *Fieldiana Botany* 15: 1–63.
- Wagner, G. E. 1982. Testing flotation recovery rates. *American Antiquity* 47: 127–132. <https://doi.org/10.2307/280058>
- Wheeler, E. A. 2011. InsideWood - a web resource for hardwood anatomy. *IAWA Journal* 32(2): 199–211.
- Wheeler, E. A., P. Baas, and P. Gasson 1989. IAWA list of microscopic features for hardwood identification, with an appendix on non-anatomical information. *IAWA Journal* 10: 219–332.
- Young, A. 1994. *The chocolate tree: A natural history of cacao*. Washington, DC: Smithsonian Institution Press.
- Zarrillo, S., and M. Blake. 2022. Tracing the movement of ancient cacao (*Theobroma cacao* L.) in the Americas: new approaches. In: *Waves of influence: revisiting coastal connections between Pre-Columbian northwest South America and Mesoamerica*, eds. C. Beekman, and C. McEwan, 121–144. Washington DC: Dumbarton Oaks Research Library and Collection.
- Zarrillo S., N. Gaikwad, C. Lanaud, T. Powis, C. Viot, I. Lesur, O. Fouet, X. Argout, E. Guichoux, F. Salin, R. Solorzano, O. Bouchez, H. Vignes, P. Severts, J. Hurtado, A. Yopez, L. Grivetti, M. Blake, and F. Valdez. 2018. The use and domestication of *Theobroma cacao* during the mid-Holocene in the upper Amazon. *Nature Ecology and Evolution* 2: 1879–1888. <https://doi.org/10.1038/s41559-018-0697-x>

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