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ORIGINAL PAPER

Uses of pre-Hispanic kitchenware from Central Nicaragua: implications for understanding botanical foodways

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Abstract

Archaeobotanical investigations in central Nicaragua are absent and preservation of organic remains is poor; therefore, we have applied starch analyses to samples from fragments of clay vessels excavated from layers dated to cal 1224 and 1391 CE at the Barillas site, Nicaragua. The approach to this dataset reveals the ways people interacted with edible plants in southern Central America. The scarcity of griddles recovered from ancient Nicaraguan archeological contexts has previously co-determined narratives on human mobility or cultural influence from the Mesoamerican culture area, due to the debatable presumption that this type of artifact necessarily entangles production and consumption of maize *tortillas*. In this article, we present results demonstrating evidence for the use of several starchy plants. The reconstructed culinary practices are vital for disentangling human–plant interrelationships and challenge earlier conceptions of ancient foodways in Central America. This research constitutes the first starch analysis in Nicaragua and the recovered plant remains belonging to manioc (*Manihot esculenta* Crantz), chili pepper (*Capsicum* sp.), and maize (*Zea mays* L.) have provided empirical evidence of ancient foodways. Concomitantly, these results have invalidated the preconception that griddles were tools used exclusively for the production of maize *tortillas*.

Keywords Nicaragua archeology · Archaeobotany · Starch analysis · Foodways · Culinary practices

Introduction

Research on pre-Hispanic foodways in southern Central America has received differential attention. While extensive work has been conducted in Panama (Cooke and Jiménez 2008; Dickau 2005; Piperno 2009; Piperno and Holst 1998; Piperno and Pearsall 1998) and some research has taken place in Costa Rica (Blanco and Mora 1994; Cooke and Sánchez 2001; Hoopes 1994), paleoethnobotanical research in Nicaragua has been very scarce (exception Dickau 1999). There is an absence of published archaeobotanical investigations for central Nicaragua. Therefore, most descriptions of pre-Hispanic subsistence practices in Nicaragua rely primarily on a single sixteenth Century Spanish chronicle, which states that squash (*Cucurbita* sp.), beans (*Phaseolus* sp.), and maize (*Zea mays* L.) were the economic botanical foods for the Indigenous peoples of southern Central America (Fernández de Oviedo 1851 [1535]). The scarce evidence of this "trinity" of staple crops has added decisive commentary to the debate surrounding Mesoamerican speakers of Otomanguean and Nahuatl languages migrating down from present-day Mexico into ancient Nicaragua (Constenla Umaña 1991; McCafferty 2015).

In addition, in 1522 CE Gil González Dávila, the first Spanish *conquistador* to arrive in what now is Pacific Nicaragua, reported cultural and linguistic similarities with parts of present-day Mexico (Somoza 1954). Beyond Pacific Nicaragua, archeological interpretations on Nicaragua's central region are also affected by this interpretive bias. The Barillas site, located in the study area (Fig. 1),was previously attributed to the Cuapa phase, initially understood to be a ceramic complex related to the arrival of a supposed foreign cultural group to the area (Gorin 1990; Rigat 1992) (for an initial critique of this see Geurds (2013)). The exogenous strangers supposedly brought new lithic tool types and pottery styles, which could have entangled new foodways (Gorin 1990). In contrast, we argue here that many of the practices

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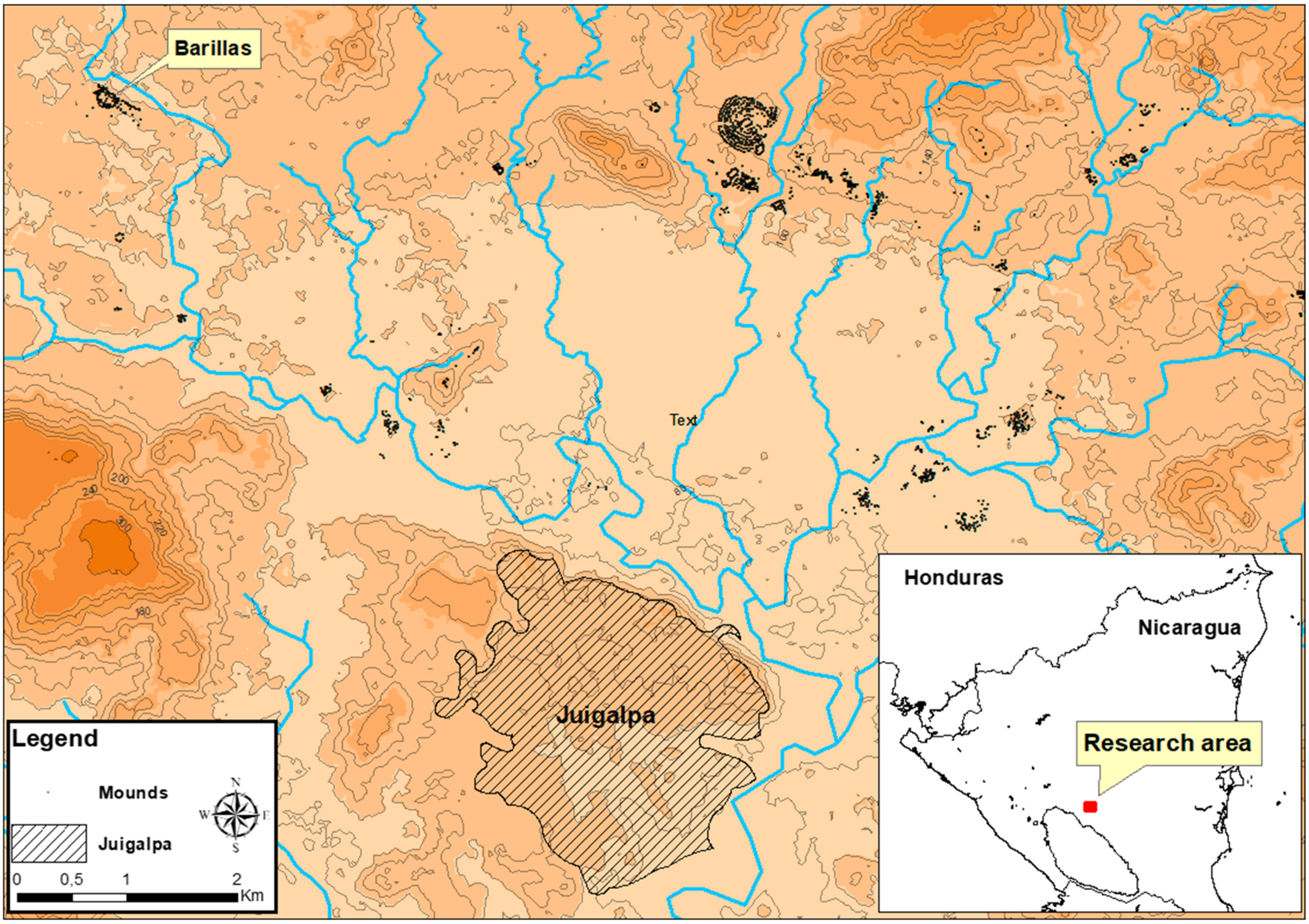

Fig. 1 The site of Barillas in central Nicaragua. Prepared by Simone Casale

detailed in this article are primarily the results of endogenous developments and not the sole consequence of unidirectional interactions with surrounding communities.

Relative to other regions of Nicaragua, the central region has a recent but by now considerable history of systematic archeological research. Following on from initial systematic work by the Proyecto Arqueológico Chontales (Gorin 1990; Rigat 1992), the Proyecto Arqueológico Centro de Nicaragua (PACEN), under the direction of Alexander Geurds has carried out research in the valley of Juigalpa, 25 km northeast of Lake Cocibolca since 2007 (Fig. 1). In 2015, with the goal to increase knowledge of pre-Hispanic food practices in central Nicaragua, a standardized protocol for macro and microbotanical sampling was included in all stratigraphic test pits excavated within the 52-km^2 study area of PACEN. As a result, both macro and microbotanical sampling was successfully carried out in 50 different excavation units from 18 archeological sites.

One of these sites, Barillas, has revealed unique finds of ceramic griddle fragments (flat "cooking" plates, which could have also been used as surfaces to process plants without cooking) (Rodríguez Suárez and Pagán-Jiménez 2008), commonly known as *comales* in Spanish literature, recovered from cultural layers dated to cal 1261 CE (± 37) ± 2σ, Beta-457276 and cal 1333 CE (± 58) ± 2σ, Beta-443734 (Donner et al. 2018; Donner and Geurds 2018) using Oxcal 4.3.2.2 (Ramsey 2017) and the IntCal 13 atmospheric curve (Reimer et al. 2013). Despite a promising number of excavations in Nicaragua, no griddles have been reported from the Pacific coastal region of the country as of yet (Bovallius 1886; Bransford 1881; Lange 1996; McCafferty 2011; McCafferty 2015; Norweb 1964; Squier and Comparato 1990). The only exception consists of three unconfirmed griddle fragments, which may well be tripod plate fragments (Healy and Pohl 1980:255). In contrast, excavations in the Caribbean watershed have yielded some interpreted griddle fragments (Gassiot Ballbé and Palomar Puebla 2006; Martinez Somarriba 1977; Vázquez Moreno 2016), but published archaeobotanical analyses are unavailable.

For the Pacific coastal region of Nicaragua, the prevailing idea is that griddles were not used and maize was primarily cooked in other types of vessels or consumed raw (McCafferty 2011). Even though there is macro and microbotanical evidence for maize cultivation in pre-Hispanic Pacific Nicaragua, it is currently not considered to have been a dominant dietary component (Dickau 1999). Instead, a variety of species including amaranth (*Amaranth* sp.), purslane (*Portulaca* sp.), beans, squash, and fruit trees have been identified, which indicate a diversity of botanical subsistence systems (Dickau 1999; López Sáez and Galeano 2007; McCafferty and Dennett 2013). The presence of grater chips has led to the idea that manioc (*Manihot esculenta* Crantz) may have been a significant dietary component (Debert 2005). However, with an inconclusive residue analysis on the thousands of *raspaditas* (microliths) recovered from the Santa Isabel site (Pacific Nicaragua), their function remains a mystery (Debert and Sherriff 2007).

Traditionally, maize *tortillas* have been regarded as central to Mesoamerican foodways, and cassava bread—a *tortilla* like flatbread made of manioc—was a prevalent food item in South America and the Caribbean (Lathrap 1973; Pagán-Jiménez 2013). However, recent studies show that both manioc and maize were used in all of these areas (Cagnato and Ponce 2017; Ciofalo et al. 2018; Ciofalo et al. 2019; Dickau et al. 2012; Pagán-Jiménez and Oliver 2008). The previously mentioned starch analyses also casted doubt upon the idea of maize only *tortillas* created on griddles from southern Central America, which complicates straightforward connections between plant species, artifact use, and cultural provenance.

In this article, suspected griddle fragments from the Barillas site in central Nicaragua were analyzed for starch content and their uses have been interpreted. Microbotanical analysis of the griddle fragments aimed to identify starchy plants and shed light on the socially learned practices entangled with local foodways. The results of this study challenge prevailing views on ancient foodways in this region and contribute to discussions regarding reconstructions of Central American foodways more widely.

Regional setting

The Barillas site is located 100 m west of the Mayales River, 5 km northwest of the city of Juigalpa. The site consists of 131 manmade mounds, built using a combination of bedrock fragments, sediment, pebbles, and debris (broken ceramic sherds and lithic artifacts). Three different excavation units were placed throughout the site, two in association with mounds (units 1 and 3), and one in the middle of a flat area surrounded by mounds (unit 2). The artifact assemblage used in this study was recovered from the first two pits, which might relate to practices associated with food preparation and consumption. Unit 1 was placed at the foot of a mound possibly related to shared practices performed near and/or in the site's central open space, while unit 3 was located at the foot of a possible household mound (see Fig. 2 Donner et al. 2019). The off-mound communal area of unit 2, in contrast, did not yield any griddle fragments. Even though the excavation units showed different stratigraphic characteristics, two types of archeological evidence were remarkably absent. First, we found no evidence of macrobotanical remains, even though the flotation protocols were standardized for the entire study area, yielding very good results in all sites with no exceptions. Second, no zooarchaeological remains were recovered from any of the units excavated at Barillas (Donner et al. 2018). Because archaeobotanical investigations in central Nicaragua are absent and preservation of organic remains are limited, we have applied starch analyses to samples from fragments of clay vessels excavated from layers at the Barillas site, dated to cal 1224 and 1391 CE.

Material and methods

Artifact management

Five artifacts—four flat sherds and a shoulder/neck fragment of a pot—were sampled and analyzed for starch content (Fig. 2). The five samples from the artifacts are referred to as sample 1, 2, 3, 4, and 5 and were processed and analyzed for starch content at the Faculty of Archeology, Leiden University (Table 1). These five artifacts were chosen for microbotanical sampling because of their morphological features, which suggested shapes like plates or griddles. The sample size was limited, partially because cooking and storage kitchenware only represents 7.3% of the ceramic sample at the Barillas site. Therefore, it is not surprising that griddles represented approximately 3% of the excavated assemblage. Subsequent studies on kitchenware will determine whether food consumption practices at the Barillas site tended towards communal and/or individual servings. Sample 4 consisted of a fragment of an *olla* (cooking pot), which was sampled for comparative purposes. Four of the five artifacts presented in this article were washed in the field following basic cataloging procedures after archeological recovery, which is not considered ideal for microbotanical analysis, although Barton (2007) achieved positive results from washed museum artifacts, and we hoped to do the same in this case. Once the artifacts were brought to Leiden University, they were photographed and sampled for microbotanical residues.

Artifact sample extractions

The recovery of microbotanical samples was a challenge possibly due to the poor preservation of organic remains at the site. However, after testing two different methods, we succeeded in the task. First, ultrasonic extraction (Sediment 1) was applied with no results. Then, minimal dry scraping in an attempt to recover plant residues while retaining technological macrotrace data for ceramic analysis (Sediment 2) was successful. Because Sediment 2 contained starch results and Sediment 1 did not, this suggests the starches from Sediment 2

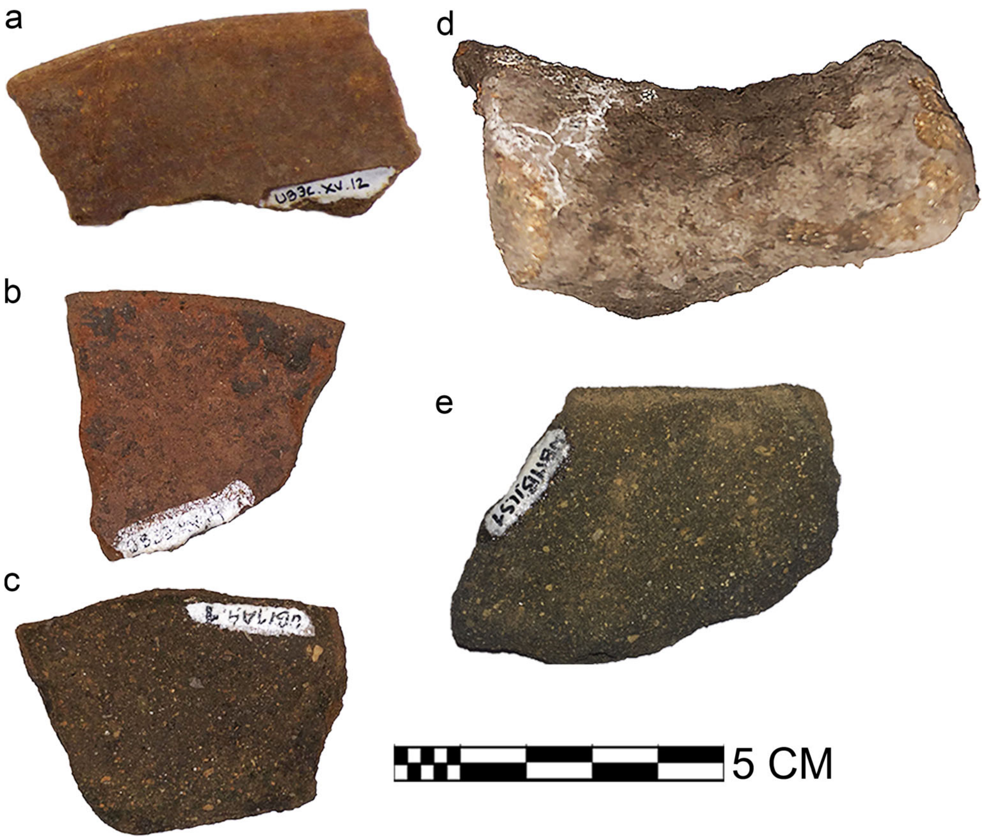

Fig. 2 The five clay artifacts that were sampled for analysis of starch content. **a** Sample 1 interpreted as a plate NR166. **b** Sample 2 interpreted as a plate NR165 **c** Sample 3 interpreted as a griddle NR168. **d** Sample 4 interpreted as an olla NR169. **e** Sample 5 interpreted as a griddle NR163.

were deposited (or absorbed) in the artifact's surface from persistent or prolonged use instead of brief contact with plant matter.

A wash bottle with ultra-purified water was used with significant water pressure to rinse the artifacts, which removed the majority of additional soil matrix that was loosely adhered and not a part of the artifacts use-history (Barton and Torrence 2015). This type of washing also assists in removing possible modern contamination (Chandler-Ezell and Pearsall 2003). Artifacts were set to dry in a dust- and wind-free area before proceeding with the following protocols.

A concern for all ancient starch analyses should be the potential for modern starch contamination, and researchers should include protocols designed to check for and mitigate this type of contamination (Crowther et al. 2014). At the Leiden Faculty of Archeology, the labs and consumables were consistently sampled separately during this study, and no modern starches were detected. The protocol was applied after Pagán-Jiménez (2007), and further modified based on (Atchison and Fullagar 1998; Barton et al. 1998; Pearsall et al. 2004; Zarrillo et al. 2008). In an attempt to retain macrotrace data, all artifacts except sample 4 were left to "soak" in ultra-purified water in separate, new plastic bags for less than 5 min. The artifacts were then placed in an ultrasonic bath for 9 min. The aqueous sediment was extracted from the sample bags and transferred to new 50-ml plastic tubes (Table 1**,** Sediment 1).

After each sample in the Sediment 1 category was separated for starch content through a flotation using a heavy-liquid solution of cesium chloride (CsCl) (described below), and residues were analyzed under a microscope with negative results for starch content, the decision was made to use an

Table 1 Artifact provenance and contextual information of the analyzed samples

Sample no.	Starch lab reference no.	Provenance	Sample type	Sediment 1 (ultrasonic) Sample volume(ml)/weight(g)	Sediment 2 (dry-scraping) Sample volume(ml)/weight(g)
Sample 1	NR166	UBI3CXV12	Clay rim fragment of a plate	1.0//.230	.2//.060
Sample 2	NR165	UBI3BXV14	Clay rim fragment of a plate	.7//.178	.3//.163
Sample 3	NR168	UBI1AIB5	Clay fragment of a griddle	2.0//.691	.3//.202
Sample 4	NR169	UBI1BIB5	Clay neck fragment of an *olla*	None	.8//.991
Sample 5	NR163	UBI1BIII5	Clay fragment of a griddle	1.2//.209	.4//.296

alternative sampling method. The absence of starch content from Sediment 1 samples are a demonstration of the cleanliness of the laboratories and can be viewed as a contamination test of lab consumables. All five artifacts had their internal surfaces (ideal for cooking or serving) minimally dry scraped with sterilized dental picks. Negative artifact surfaces (i.e., pores, cracks, crevices) were targeted first, as such surfaces help preserve starches that were manipulated, processed, or cooked with the artifacts (Hart 2011). The preservation of starches in the artifact's negative surfaces is explained through a limited post-depositional exposure to destructive agents, such as enzymes, microorganisms, fluctuations of soil moisture, temperature, and pH levels (Haslam 2004). Because the average weight of residues and artifact material removed was 0.34 g, (Table 1), this scraping procedure was determined to have been minimally destructive and has retained macrotrace data in the areas that were not scraped. The scraped residue fell onto new printing paper for collection. The dry residues (Table 1**,** Sediment 2) were carefully funneled into new 1.5-ml plastic tubes, and then labeled.

Macroscopically, the sampling procedure for Sediment 2 (dry scraping) appeared to have been more intrusive and damaging to the artifacts than the sampling procedure for Sediment 1 (ultrasonic). However, both the weight and volume of all Sediment 1 samples were more than that of the Sediment 2 samples (Table 1). We can therefore suggest that the sampling procedure for Sediment 2 samples was the least destructive method that allowed the recovery of data for both archaeobotanical and macrotrace analyses.

Heavy density liquid separation for the recovery of starches

After each sample was completely dried, a heavy-liquid solution of CsCl and ultra-purified water was added, prepared to 1.79 g/cm^3 density. The sample with solution was agitated and mixed using an ultrasonic bath for at least 1 min. Next, ancient starches were separated from other particles using a centrifuge operated at 2500 rpm for 8 min (procedure modified from Atchison and Fullagar 1998; Barton et al. 1998; Pagán-Jiménez 2007; Pagán-Jiménez et al. 2015; Pearsall et al. 2004). The supernatant (liquid lying above the solid residue) was decanted into new centrifuge vials. Ultra-purified water was added to each vial, and they were centrifuged for 8 min at 9000 rpm, which initiated the process to remove CsCl from the sample. As the starches began to sink during this part of the process, the supernatant was removed, more ultra-purified water was added, and the sample was centrifuged at 9000 rpm but for 5, rather than 8 min. Again, the supernatant was decanted and ultra-purified water was added, then the sample was centrifuged again at 9000 rpm for 5 min. Finally, after the CsCl was sufficiently diluted and removed from the samples, they were slide-mounted in a small drop of glycerin for microscopic observation.

For the purpose of comparison for taxonomic ascription, we used an assembled reference collection of starches obtained from recent economically useful and edible plants with the majority collected and processed by Dr. Jaime Pagán-Jiménez in Puerto Rico, who also obtained some samples from CIMMYT's Maize Genetic Resources (Pagán-Jiménez 2007; Pagán-Jiménez 2015a). Other samples were obtained from the Economic Botany collection of Naturalis Biodiversity Center Leiden and from markets and wild growing plants in the Neotropics. In sum, the reference collection contains modern starches from more than 140 specimens representing 70 genera and 63 species from the Antilles, continental tropical Americas (mainly the continental Greater Caribbean area), and from the Old World.

Descriptive analysis of modern samples with detailed explanations of morphometric features allowed for the taxonomic identifications of ancient starches through comparison (e.g., Pearsall et al. 2004; Perry et al. 2007; Piperno and Holst 1998). For this study, the morphometric features used were the starch's size, shape, and border (edges). In addition, the ancient starch's shape and position of extinction cross, hilum appearance and location, and presence and shape of both fissures and compression facets were documented. If the ancient starch characteristics were not observed in our modern reference collection or in published sources (Cagnato and Ponce 2017; Dickau 2005; Pagán-Jiménez 2007; Pagán-Jiménez 2015a; Perry 2002b; Perry et al. 2007; Piperno 2006; Piperno and Holst 1998; Reichert 1913), then taxonomic ascription was deemed uncertain. If a starch had an uncertain taxonomic identification, the prefix "cf." was used to indicate the closest possible taxonomic ascription, and when a starch was not successfully identified, we just used the term not identified. This research also had a focus on food processing damage signs on the ancient starch based upon comparisons with experimental studies in published literature (Babot 2003, 2006; Henry et al. 2009; Mickleburgh and Pagán-Jiménez 2012; Pagán-Jiménez 2015a; Pagán-Jiménez et al. 2017).

For observations and descriptions, each starch was photographed using a Leica DM2700 P polarizing light microscope with different focal lengths and rotated, when possible, to record and describe its characteristics. After the initial analysis, slides were stored in new cardboard holders for further observation and preservation. Furthermore, every sample collection tube with remaining residue was filled with ultra-purified water, temporarily sealed, and set aside for preservation.

Results

The starches from this study were recovered only from dry scraping layers of clay and thus releasing the starches from their protected microenvironment. We postulate the most likely cause for the entrapment of starches within the clay artifact's surfaces was through intense or prolonged use of the ceramics as food-related implements. Table 2 synthesizes the results attained from studying these samples. Overall, the plant remains identified demonstrate the use of seed, fruit, and tuber crops, which has helped expose human processing of starchy plants through socially learned practices.

The ceramic analysis determined that this artifact (Fig. 2 a) was part of a medium-grained plate with feldspar tempering excavated on mound. Manufacturing practices, from clay procurement to firing and decoration, followed the local tradition of ceramic production (Donner et al. 2018). One starch grain (Fig. 3(a, a1, a2)) identified as maize was recovered from the surface of this ceramic fragment measured 23.9 μm × 19.2 μm and had a pentagonal shape with an undulating extinction cross. No lamellae were visible. The hilum was centric, a Y-shaped fissure was present, and a continuous double border was observed. This starch had a circular central depression (Fig. 3(a1)), which was consistent with damage patterns from grinding maize (Mickleburgh and Pagán-Jiménez 2012; Vinton et al. 2009). In addition, this starch featured a crack and thin striations near its center, alterations due to pressure (grinding, cutting, scraping, or pounding) consistent with practices involving the preparation of flour-based foods (Mickleburgh and Pagán-Jiménez 2012).

This artifact (Fig. 2b) consisted of a clay fragment from a coarse-medium-grained plate, with feldspar temper that measured 25 cm in diameter and was excavated on mound. The lip of the sherd was flat and beveled, and the manufacturing practices determined from this sample were of local origins (Donner et al. 2018). This sherd had no evidence of starch recovered from its surface.

The sample was taken from an artifact (Fig. 2c) that was determined to have been a part of a coarse-grained, quartz-tempered griddle, with a 25-cm diameter, excavated off-mound. The recovered sherd had no visible surface treatment or decorations. As in the samples described above, the steps for the manufacturing process followed the local tradition for pottery manufacture. There were two starches recovered from the used surface of this griddle. The first starch grain identified as maize (Fig. 4(a, a1)) measured 16.9 μm × 13.9 μm. The extinction cross had three straight arms and one bent. The starch was oval shaped. No lamellae were visible. The hilum was open and centric with a bright ring around the hilum. There was no fissure present, but a double border was visible. There were a few striations from the hilum to the border. The striation and the bright ring indicated the plant organ that produced this starch was modified by pressure. The second starch (Fig. 4(b, b1)) was unidentified because the starch would not rotate, and it was partially covered by other organic material, thus the three-dimensional shape could not be determined. However, there were thin striations along the border indicating pressure was applied during culinary practice. The cooking environment was likely hot and slightly humid which was interpreted from this unidentified starch's large central depression and optical loss of birefringence (Henry et al. 2009; Pagán-Jiménez et al. 2017).

This sherd (Fig. 2d) was determined to have been a part of an *olla*. The vessel was medium grained, quartz tempered,

Table 2 Distribution of recovered starches per sample and their plant sources

Sample id	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5		
Sample type	Clay rim fragment of a plate	Clay rim fragment of a plate	Clay fragment of a griddle	Clay neck fragment of an *olla*	Clay fragment of a griddle		
Taxa						Starch count	[a]Ubiquity (%)
Manihot esculenta (manioc)				2	1	3	40
cf. *Manihot esculenta* (manioc)				1		1	20
Capsicum sp. (chili pepper)					1	1	20
Zea mays (maize)	1		1		4	6	60
Not identified			1			1	–
Starch count	1	0	2	3	6	–	–
[b] Minimum species richness	1	0	1	1	3	–	–
Ceramic technology possibly related to cooking			Quartz tempering	Quartz tempering	Quartz tempering		

[a] Ubiquity refers to the occurrence of identified taxa among the sampled artifact assemblage. It was calculated by dividing the presence of securely identified taxa by the total number of analyzed artifacts

[b] Minimum species richness combined both tentative ("cf.") and secure identifications. This excluded starches that were not identified because they could have been produced by some of the identified taxa

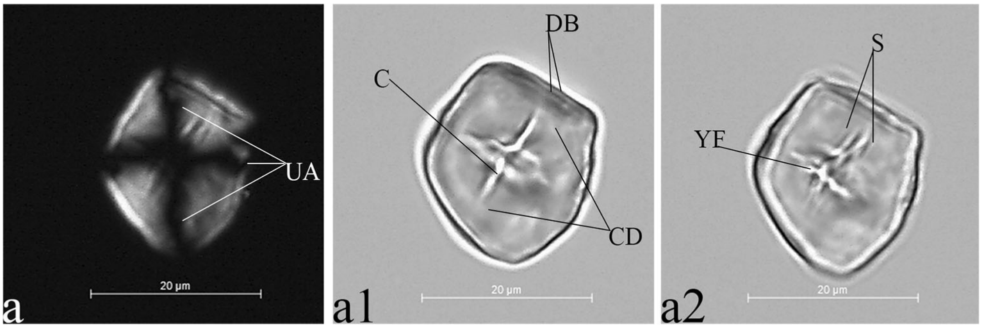

Fig. 3 Starch recovered from Artifact Sample-1. a Maize starch under polarized light and dark field view. a1 The same maize starch under bright field view. a2 The same maize starch under bright field view at a different focal length. "C" crack "CD" central depression; "DB" double border; "S" striation; "UA" undulating extinction cross arm; "YF" Y-shaped fissure

with a 7.5-cm throat diameter, and it was excavated off-mound. As in the previous samples, it was manufactured and followed the local technical tradition for ceramic production. Three starches were recovered from the interior area of the neck of this vessel. Two of the starches have been positively identified as manioc and one was identified as cf. manioc. The tentatively identified manioc starch (Fig. 5(a, a1, a2)) measured 18.3 µm × 18.2 µm was approximately spherical but had some basal flattening when rotated (Fig. 5(a2)). There were no lamellae visible. A diagnostic stellate fissure was present. This starch exhibits enough characteristics to be identified as cf. manioc. There were thin asymmetrical striations near the fissure, suggesting that applying pressure was part of culinary practices.

The manioc starch grain (Fig. 5(b, b1, b2)), which measured 19.9 µm × 19.8 µm, had a truncated bell-shape, with four flat basal compression facets, noticed when rotated (Fig. 5(b2)). No lamellae were visible. A Y-shaped fissure was present, as well as a centric hilum. This starch exhibited white striations from the center of the fissure extending to the border and a small central depression, which suggest light pressure was applied to the plant organ as part of culinary practices (Mickleburgh and Pagán-Jiménez 2012; Vinton et al. 2009).

The next starch grain identified as manioc (Fig. 5(c, c1, c2)), measured 19.7 µm × 18.2 µm, also had a truncated bell-shape but with two flat basal compression facets. No lamellae were visible, and a Y-shaped fissure was present. The hilum was closed and centric. For this truncated bell-shape of manioc starches, this starch has a longer than average (16 µm) length measurement, with an enlargement possibly due to culinary practices (Pagán-Jiménez 2007:221). This starch also has asymmetrical striations near the fissure, suggesting a degree of pressure occurred as part of culinary practices.

This sample was taken from one sherd of three articulating fragments, which belonged to a coarse-grained griddle (Fig. 2e) that was excavated off-mound. The vessel measured 42 cm in diameter, with a wall thickness ranging from 7.5 to 12.0 mm. The manufacturing process followed the same local technical signatures as the samples described previously. Six starches were recovered from the surface of this kitchen implement, and more than 50% of them had damage signs indicating the plant masses were altered by heat (sensu Henry et al. 2009). Of the recovered starches, the majority have sufficient characteristics to be securely identified as maize (4), one as chili pepper (*Capsicum* sp.), and one as manioc.

The starch grain (Fig. 6(a, a1)) securely identified as maize, measured 19.9 µm × 19.3 µm, and was spherical in shape with

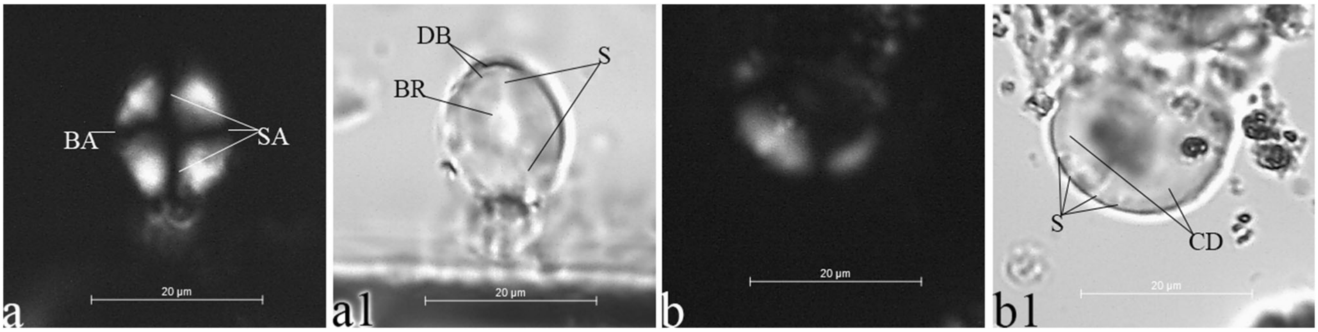

Fig. 4 Starches recovered from Artifact Sample-3. a Maize starch under polarized light and dark field view. a1 The same maize starch under bright field view. b Unidentified starch under polarized light and dark field view; note the optical loss of birefringence. b1 The same unidentified starch under bright field view. "BR" bright ring; "BA" bent extinction cross arm; "CD" central depression; "DB" double border; "S" striation "SA" straight extinction cross arm

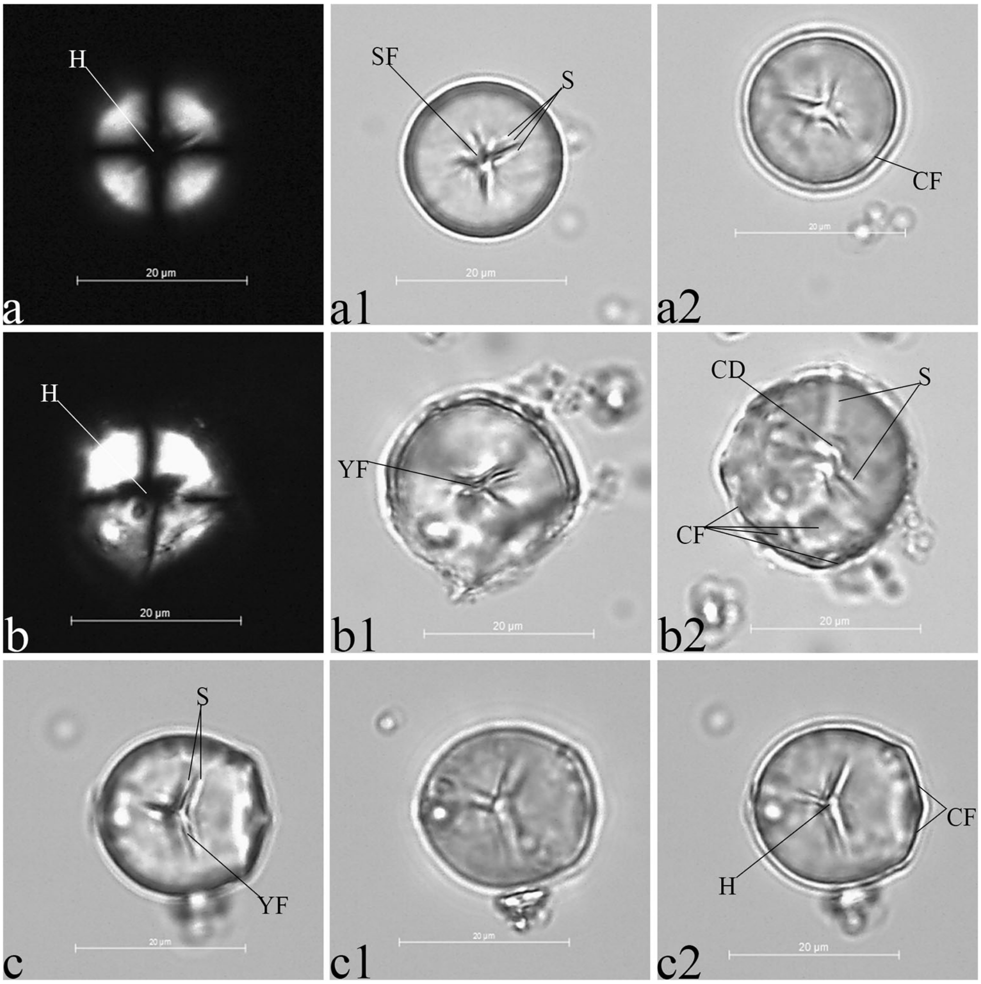

Fig. 5 Starches recovered from Artifact Sample-4. a cf. manioc starch under polarized light and dark field view. a1 The same cf. manioc starch under bright field view. a2 The same cf. manioc starch but rotated. b Manioc starch under polarized light and dark field view. b1 The same manioc starch under bright field view. b2 The same manioc starch but rotated. c Manioc starch under bright field view. c1 The same manioc starch at a different focal length. c2 The same manioc starch at a different focal length. "CD" central depression; "CF" compression facet; "H" hilum; "S" striation; "SF" stellate fissure; "YF" Y-shaped fissure

no visible compression facets. No lamellae were present. A Y-shaped fissure and double border were both visible. The hilum was closed and centric. The extinction cross had three straight arms and one bent arm. These characteristics were consistent with our reference collection and documented starches from published sources, which helps secure the taxonomic identification as maize (Holst et al. 2007; Mickleburgh and Pagán-Jiménez 2012; Pagán-Jiménez 2007; Pagán-Jiménez 2015a; Pagán-Jiménez et al. 2015; Pearsall et al. 2004). There were asymmetrical striations near the fissure indicating this starch was altered by pressure.

The starch grain (Fig. 6(b, b1, b2)) securely identified as maize, measured 18 µm × 14.8 µm, and had a pentagonal shape. It had at least two concave compression facets. No lamellae were present. A Y-shaped fissure and double border were both prominent. The extinction cross had two straight arms and two bent arms at the compression facets (Fig. 6(b)). These diagnostic characteristics were all found in samples of maize in our reference collection and in published sources (Holst et al. 2007; Mickleburgh and Pagán-Jiménez 2012; Pagán-Jiménez 2007, 2015a; Pearsall et al. 2004). This starch grain also had a swollen appearance most noticeable in Fig. 6(b2) (compared to starches in the reference collection), possibly suggesting it was cooked in a partially humid and hot cooking environment (Crowther 2012).

The starch grain (Fig. 6(c, c1, c2)) securely identified as maize, measured 21.6 µm × 18.8 µm, and had a pentagonal shape with at least three flat compression facets. No lamellae were present. A Y-shaped fissure and double border were visible. The extinction cross had three straight arms and one bent arm. When the starch was rotated and the focal length was changed (Fig. 6(c2)), pits on its surface became apparent, which were likely caused from enzyme degradation (Pagán-Jiménez 2015b).

Another starch grain (Fig. 6(d, d1, d2)), securely identified as maize, measured 21.9 µm × 16.8 µm, and had a hexagonal shape with at least six flat compression facets. No lamellae were present. A Y-shaped fissure and double border were both noticeable. The hilum was open and slightly eccentric. The extinction cross had at least one bent arm. These were all characteristics of maize starch that were found in our reference collection, which helps secure the identification. There were thin asymmetrical striations near the hilum caused from pressure as part of culinary practices.

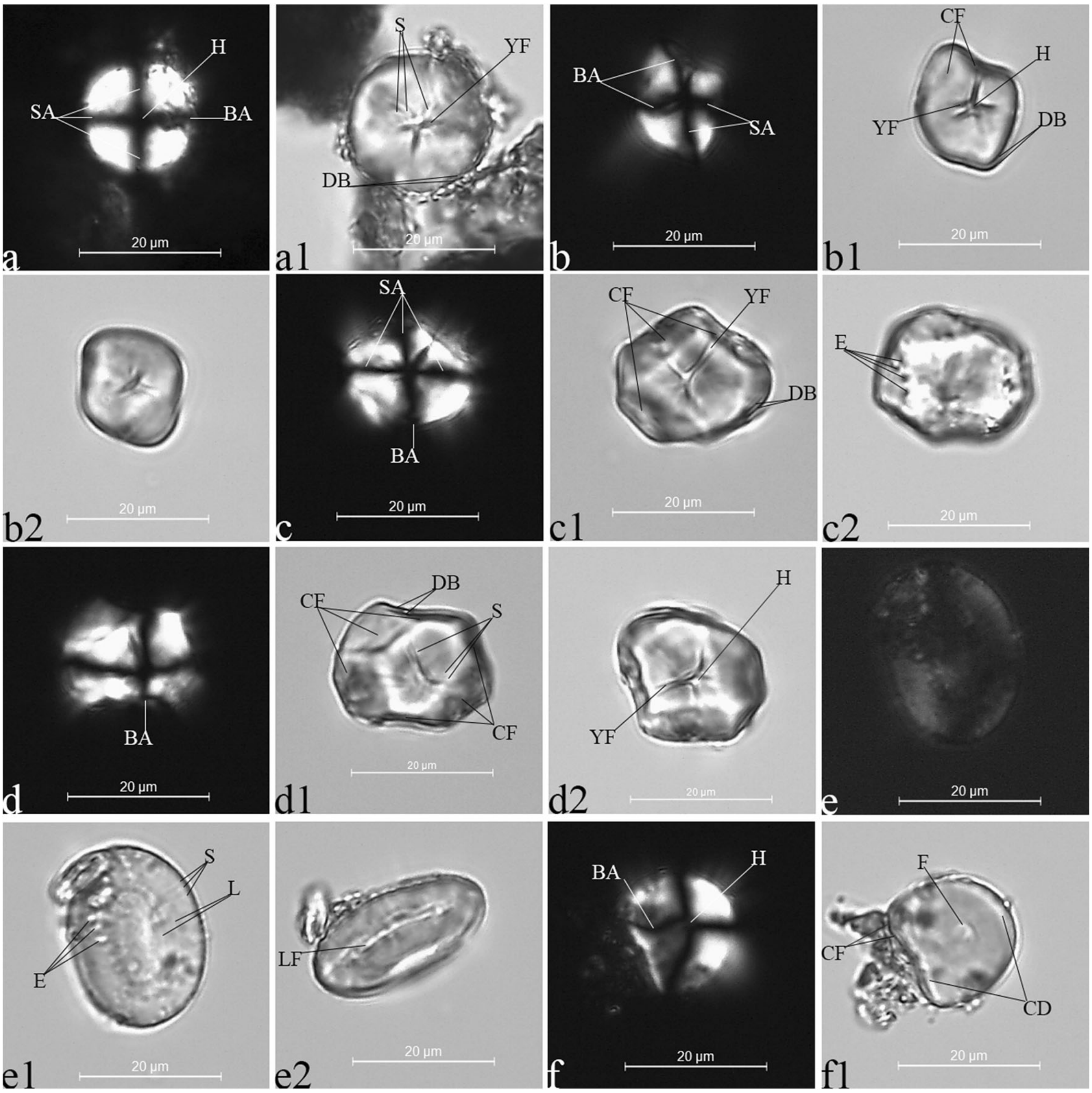

Fig. 6 Starches recovered from Artifact Sample-5. a Maize starch under polarized light and dark field view. a1 The same maize starch under bright field view. b Maize starch under polarized light and dark field view. b1 The same maize starch under bright field view. b2 The same maize starch under bright field view but rotated. c Maize starch under polarized light and dark field view. c1 The same maize starch under bright field view. c2 The same maize starch under bright field view but rotated and at a different focal length. d Maize starch under polarized light and dark field view. d1 The same maize starch under bright field view. d2 The same maize starch under bright field view but rotated. e Chili pepper starch under polarized light and dark field view. e1 The same chili starch under bright field view. e2 The same chili starch under bright field view but rotated. f Manioc starch under polarized light and dark field view. f1 The same manioc starch under bright field view. "BA" bent extinction cross arm; "CD" central depression; "CF" compression facet; "DB" double border; "E" enzymatic damage; "F" fold; "H" hilum; "L" lamellae; "LF" lineal fissure; "S" striation; "SA" straight extinction cross arm; "SF" stellate fissure; "UA" undulating extinction cross arm; "YF" Y-shaped fissure

The third starch grain (Fig. 6(e, e1, e2)) has been identified as originating from a chili pepper. The starch measured 25.5 µm × 18.6 µm and had an oval shape with no visible compression facets. Concentric oval lamellae were present. When the starch was rotated, a diagnostic lineal fissure was present (Perry et al. 2007). The extinction cross was diffuse and faint. There were thin striations along the border due to applied pressure as part of culinary practices. There were also pits on the surface of this starch likely due to enzyme degradation (Henry et al. 2009).

The last starch grain (Fig. 6(f, f1)) has been identified as manioc, measured 17.6 µm × 15.1 µm, and had a truncated bell-shape with at least two flat compression facets. No lamellae were present. The hilum was slightly eccentric. The extinction cross had one arm that was bent. These characteristics of manioc starches were found in our reference collection and published sources securing the taxonomic identification as manioc (Cagnato and Ponce 2017; Pagán-Jiménez 2015a; Perry 2002b; Piperno 2006). There was partial loss of optical birefringence (Fig. 6(f)), the beginning of a fold, and a large central depression, which helped us interpret that the food was prepared in a hot and partially humid cooking environment (Pagán-Jiménez et al. 2017).

In sum, two of the maize and one chili starch grains had damage from pressure applied as part of culinary practices. The manioc starch had evidence for the beginning of a fold caused by cooking foods in a hot and slightly humid cooking environment, which is consistent with the way that flatbreads are prepared on griddles (Pagán-Jiménez et al. 2017). Both the chili pepper and one maize starch grain had signs of enzymatic damage (sensu Henry et al. 2009; Pagán-Jiménez 2015b; Wang et al. 2017).

Discussion

Results from this study contribute towards understanding the distribution of ancient foodways associated with manioc, chili pepper, and maize in southern Central America. This data provides evidence of diverse starchy culinary practices which included several ways of processing foods culminating in a limited, yet enlightening, picture of pre-Hispanic foodways in central Nicaragua. Among our sample spectrum, maize was the most ubiquitous plant represented (Table 2). Perhaps foodways were focused on cultivating, processing, and consuming maize, but at this stage of our research, we cannot infer economic or cultural significance of one plant over others at the site or regional levels. For doing so at different chronological and geographical scales, the study of many other types of artifacts, different research methods, or at least the analysis of a larger number of samples must be carried out. In this study area and at the end of the pre-Hispanic period, the indigenous communities may have been in a process of significant changes in culinary practices, but we need more studies to conclusively comment on this process. However, the limited number of studied samples provides sufficient evidence to place the identified plants and associated culinary practices in specific chronological and geographical contexts for the first time in central Nicaragua. Important for future research is our additional line of evidence that agrees with Barton (2007) showcasing the type of information still available from washed or museum curated artifacts.

Due to the fact that heat and pressure were two of the main causes of alterations for the recovered starches, it is expected that a range of plant derivatives (e.g., *albondigas*, *tamales*, *salsas*, *tortillas*, and other flatbreads) were made from the identified plant sources (Cagnato and Ponce 2017; Pagán-Jiménez et al. 2005; Rodríguez Ramos 2005; Rodríguez Ramos et al. 2013). In the entire 52 km^2 study area, the presence of griddles is exclusive to the Barillas site. Even though Barillas shares a technical ceramic tradition that is present in the area since at least 300 CE, foodways associated with griddles have only been identified at this site (Donner et al. 2018). The recovered starchy residues and their damage patterns from food processing, in conjunction with the analyzed ceramics from this study demonstrate the existence of particular phytotechnological abilities (knowledge and tools to transform plants) that included intersecting operational sequences such as plant procurement, peeling, grinding, grating, flour preparation, fuel acquisition, fire creation, production, and employment of different lithic artifacts for these tasks, use of ceramic vessels for cooking, serving, and consumption, as well as practices related to discarding debris.

After plant procurement, interpretations regarding enzymatic damage to these plant organs can shed light on pre-preparation storage practices. On the one hand, the maize cob/peduncle may have been kept in a shady storage area without refrigeration, where the tropical heat could have caused the maize to naturally process through the early stages of fermentation (i.e., enzymatic degradation). The choice to use the "old" (long after being harvested) maize could have been one to prevent the organ from completely spoiling. On the other hand, the chili pepper may have been purposefully used after being partially digested by enzymes (old), due to their potential to transform and enhance flavors, as is still done in *salsa* preparation practices today.

Then, in the case of maize related meals, it is likely that the foods prepared with these tools required the maize kernels to be removed from the cob before further processing (Pagán-Jiménez et al. 2016). Ostensibly, the processed maize and manioc involved pressure from either grating or grinding, or both processes. Samples 3 and 5 exhibited recovered starches with signs of pressure damage combined with heat alterations, possibly suggesting the production of *tortillas* or flatbreads (Pagán-Jiménez et al. 2017). In contrast to the griddles, the starches recovered from the *olla* fragment (Sample 4) only had signs of pressure damage, but no evidence of heat alterations. Due to the collated information from different vessel samples, we can ascertain that manioc was prepared using different types of vessels (griddles and *ollas*), whereas maize was only recovered from griddles and a plate. While these differences in the samples might be related to conservation issues and sample bias, it could also be connected with dissimilar meals, some being prepared on griddles and others in *ollas*.

Regarding ceramic vessel technical traits, samples 3, 4, and 5 consisted of kitchenware, with shared paste preparation practices involving the addition of quartz as temper. Sample 4 was identified morphometrically as a cooking pot, used for preparing manioc-based foods. Sample 3, 4, and 5 possibly had more starches recovered because they pertained to vessels used for cooking rather than only serving. Samples 3 and 5 were the only samples that had starches affected by a partially humid cooking environment which is consistent with, but not exclusive to, experimental damage patterns from the use of griddles to prepare flatbreads (Pagán-Jiménez et al. 2017). Sample 5 was used for processing a broad suite of plants as shown by the residue of a variety of plant species recovered from its surface. We propose both samples 3 and 5 represent novel evidence of ceramic griddles based on the combination of shape, paste, the recovered starches, and their associated damage patterns. As the griddle vessels were flat, the humidity in the cooking environment was likely generated by the plant mass as opposed to an added external liquid cooking environment (i.e., dough, not soup). Manioc recovered from griddles supports the idea that the tubers were first altered by grating to be turned into a flour and thus dough, which, to our knowledge, would be a culinary practice absent from primary European chronicles that mention manioc in Central America (Cortés 1908 [1519]:162; Díaz del Castillo 1844 [1576]:22; Fernández de Oviedo 1851 [1535]).

This reconstruction of central Nicaraguan starchy foodways has been used to identify misconceptions based on the absence of evidence and the lacuna of botanical analyses. Thus, the incorporation of griddles—a completely novel utensil not known in the area before, but with signatures of local production—suggests transformations in kitchenware and their entangled foodways. Our data do not validate, nor indicate, explanations of direct migration or indirect Mesoamerican “influence.” The griddles and cooking pot appear to have had intentional addition of tempering materials, which has been interpreted as related to local cooking practices and the desire for adequate thermal transfer and crack resistant kitchenware (Donner et al. 2019). Diachronic studies of culinary practices in the region will shed more light on the local and regional histories of food production and consumption.

Conclusions

Overall, the results of this study offer a first insight into the phytocultural dynamics of the research area. For example, we are now able to propose that practitioners at the Barillas site consumed chili pepper, maize, and manioc prepared on griddles. These results challenge the bias that equates the use of griddles to the exclusive preparation of maize *tortillas*. Our data reflects previous conclusions that vessel form does not imply function; and function does not determine use (DeBoer 1975; Perry 2002a, 2005). In addition, the technological analysis of the manufacturing choices made by potters to produce the griddles, suggests their local production (Donner et al. 2018). When the manufacturing choices are combined with the inferred culinary practices, this problematizes existing narratives regarding migration and diffusion of practices by Mesoamerican groups after 900 CE, who have been traditionally linked to griddles and maize *tortillas*.

Since at least cal 600 CE, the indigenous communities living in the valley of Juigalpa participated in trade networks that connected them, across Lake Cocibolca, to parts of Pacific Nicaragua, and may have extended as far as central and northern Honduras (Donner, 2020; Donner and Geurds 2018). Habitual practices such as the ones linked to technological choices in ceramic manufacture or architectural techniques show strong local signatures, but the occasional incorporation of foreign materials and objects was also part of daily practices. For example, the occurrence of obsidian or imported polychrome vessels from cal 950 CE on did not coincide with archeological indications of a population shift, but rather reflects changes experienced in long-distance relationships between communities (Donner and Geurds 2018).

The griddles recovered at Barillas are significant in light of their hitherto unseen shape, in combination with the association with the culinary practices of special food items (*tortillas*) not made with other types of vessels, spatially connected to centrally located mounds at the site (Donner et al. 2019). Importantly, however, griddles were manufactured using the same technical sequence shared by all other fired clay kitchenware at the site (Donner, 2020). The evidence presented here does not provide indication of potential ethnic changes in the region, as was previously suggested (Gorin 1990), and initially raised in the early Colonial Spanish chronicle (Fernández de Oviedo 1851 [1535]). Griddles were absent from the investigated Barillas’ residential mounds (Donner et al. 2019), so it is possible that consumption of foods prepared on them was constricted to practices related to the Barillas central open space, or to a circumscribed group that controlled the trade networks.

The recovered starches provide the first empirical evidence of ancient central Nicaraguan foodways, providing an alternative to earlier archeological ideas regarding plant use that were based on indirect evidence. In light of this novel data, the results from this study help to understand pre-Hispanic botanical foodways in this region of southern Central America. The recovered plant residues have created a direct link among plants, people, and kitchenware, revealing a sophisticated set of locally developed culinary practices that were previously unknown for pre-Hispanic Nicaraguan foodways. Apart from that, this study has demonstrated the appropriateness of starch analysis in environments with limited preservation of organic remains, as well as the ability to obtain microbotanical data from washed artifacts. Concomitantly, these results invalidate the preconception that griddles were tools used exclusively for the production of maize *tortillas*, thereby nuancing straightforward associations drawn between ethnic identity and foodways.

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