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Starch grain analysis of ceramic residue from forest islands associated with raised fields in west central Mojos, Bolivia

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ABSTRACT

This study analyzed starch grain residues from 65 ceramic artifacts recovered from excavations of inhabited forest islands situated near raised fields in the Llanos de Mojos region of the southwestern Amazon Basin. The assemblage of starch grains from the forest island contexts represents a diverse array of plant resources including maize and manioc, but also other plants such as achira, arrowroot, and the first archaeological evidence for arracacha in the southwest Amazon. The artifacts sampled and plants identified in this study represent resource use by people living on forest islands who constructed and maintained adjacent raised fields for cultivation. The study highlights the importance of research into the diversity of local and regional foodways in the Llanos de Mojos.

1. Introduction

Archaeological starch grain analysis in the Amazon region is still novel despite significant contributions to our understanding of crop dispersals, such as cacao from southeastern Ecuador (Zarrillo et al. 2018), domestication, i.e. *Phaseolus* in Brazilian SW Amazonia (Watling et al. 2018), agricultural landscapes in French Guiana (McKey et al. 2010), and large habitation mounds in the Llanos de Mojos (Dickau et al. 2012). In this paper, we present the results of starch grain residue analysis from ceramic artifacts recovered from four pre-Columbian inhabited forest islands in West Central Llanos de Mojos, Bolivia (hereafter, WCM) from contexts dating between c.600 CE – 1500 CE and directly associated with raised fields. We document manioc and maize from domestic contexts including a wide variety of other lesser-known cultivars, such as arrowroot (*Maranta arundinacea* L.), and the first archaeological evidence of arracacha (*Arracacia xanthorrhiza* Bancr.) in the southwest Amazon. We hypothesize that cultivars grown on adjacent raised fields were brought into the domestic sphere through processing, cooking, and/or consumption by people living on the forest islands. The results of this study show that pre-Columbian Amazonians exploited an extensive array of plant taxa and participated in complex cuisines and foodways (Dickau et al. 2012) which are best understood through archaeological analyses from throughout the landscape.

The Llanos de Mojos of Bolivia (or Mojos) in the southwestern Amazon basin (Fig. 1) is a mosaic landscape composed of seasonally-inundated savannas, permanent wetlands, and patches of forest rich in riverine and terrestrial resources. The region is hypothesized to be a center for independent domestication of several major worldwide crops (Piperno and Pearsall, 1998; Piperno 2011), including manioc (*Manihot esculenta* Crantz), sweet potato (*Ipomoea batatas* (L.) Lam), chili pepper (*Capsicum* sp.), urucu or achiote (*Bixa orellana* L.), squash (*Cucurbita* sp.), and peach palm (*Bactris gasipaes* L.) (Clement et al. 1999, Clement et al., 2010; Iriarte et al. 2020). Recent investigations in the region reveal evidence that people cultivated squash and manioc in the early Holocene by 10,000 cal BP and maize as early as 6,850 cal B.P. (Lombardo et al. 2020). Thus, Mojos is a landscape that has been in dialogue with humans for millennia. Over time, Pre-Columbian peoples of Mojos constructed earthworks and raised fields that integrated the unique hydrology of the basin of the Rio Mamoré into a complex system of agriculture, fisheries management, and anthropogenic forests spanning over 110,000 square kilometers (Walker 2008; Duncan et al. 2021) and in doing so created one of the most significant examples of Pre-Columbian anthropogenic landscapes (Erickson 2008).

Prior to Jesuit contact and subsequent depopulation of Indigenous societies, Mojos was one of the most culturally and linguistically diverse areas in South America (Denevan 1966:40; Hill and Hornborg 2011:2). Jesuits, particularly Francisco Javier Eder, (1985[1791]) who spent several years in Mojos in the early 18th century, described the people of the region as expert producers of food who cultivated on raised and ditched fields, lived in large villages connected by causeways and canals,

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produced goods such as carved wood, exquisite featherwork, and fabric made from wood bark and cotton (*Gossypium*). Crops reportedly grown at the time of contact included manioc, maize, sweet potato, squash, gourds (*Lagenaria siceraria* (Molina) Standl.), beans (Fabaceae), peanuts (*Arachis hypogaea* L.), chili (*Capsicum*), tobacco (*Nicotiana*), arracacha, cacao (*Theobroma*), papaya (*Caraca papaya* L.), cotton (*Gossypium*), and farmers quickly adopted Old World cultigens such as bananas (*Musa acuminata* Colla) and sugarcane (*Saccharum officinarum* L.) (Eder 1985 [1791]; Metraux 1942; Denevan 1966).

Earthworks and raised fields described in the historic accounts are still present across a large area in WCM and plainly visible in satellite or drone imagery (Fig. 2) (Denevan 1966; Erickson and Balee 2006; 2010; Lee and Walker 2022; Lombardo et al. 2011; Walker 2004, 2008, 2018; Prumers et al. 2022). Raised fields have long been understood to be an important part of the history of cultivation and agriculture in the Llanos de Mojos and throughout the Americas (Denevan 2001) Directly dating the raised fields is complicated by a lack of organic material (Erickson 1995; Whitney et al. 2014:238), but occupation layers of associated Pre-Columbian settlements date to cal BCE 1200 (Walker 2018:48). The chronology of raised field agriculture remains difficult to establish, but some basic framework can be constructed. First, the paucity of historical references to raised field agriculture in particular suggests that the practice was largely abandoned by the time Jesuit missionaries were describing their new missions, in the 17th and 18th centuries CE. A sequence of 49 radiocarbon dates from across WCM tails off sharply at about 1500 CE, suggesting that the conquest was a causal factor in the abandonment of raised field agriculture (Walker 2004). On the other end of the sequence, long-term term environmental record in WCM (Duncan et al 2021) suggests that raised-field agriculture could have begun as early as 1700 BCE, and probably was in use by 200 CE.

Archaeological evidence of crops grown on the raised fields is scant, however, microbotanical analyses of sediments from raised fields have significantly identified a few potential crops, such as pollen from *Xanthosoma*, *Bixa, Ilex,* (Erickson 1995), and phytoliths of maize, sweet potato (*Ipomoea* spp.), *Inga*, *Heliconia,* and Marantaceae (Dickau et al. 2016; Whitney et al 2014). Raised fields are abundant west of the Mamoré river, however most paleoenvironmental and paleoethnobotanical investigations have been conducted to the east, where raised fields are not present (Dickau et al. 2012; Iriarte et al. 2020; Lombardo et al. 2011, 2020; Mayle and Iriarte 2014; Whitney et al. 2013, 2014). This is the first study of domestically-derived evidence of plant use in WCM where raised fields are directly associated with habitation areas.

The construction of raised fields on the savanna had multiple advantages from mitigating floods (Lombardo et al. 2011), to altering local hydrology (Duncan et al. 2021), and for improving soil conditions for

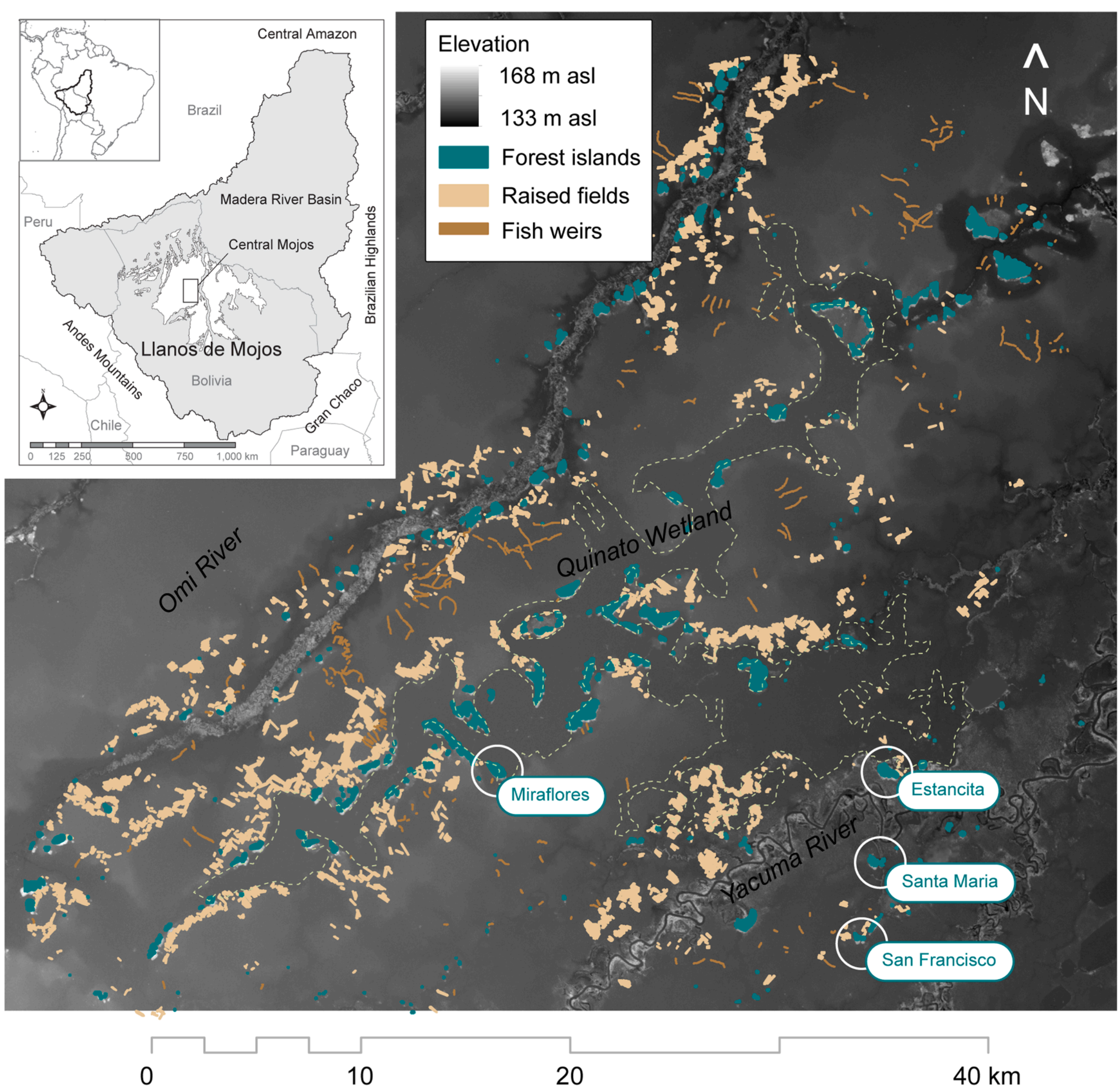

Fig. 1. Locations of forest island contexts in West Central Llanos de Mojos, Bolivia.

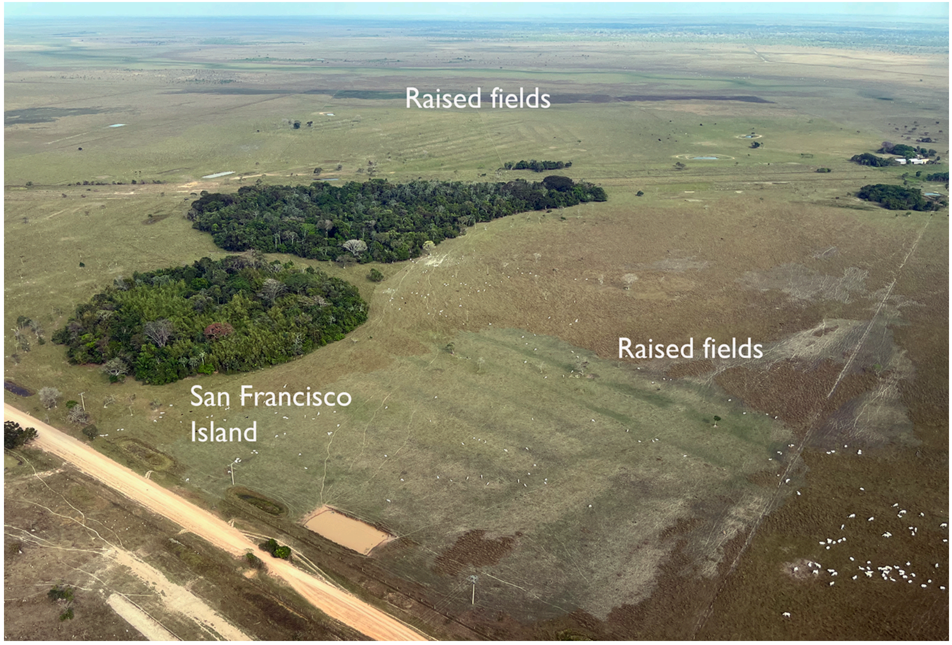

Fig. 2. Oblique aerial photograph showing San Francisco island with raised fields in direct association. Small white shapes are cattle. Photo taken August 2022, by J. Walker.

economic plants (Whitney et al. 2014:231). Wetland cores taken from the Quinato Wetland near forest islands in this research provided further evidence of agriculture and domestication of the landscape (Duncan et al. 2021), but a precise and accurate record of agricultural practice remains elusive. Furthermore, documenting the social organization, agricultural economies, cuisines, and patterns of habitation associated with raised fields in WCM has also lagged behind. Basic questions including the crops grown on raised fields, processing techniques, cooking techniques, serving contexts, and other aspects of daily, weekly, and yearly life have been much less well-studied.

The clearest paleoethnobotanical evidence for agriculture comes from forest islands and other habitation areas (Bruno 2010; Dickau et al 2012; Watling et al 2015), not directly from raised fields or wetland cores. Thousands of forest islands, discrete areas of arboreal vegetation, dot the forest savanna landscape in WCM. Often elevated, forest islands provide hospitable conditions for sturdy plants such as *motacú* (*Attalea phalerata* Mart. ex Spreng.), *tacuara* (*Guadua* spp. Kunth), and *chonta* (*Astrocaryum* spp. G. Mey.), creating closed canopy "islands' ' within the flat sea of surrounding savannas (Denevan 1966; Hanagarth, 1992; Langstroth 1996; Walker 2018:42). In 3 out of 4 cases, forest islands provide evidence of human habitation, and many of these islands have seen continual use and reoccupations by Pre-Columbian peoples since Mojos was first inhabited c.10,400 years ago (Walker 2018:43; see also Lombardo et al. 2013). Forest islands manifest both natural and cultural features, which combine evidence for human activities such as the use of ceramics for cooking, the creation of earthworks for defense, water control, or water conservation, and the accretion of forest island soils.

Here we present a unique dataset: starch grains recovered from ceramic residues from four forest islands, Estancita, Miraflores, San Francisco, and Santa Maria, that are in association with raised fields. (Table 1). All four forest islands were occupied for hundreds of years during the interval between 700 CE and 1500 CE, when raised fields were actively utilized. Ceramics were sampled from contexts dating to within this time frame. Estancita and San Francisco have much older occupations that may not be associated with raised fields at earlier points in time. Chronological control of ceramic styles is not sufficient to distinguish between the San Juan, Estancita 1 and 2, and Cerro phases on the basis of ceramic attributes alone (Walker 2011, 2012, 2018).

Starch grains from the ceramic residues are consistent with a wide range of useful plants including: manioc, arrowroot, arracacha, achira (*Canna* sp.), sweet potato, achiote, beans (Fabaceae), and maize. Additionally, a wide range of less-easily identified starch grains are present, which may correspond to previously undocumented economic plants, or varieties of cultivars yet to be identified. These data present direct evidence of what plants were processed, cooked, and consumed in domestic contexts, which in turn are directly associated with raised fields.

2. Materials and methods

Ceramic artifacts recovered from the WCM forest islands of Estancita, Miraflores, San Francisco, and Santa Maria were analyzed for starch grain residues. (Fig. 2). Artifacts from Santa Maria and Miraflores were

Table 1
Residue samples sorted by forest island and chronological period, with forest island area, number of raised fields within 1 km, mean area, and total raised field area. Numbers in the third column (*italics*) represent residue samples dated to one of the two later periods.

name	starch grain residue samples Estancita I (700–1000 CE)	Estancita II (1000–1200 CE)	*(1000–1500 CE)**	Cerro (1200–1500 CE)	area (ha)	Fields within 1 km	mean field area (ha) within 1 km	total field area within 1 km (ha)
Santa Maria	5		*7*	13	14.52	75	0.192	14.400
Estancita	4			11	37.09	16	0.273	4.368
Miraflores			*4*	7	36.78	59	0.116	6.844
San Francisco		4	*3*	0	2.66	74	0.356	26.344

* numbers in this column represent samples dated to one of the two later periods.

collected during excavations in 2018 and 2019, respectively. Unwashed and well-conserved artifacts from Estancita and San Francisco were pulled from the repository of the Museo Arqueológico Regional Yacuma in 2019.

2.1. Santa Maria

Santa Maria (-13.746505°, −65.458490°) covers about 14 ha and is located less than three kilometers west of the modern town of Santa Ana del Yacuma. Excavations in 2018 revealed several strata associated with human habitation. The sequence of radiocarbon dates from Santa Maria indicates that habitation was continuous from 650 to 1450 CE, associated with raised field construction and use (Walker et al. 2018; Walker et al. in preparation). Vegetation on the forest island includes economically useful species such as Arecaceae (palms), Malvaceae (ceiba), and Musaceae (banana). A total of 31 ceramic artifacts were sampled from two excavation units for this study.

2.2. Estancita

Estancita (-13.707105°, −65.452331°) covers 37 ha and is located on the southeast extension of the Quinato Wetland and within 800 m of the Yacuma river. (Walker 2018). It was excavated in 2011 and 2012 (Walker et al. 2011; Walker 2018). Radiocarbon dates from excavated strata show that the island was inhabited over at least 900 years (600–1500 CE) (Walker 2011). Ceramics from Estancita included in this study are associated with the Estancita I and Cerro phases (Table 1). Estancita is located adjacent to raised fields and is encircled by a ring ditch which is associated with the Estancita II phase. Modern vegetation on Estancita includes several economic plants such as motacú, tacuara, chonta, and mango (*Mangifera indica* L.) (Walker 2018:59). Fifteen ceramic fragments were sampled for residue analysis, taken from two excavation units less than 200 m apart.

2.3. Miraflores

Miraflores (-13.704758°, −65.624029°) covers about 36 ha and is located northeast of the Santa Maria forest island and the modern town of Santa Ana del Yacuma. The Miraflores forest island is situated just north of a large *curiche* (swamp) between the Omi and Yacuma rivers. This forest island was inhabited between 700 and 1450 CE. Later dates are associated with raised field construction and use (Walker et al. 2019; Walker et al. in preparation). This forest island is currently inhabited by a local community of about thirty people. The forest island rises nearly-two meters above the surrounding pampas. Several economic crops thrive today on the forest island, including banana, mango, manioc, and *motacú*. Ceramics from Miraflores included in this study are associated with the Estancita II and Cerro phases. Eleven ceramic fragments were sampled for residue analysis, taken from the two excavation units.

2.4. San Francisco

San Francisco (-13.779327°, −65.461562°) is a forest island covering 2.66 ha, located about five kilometers south of Santa Maria forest island and Santa Ana del Yacuma. This forest island lies between the Yacuma and Rapalo rivers, a few kilometers from each. San Francisco rises over a meter above the surrounding fields and savannas. Test excavations (Walker 2018:60) confirmed that layers of anthrosols accumulated over long-term human occupation of the island, artificially elevating the island above the surrounding savanna. San Francisco may have even been the original location of the Mission of Santa Ana (Walker 2018). The sequence of radiocarbon dates from San Francisco indicates that habitation was continuous from 600 to 1500 CE, while earlier dates indicate that the island was inhabited by 1500 BCE. Later dates are associated with raised field construction and use (Walker 2018:48). Eight ceramic artifacts were sampled from the excavations for residue analysis.

2.5. Sampling and processing

In total, 65 ceramic artifacts from the four forest islands were sampled. Sherds from a variety of ceramic vessel forms were selected at random for analysis, including six grater fragments (Fig. 3a). Vessel function, i.e. cooking, serving, and/or storage of food was not known. Ceramic graters in the assemblage of artifacts have a specific function related to their form and may be traditionally associated with root crop agriculture, specifically manioc (Jaimes Betancourt 2012; Lathrap 1970; DeBoer 1975; Perry 2005). The graters in this assemblage feature a furrowed surface against which roots, tubers, and/or rhizomes could be grated. The residues from graters and vessel forms were sampled from the interior surface of each artifact using distilled water and a single-use sterile sonicating toothbrush in order to loosen starch grains from the ceramic matrix. The supernatant was collected in individual, sterile test tubes and labeled with provenience (See Supplementary Information).

Samples were exported for chemical processing to the University of Central Florida Paleoethnobotany and Environmental Archaeology Laboratory. Standard processing procedures were followed to isolate starches from the ceramic residues (Duncan et al. 2009; Zarrillo 2012; Pearsall 2015, see also Supplementary Information) which include deflocculation of the samples using sodium hexametaphosphate followed by heavy liquid flotation with lithium metatungstate (LMT).The samples were then rinsed of heavy liquid and the starch extracts were mounted onto slides with glycerol and sealed with lacquer. A Zeiss Axio Imager.A2 microscope with polarization at an objective power of 400x was used to identify starch grains, and images were captured using ZEN image analysis software. Taxonomic identification of starches was determined by comparing archaeological starch grains to modern comparative Neotropical starch grains representing over 200 taxa, a collection begun by Deborah Pearsall at the University of Missouri-Columbia now housed at UCF. Starches were identified to family, genus, or species when possible. A conservative designation of "cf." was applied to identifications where the starch grain could be compared to, or is similar to, a known taxon (Lucas 1986) but does not fit all diagnostic criteria.

3. Results

A total of 247 starch grains were recorded representing at least 15 different taxa that were identified or consistent with known starch morphotypes (Table 2, **Supplementary Tables si1-4)**). Other starches were tallied that are not presently identified but are consistent with root/tuber, fruit, or seed morphotypes. Unidentifiable starches include those grains which are small in size (less than 8 μm), lack morphologically distinct characters, and/or are extensively damaged. Maize was the most ubiquitous and abundant taxon associated with the ceramics from all forest islands, however the richness of other taxa represented at Santa Maria and Estancita was much higher than at Miraflores and San Francisco. The results from each forest island are presented below.

3.1. Starch grains from Santa Maria

Thirty-one ceramic artifacts were sampled from Santa Maria and starch was recovered from 21 sherds. Maize at Santa Maria was highly ubiquitous and relatively abundant (Table 2**;** Fig. 4, **Supplementary Table si-1**). Root/tuber starch grains were taxonomically rich and well-represented including manioc, achira, arrowroot, Maranta/Calathea, arracacha, sweet potato (*Ipomoea batatas* (L.) Lam.), and yam (*Dioscorea*). Other fruit and seed derived starches were also present and include squash and gourd (Cucurbitaceae), beans (Fabaceae), and *urucu*. Over 35 % of the artifacts sampled yielded starches not unidentified to taxa. Of the 21 starch-bearing sherds, three artifacts yielded 71 % (n = 90) of the total number of starch grains from Santa Maria. Two of these

Fig. 3. Selected ceramic sherds excavated from four forest islands and sampled for starch grain residue. (a) grater fragment, UCF48 from Santa Maria, dating to Estancita I phase, see Table si-4. (b) basket impressed, UCF31 from Santa Maria, dating to Estancita II phase, see Table si-4. (c) painted, UCF77, from Estancita, dating to Cerro phase, see Table si-1. (d) painted, UCF83, from San Francisco, mixed context, see Table si-3. (e) plain, UCF100, from Miraflores, dating to Cerro phase, see Table si-2.

Table 2
Percent Presence of Starch on Ceramic Artifacts and Counts (in parentheses) by Forest Island.

Forest Island: Number of Sherds:		Santa Maria N = 31	Estancita N = 15	Miraflores N = 11	San Francisco N = 8
Name	**Specificity of ID**				
Maize	*Zea mays*	32 % (44)	26.7 % (26)	27.3 % (3)	37.5 % (5)
cf. Maize	*Z. mays*	22 % (18)	6.7 % (1)	18.2 % (3)	75 % (9)
Non-maize grass	*Setaria* spp.	6 0.5% (3)			
Yuca/Manioc	*Manihot esculenta*	6.5 % (2)	13.3 % (2)	9.1 % (1)	
cf. Manioc	*M. esculenta*	9.7 % (3)	6.7 % (2)		
Achira	*Canna* sp.	3.2 % (1)		9.1 % (1)	
Arrowroot	*Maranta arundinacea*	9.7 % (4)	6.7 % (1)		
Maranta/Calathea	Marantaceae		6.7 % (1)		
Arracacha	*Arracacia xanthorrhiza*	6.5 % (2)			12.5 % (1)
Sweet potato	*lpomoea batatas*	6.5 % (3)			25 % (2)
cf. Sweet potato	*I. batatas*	3.2 % (1)	6.7 % (1)		
cf. Yam	*Dioscorea* spp.	3.2 % (I)			
Squash family	Cucurbitaceae	3.2 % (1)			12.5 % (1)
cf. Bottle gourd	*Lagenaria siceraria*	3.2 % (1)			
Bean family	Fabaceae		6.7 % (1)		12.5 % (1)
Common bean	*Phaseolus vulgaris*	3.2 % (1)			
Fabaceae	*Fabaceae*			9.1 % (1)	
Urucu/annato	*Bixa orellana*	9 0.7%(4)	6.7 % (1)		12.5 % (1)
cf. Urucu/annatto	*B. orellana*		6.7 % (1)		
Unidentified morphotypes		35.5 % (36)	26 %(10)	63.6 % (14)	50 % (8)
Unidentifiable starch		9.7 % (5)	26 %(6)	36.4 % (4)	75 % (9)
Total Count Starch Grains		**129**	**53**	**28**	**38**

artifacts were identified as grater plates (see example, Fig. 3**a**). Taxonomic richness is relatively high with 14 taxa identified by starch morphotypes. Unidentified starch morphotypes may represent an additional 11 taxa that were economically important.

3.2. Starch grains from Estancita

From Estancita, starch grains were recovered from 8 of 15 (53 %) ceramic artifacts sampled (Table 2; Fig. 3**c**; Fig. 4, **Supplementary Table si-2**). Maize starch grains were ubiquitous and abundant. In addition, root/tuber starch grains from manioc, arrowroot, and sweet potato were identified along with bean and *urucu*. One artifact from Estancita yielded 62 % (n = 33) of the starches, and most (88 %) of the maize starch grains identified from this forest island. Estancita is not as taxonomically rich as Santa Maria, having only 7 identified taxa. An additional 8 unidentified starch morphotypes may represent other economic taxa.

3.3. Starch grains from Miraflores

Eleven ceramic artifacts were sampled from Miraflores, only one of which was unproductive. Again, maize is the most abundant and ubiquitous starch morphotype, but manioc, achira, and bean are present in the artifact residues from Miraflores (Table 2; Fig. 3**e**, Fig. 4 **Supplementary Table si-3**). Taxonomic richness is lower than Estancita and Santa Maria with only five identified economic plants. However, half of the starch grains recovered from the Miraflores artifacts could not be identified (n = 14) and may represent 13 other economic plant taxa.

3.4. Starch grains from San Francisco

Seven of 8 ceramic artifacts from San Francisco yielded starch grains (Table 2; Fig. 3**d**; Fig. 4, **Supplementary Table si-4**). Similar to the other three forest islands, maize was the most abundant and ubiquitous. However, root/tuber starches at San Francisco are less well-represented than at the other forest islands with only arracacha and sweet potato present. Squash, bean, and *urucu* are also represented. The richness of taxa identified at San Francisco is comparable to Miraflores, 5 taxa represented, but lower than Santa Maria and Miraflores. Unidentified morphotypes may indicate 5 other economic plants not yet known.

3.5. Summary of results

Starch grains were recovered from four of the six ceramic grater fragments from Santa Maria and Estancita. Two graters from Santa Maria notably yielded abundant starch grains, 19 and 17 grains respectively, and about 17 % of the total number of starches were recovered from graters. Individual graters often yielded multiple taxa; all the graters from Santa Maria had at least one taxa identified. Two samples from Santa Maria, UCF48 and UCF49, were the most productive graters, having 7 and 6 taxa on them, respectively (maize, manioc, *urucu*, arrowroot, sweet potato, arracacha, and three unidentified taxa).

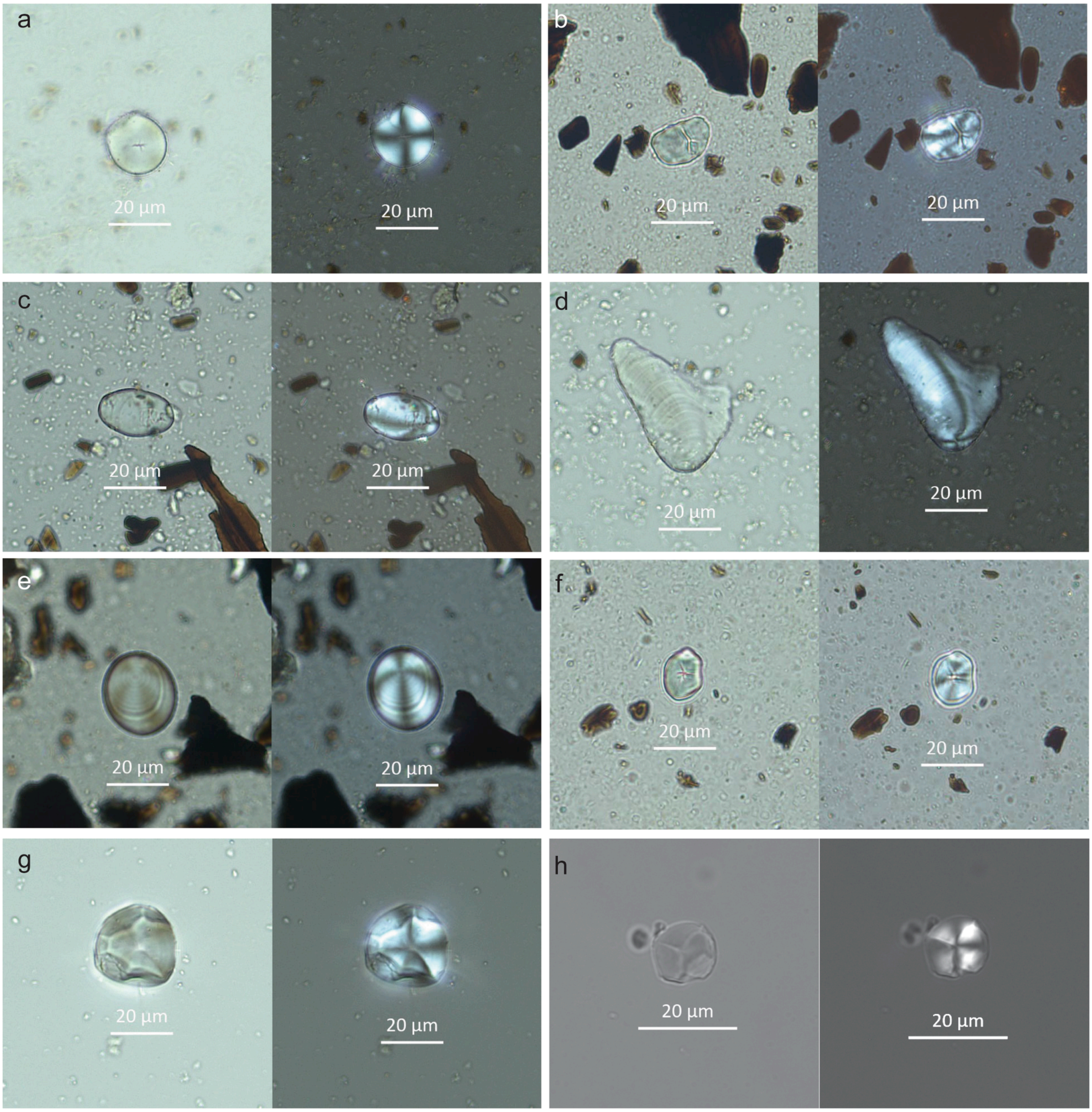

Fig. 4. Selected archaeological starch grains identified to taxa, each grain photographed in transmitted light (left side) and polarized light (right side). (a) Manioc *(Manihot esculenta)* from Estancita. (b) Arrowroot *(Maranta arundinacea)* from Santa Maria. (c) *Maranta/Calathea* type from Estancita. (d) Achira *(Canna* sp.*)* from Miraflores. (e) Cucurbitaceae from Santa Maria. (f) Maize *(Zea mays)* from Santa Maria. (g) archaeological Arracacha *(Arracacia xanthorrhiza)* from San Francisco. (j) comparative modern Arracacha tuber starch grain.

Two taxa (maize and an unidentified taxon) were each identified on graters UCF21 and UCF46 from Santa Maria. Two graters, UCF33 from Santa Maria and UCF76 from Estancita, did not yield starch grains.

In addition, a significant number of starch morphotypes remain unidentified (See Supplementary Table si-5). Sixty-eight (68) starch grains representing 29 unidentified starch morphotypes were recovered during the analysis. Eleven (11) unidentified starch types were recovered on artifacts from Santa Maria; 8 unidentified starch types were recovered on artifacts from Estancita, 13 on artifacts from Miraflores, and 5 on artifacts from San Francisco. Overall, 28 % of all starch in this analysis remains unidentified. Seven (7) of the unidentified types can be tentatively categorized as root/tuber starch, even if the specific taxa identification remains elusive. In general, many root/tuber starches tend to be large (between 15 and 20 µm), ovate, with eccentric hila and visible lamellae (Dickau et al. (2012:365). No unidentified types that are generally consistent with root/tuber starch were recovered on ceramics from San Francisco. The other 22 types likely represent fruits or seeds from various crops.

4. Discussion

The results of this study demonstrate that for several centuries pre-Columbian indigenous communities in Mojos did not rely exclusively on maize or manioc, but rather utilized a rich variety of cultivated plants, including root-tubers, fruits, and seeds. Although maize and manioc ubiquity is high, as predicted by the Jesuit accounts, peoples of

WCM supplemented their diet with a rich variety of other plant foods. Several plants hypothesized to have been abandoned in other parts of South America in favor of manioc (Pearsall 2014), such as arrowroot and achira, appear to have been cultivated and incorporated into the local cuisine.

Island to island comparison of starch assemblages is hindered due to differences in sampling effort among the four forest islands. Nearly half (n = 31) of the 66 artifacts analyzed came from excavations at Santa Maria and provided the highest number of starch grains and the richest assemblage of identified taxa. Equivalent sampling of the other three islands would likely increase richness and abundance of taxa. The differences between the forest islands might be explained by culinary preference or emphasis, or culturally-based cuisines, an hypothesis for future research.

The taxa identified on graters from Santa Maria and Estancita include Amazonian crops such as maize, manioc, *urucu*, arrowroot, sweet potato, and arracacha as well as yet unknown plants. The presence of these plants on the surfaces of ceramic graters demonstrates that they were actively processed and transformed into foods. The multiple plant taxa identified upon the graters is a testament to the use-lives of the tools themselves and is consistent with findings elsewhere in lowland tropical South America that graters, whether microlithic (Perry 2004;2005) or ceramic, were not restricted to the singular use of manioc. Graters from which we did not recover starch may have been used for other purposes than culinary or starch simply did not preserve in the residues. Although the quotidian activities involved in cooking and eating meals are often overlooked by researchers for the more extravagant religious and ecstatic rituals as cornerstones for making and transmitting culture, archaeologists are beginning to understand that the very “everydayness” of daily foodways is an experimental space where cultural traditions are reinforced, subverted, modified, or even outright rejected (Hastorf 2016). The graters and other ceramics included in this analysis were recovered from forest islands, thus indicating that the processes and transformations of the meal occurred here.

In addition, the unidentified starches suggest that several potential unknown cultivars were utilized in Mojos. Together with the seven identified root/tuber morphotypes, we present evidence that as many as 14 root/tubers may have been cultivated in Mojos, and not simply manioc. One lesser known cultivar in WCM is *arracacha:* its starch was identified in two forest island contexts, Santa Maria and San Francisco. Two starch grains from Santa Maria were identified from contexts dating to Estancita I (700–1000 CE) and one from Cerro phase (1200–1500 CE), evidencing the use of arracacha in late prehistoric to historic contexts. Additional contexts at San Francisco are undated. The Jesuits reported arracacha cultivation in lowland WCM (Métraux 1942:59 [Eder 1791]; Denevan 2001:77 [Castillo 1906]) and Nordenskiöld (1906) reported it in the mid-elevation Andes adjacent to WCM. Botanical identifications in early European accounts are not always reliable, but our identification of arracacha here would confirm these reports.

Arracacha comparative starch in our collection was obtained from a cultivated root purchased by Duncan in Chiclayo, Peru. Starches produced in the root are primarily single grains, however, compound granules are not uncommon. Starch grains range in size from 8 to 26 μm; ovate, spherical, and hemispherical forms predominate. Hila are closed and grains do not exhibit lamellae. Extinction crosses are pronounced but often irregular, especially on the distinctively multifaceted spheres which appear to be a defining starch morphotype of this species (Fig. 4**h**).

Arracacha is known in other parts of the neotropics as a cultivated root (Hodge 1954) including the Andes, Colombia, Puerto Rico, Cuba, Haiti, and the Dominican Republic (NRC 1989). A member of the Apiaceae, arracacha is similar in texture to roots of its Old World relatives, parsnip and carrot. Arracacha is a stout perennial herb, its stems and leaves grow up to a meter in height, and roots can grow from 5 to 25 cm long and 2–6 cm thick (NRC 1989:54). Wild species of *Arracacia* grow from temperate Bolivia as far north as Mexico (Hermann 1997) and can tolerate conditions with variable precipitation from 300 to 3,000 msl (Tapia and Fries 2007). The domesticated forms of *A. xanthorrhiza* most closely resemble wild forms found in mid-elevation Peru and Bolivia (Hermann 1997; Blas et al. 2008; Piperno and Pearsall 1998:128) and based on molecular similarity, these wild perennial *Arracacia* are likely ancestors of cultivated arracacha (Morillo and Sécond 2016; Morillo et al. 2017). The timing of initial domestication of arracacha is not known, however archaeological remains of desiccated arracacha tubers were reportedly recovered from graves at the necropolis of Ancon in coastal Peru (Safford 1917, plate II) and root clusters may be represented on Nasca pottery, possibly misidentified as manioc (Hodge 1954; Yacovleff and Herrera 1934).

Ethnographically, arracacha has several additional names including *lakachu* or *laqachu* in highland Bolivia and *racacha* and *virraca* in Peru (Cardenas 1969: 65–66; Oblitas Poblete 1969:77). The plant is also used as food and medicine. In addition to being eaten raw (Metraux 1942:61), arracacha can be cooked “al horno'' similar to yuca or potato (Cardenas 1969:66–7). Oblitas Poblete (1969:77) recorded arracacha use by the traveling Kallawayas healers of highland Bolivia to include several medicinal purposes, including as a decoction of roots and leaves as a bath or drink to treat jaundice, as poultice to treat tumors, and as a treatment for symptoms of rheumatism.

Today, arracacha is not known to be cultivated in WCM, but wild forms and cultivars are found on the eastern slopes of the Andes (Jørgensen et al. 1999). Its presence in WCM in the past suggests possible trade or there may have been ecological and botanical limitations that farmers in Mojos overcame. For instance, experiments in Florida (Hodge 1954) were unsuccessful at growing arracacha and reported poor root development from seeded arracacha plants. However, in South America, most cultivated arracacha is propagated from root cuttings (Hermann 1997); it is unclear if this difference in propagation affected the plant's potential in a sub-tropical region, such as Florida. Nevertheless, arracacha is cultivated commercially today in southeastern Brazil (Hermann 1997:80). Overall, arracacha is a “root crop worthy of investigation” (Hawkes 1989:491); its past use in the Amazon underscores the notion that our modern understanding of crops cultivated, traded, or otherwise obtained and used in Amazonia is limited and highlights the importance of further research into past people-plant relationships in this region.

5. Conclusion

Maize and manioc appear to be cornerstone starches for communities in WCM, however, the high number of unique, unidentified starch grain types indicates a local cuisine that targeted a number of plants that may have fallen out of favor with modern populations and no longer considered food sources, or are extinct or too rare in contemporary times to be targeted for food. The overall richness of the assemblage of identified and unidentified taxa highlights our present lack of understanding of the full breadth of diversity, richness, and complexity of the local cuisine in WCM in the past. Considering the southwest Amazon is one of the most biodiverse environments in the world, it should not be surprising that a rich and diverse selection of plants were utilized for food, medicine, ritual, and other necessary needs.

Starch grains recovered in this study from ceramics excavated at forest islands associated with raised fields in WCM provide insight into a variety of potential crops that could have been grown on a large scale. The plants identified in the context of domestic space of the forest islands document the recursive habits of food preparation and cooking that reinforce the centrality food takes in daily life: “food processing is part of the long cycle of control and domestication of the environment” (Hastorf 2017:91). In the context of pre-Columbian Mojos, this statement is especially powerful, where the landscape was visibly transformed through the construction of raised fields to grow crops, which were then processed and transformed again in forest islands to be consumed or utilized. The results of this study show that pre-Columbian inhabitants of west central Mojos targeted a rich suite of plants that were likely to have been cultivated upon the raised fields adjacent to their forest island homes.

Recent research (Duncan et al., 2021) has established that environmental data obtained from sediment cores in permanent wetlands, can resolve significant differences in environmental history between locations separated by only tens of kilometers. Understanding the relationship between these long term ecological histories, reconstructed through other paleoecological data such as pollen, phytolith, diatom, and charcoal data, and human activity requires the use of archaeological data, such as the starch grain data presented here, because it offers a more intimate perspective on human-plant relationships. Coupled with larger-scale environmental questions currently being pursued, this study continues to fill out the picture of past human-plant interactions in the Amazon. The Llanos de Mojos of the past was culturally and linguistically diverse. However, there are similarities in starch grain assemblages between WCM, where raised fields are omnipresent, and those from sites to the south and east where raised fields are not found (Dickau et al. 2012). Maize and manioc are similarly ubiquitous, however the raised-field adjacent contexts of the forest islands recovered a richer variety of taxa and several taxa not yet recorded in other areas of Mojos, such as root crops including achira, arrowroot, arracacha, and sweet potato. It is still unknown if these differences are due to indigenous local cultural preferences, traditions, or cuisine, or due to exogenous factors such as sampling effort. This research highlights the importance of further research into understanding the diversity of the original peoples of the Llanos de Mojos who intensively managed this landscape.

CRediT authorship contribution statement

Danielle N. Young: Conceptualization, Investigation, Writing – original draft. **Neil A. Duncan:** Conceptualization, Investigation, Funding acquisition, Writing – review & editing. **John H. Walker:** Conceptualization, Investigation, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2022.103761.

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