LETTERS

Early maize agriculture and interzonal interaction in southern Peru

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Over the past decade, increasing attention to the recovery and identification of plant microfossil remains from archaeological sites located in lowland South America has significantly increased knowledge of pre-Columbian plant domestication and crop plant dispersals in tropical forests and other regions[1–4]. Along the Andean mountain chain, however, the chronology and trajectory of plant domestication are still poorly understood for both important indigenous staple crops such as the potato (*Solanum* sp.) and others exogenous to the region, for example, maize (*Zea mays*)[5,6]. Here we report the analyses of plant microremains from a late preceramic house (3,431 ± 45 to 3,745 ± 65 ^{14}C BP or ~3,600 to 4,000 calibrated years BP) in the highland southern Peruvian site of Waynuna. Our results extend the record of maize by at least a millennium in the southern Andes, show on-site processing of maize into flour, provide direct evidence for the deliberate movement of plant foods by humans from the tropical forest to the highlands, and confirm the potential of plant microfossil analysis in understanding ancient plant use and migration in this region.

Test excavations at the open-air site of Waynuna (15° 16′ 01″ S, 72° 44′ 55″ W; site CO-38; ref. 7) in the Cotahuasi Valley, Arequipa Department, southern Peru, uncovered a portion of a late preceramic house (Fig. 1 and Table 1). The site lies in the shadow of Cerro Aycano, a peak at 4,475 m above sea level (a.s.l.) that anchors the northwest end of the Alca obsidian source, one of the two most important sources of obsidian in the south Central Andes[8] and a magnet for humans since Paleoindian times[9]. Waynuna occupies a natural terrace on a narrow finger ridge, which affords the site both morning and afternoon sun; other natural terraces are within an hour's walk and the site is less than 500 m from a perennial stream that descends from Cerro Aycano. At 3,625 m a.s.l., Waynuna lies at the interface of two distinct ecological zones with different agricultural potentials that currently support dissimilar staple crops (for example, see refs 10, 11). From 2,300 to 3,600 m a.s.l. is the *qheshwa* or *valle* temperate zone, characterized by intensively irrigated maize production. From 3,600 to 4,000 m a.s.l. is the *suni* or *echadero*, a cool upland zone devoted to tuber cultivation that is beyond the practical limits for irrigation-dependent maize farming.

Large surface areas of Waynuna are today occupied by abandoned agricultural terraces apparently built during the Middle Horizon (~1,200–950 calibrated years (cal yr) BP; ref. 7), indicating that the site itself was once under cultivation, albeit at the modern upper limit for maize. The preceramic deposits at Waynuna were covered by 1 m of Middle Horizon terrace fill containing abundant faunal remains, lithics (largely obsidian), potsherds, and several neonatal or infant burials. The preceramic strata yielded a lower density of artefacts, although obsidian debitage remained abundant. Level 3a–3b was a thick homogenous level, possibly fill, that included three small fragments of grinding stones. Level 4, the use deposit, covered a well-defined dirt floor (level 5) inside an arced house wall formed by boulders up to 50-cm high (Fig. 1). Although only about a quarter of the house was excavated, the plan appears circular with a diameter of about 2.10 m. A 30-cm opening on the north side served as a doorway. This layout is typical of Late Preceramic period houses in the Central Andes, although the diameter falls on the low end of the known range[12]. Below the floor were two stratigraphically equivalent, ashy levels (6 and 7i), separated by a protrusion of the sterile surface (level 7). Some archaeological material had intruded into this sterile soil, but density dropped off rapidly with depth while the matrix remained unchanged.

Waynuna is in a region of seasonal rainfall, and dead wood decomposes rapidly on the soil surface. Site elevation is above the modern limit for large trees; thus, available wood does not contain core material significantly older than the date of tree death. For both of these reasons, our bulk charcoal samples should not overestimate site age. Furthermore, the dates from Waynuna are coeval with the end of the Late Preceramic period in the south Central Andes; thus, it is unlikely that the true age of the site is younger than the age indicated by the ^{14}C results. Radiocarbon dates for levels 4–7i (those on and below the floor) are clustered, and level 3b seems to be slightly more recent (Table 1).

Because plant macroremains preserve poorly in this seasonally wet environment, microbotanical analysis of starches and silica phytoliths was selected as the best approach for examining the archaeobotanical assemblage. Unscreened soil samples from all preceramic strata from level 3b down to and including the preoccupation surface (level 7), and three unwashed fragments of grinding stones from levels 3a and 3b were analysed for plant microfossil remains by L.P. and D.R.P. by standard methods (see Supplementary Information). We recovered 1,077 starch granules from the soil samples and lithic tools (Table 2). Maize remains (Fig. 2d, e) were the most prevalent: we found 970 definitively identified starch granules and 49 probable maize granules. Remains of arrowroot (*Maranta* sp.; Fig. 2b) were recovered from level 3b as starch from a groundstone tool fragment. Arrowroot is a plant of the lowland tropical forest and cannot be grown above about 1,000 m a.s.l. (ref. 1). The starchy remains of what is probably potato (cf. *Solanum* sp.) occurred on a single groundstone fragment also from level 3b.

Phytolith content of the samples was generally good, apart from a sample collected from a culturally sterile context (level 7) where

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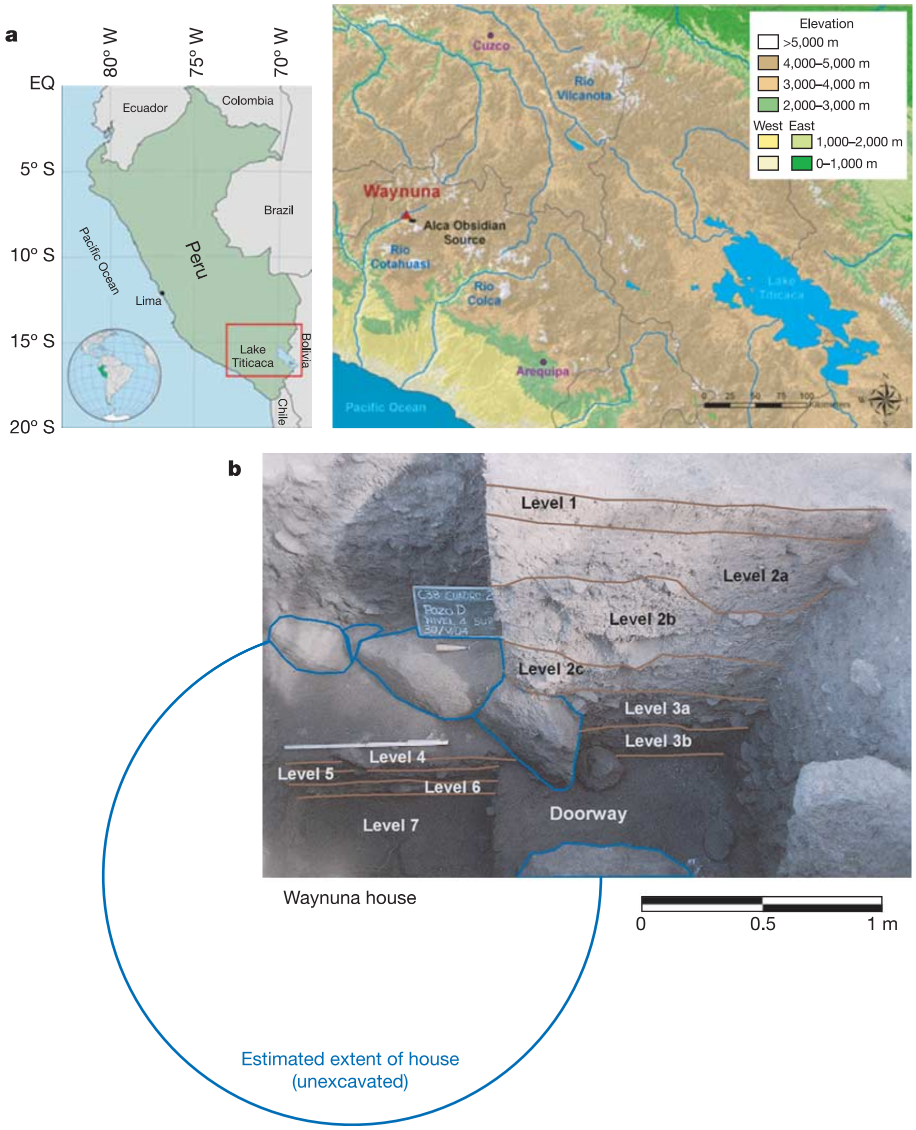

Figure 1 | Location of Waynuna and detail of the excavated Late Preceramic house and associated stratigraphy. a, Location of Waynuna. **b**, West profile of Waynuna house showing strata boundaries, pit 1A (right), pit 1C (lower left), and unmarked upper profile of pit 2D in the left background. Outlined stones are part of the preceramic house, the reconstructed outline of which is shown in blue.

virtually no phytoliths occurred (Table 2). Both maize leaf and cob phytoliths were recovered from level 5 (catalogue no. 33, second sample; Fig. 2c). Cob phytoliths were present in most other samples but, with the exception of those from level 5, maize leaf silica bodies could not be unequivocally identified because cross-bodies were very few in number ($n < 10$ from scans of the whole slide) or were of a size class smaller than those that identify maize. In level 3b (catalogue no. 30), conical phytoliths diagnostic of the plant family Marantaceae were found (Fig. 2a). They are typical of silica bodies that occur in the bracts and flesh of arrowroot rhizomes, and can also be found in

Table 1 | Radiocarbon dates from Waynuna

Cat. level	Sq	Pit	Feat.	RCY BP	Lab. No.	cal yr BP 2σ	$\delta^{13}C$	Comments
15: 3b	1	C		3,431 ± 45	BGS 2576	3,472–3,723, 3,797–3,816	−24.00‰ (+16 yr)	Posthouse deposit
16: 3b	1	C	1C-1	3,544 ± 55	BGS 2578	3,590–3,600, 3,612–3,905	−24.18‰ (+13 yr)	Posthouse deposit
18: 4	1	C		3,628 ± 65	BGS 2552	3,690–4,010, 4,028–4,083	−24.83‰ (+3 yr)	Use deposit on floor
32: 4	2	D		3,545 ± 45	BGS 2577	3,638–3,886	−23.97‰ (+16 yr)	Use deposit on floor
20: 4	1	C	1C-2	3,582 ± 100	BGS 2581	3,559–4,090, 4,131–4,137	−24.47‰ (+9 yr)	Feature on floor (L. 5)
22: 5	1	C		3,631 ± 45	BGS 2575	3,716–3,986, 4,049–4,063	−24.40‰ (+10 yr)	Floor
33: 5	2	D		3,509 ± 70	BGS 2580	3,486–3,502, 3,506–3,524, 3,555–3,901	−25.08‰ (−1 yr)	Floor
34: 6	2	D		3,745 ± 65	BGS 2573	3,842–4,183, 4,196–4,234	−24.80‰ (+3 yr)	Subfloor deposit
24: 7i	1	C		3,590 ± 45	BGS 2551	3,689–3,931, 3,942–3,969	−24.79‰ (+3 yr)	Subfloor deposit
25: 7	1	C		3,633 ± 85	BGS 2574	3,640–3,672, 3,677–4,093, 4,125–4,143	−23.69‰ (+21 yr)	Sterile with intruded material from 6, 7i

All assays were run at the Jaan Terasmae Radiocarbon Laboratory, Brock University, Canada, on bulk charcoal samples corrected for $^{12}C/^{13}C$ isotopic fractionation ($\delta^{13}C = [(^{13}C/^{12}C)_{sample}/(^{13}C/^{12}C)_{standard}] - 1$). Calibrations were run with Calib 5.0.1 (refs 28–30) using the Southern Hemisphere atmosphere correction. Cat., catalogue no.; Feat., feature; RCY, radiocarbon years (±s.d.).

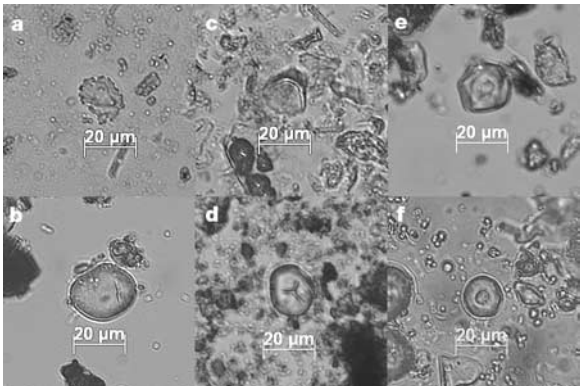

Figure 2 | Starch granules and phytoliths recovered from sediment samples and tool surfaces. **a**, Phytolith of Marantaceae (catalogue no. 30). **b**, Starch granule of arrowroot (tool 11). **c**, Rondel phytolith of maize (catalogue no. 33 segunda). **d**, Starch granule of maize (catalogue no. 32). **e**, Damaged starch granule of maize showing a scooped out area at the centre (tool 29). **f**, Modern starch granule subjected to grinding.

other species of the Marantaceae[13]. Given the occurrence of starch remains from only a single member of the Marantaceae, arrowroot, it is likely the phytoliths derive from this cultivar. They provide additional evidence for the presence of tropical forest cultivars in this highland location. The possibility that the microfossils are from wild members of the Marantaceae can be ruled out because this lowland family is not naturally distributed at this elevation.

Overall, the total numbers of microfossils remain fairly consistent throughout the column, with the exception of a peak in concentrations of both starches and phytoliths at level 5, the stratigraphic level that corresponds with the house floor. This finding supports the functional identification of the floor.

We divided maize granules into categories on the basis of both morphological features and structural damage resulting from grinding and pounding (Table 2 and Supplementary Information). Starch granules from flour-type corns differ from harder endosperm corns such as popcorn or dent corn, and this distinction has been noted in archaeological starch residues from Ecuador, Panama and Venezuela[3,14–16]. Although many modern Peruvian maize specimens in our comparative collections contain both morphologies within the same kernel, the presence of two distinct assemblages on the lithic tools, each dominated by either flour or hard endosperm type starch, indicate that at least two races of maize were in use at Waynuna (Table 2).

The percentage of maize starch granules that showed damage consistent with that produced by grinding ranged from 11 to 51% in each sample (Fig. 2e, f). The nature of maize starch itself supports the hypothesis that the observed damage is due to grinding. The surface of maize starch granules is pockmarked by small pores[17]. Enzymes enter the granule through these pores so that the granule is effectively digested from the inside out[17,18]. Thus, surface damage would not result from the digestive enzymes of soil-borne microorganisms but from external mechanical forces such as grinding.

Although many models of the rise of the state in ancient South America have relied on intensive agriculture, often involving maize (for example, see refs 5, 19, 20), the documented history of Andean maize is discontinuous. To the best of our knowledge, the earliest conclusive evidence for maize previously reported from the Central Andean highlands dates to ~2,500 cal yr BP (ref. 5). This region saw the rise of the maize-dependent empires of the Wari, Tiwanaku and Inca[21]. The starch and phytolith assemblages from Waynuna testify to the use of maize by 4,000 cal yr BP, whereas damage to starch granules extracted from the worn surfaces of the grindstone tool fragments confirms on-site processing of maize for food use. The presence of both leaf and cob phytoliths in the same context strongly suggests that maize was cultivated and processed on site.

Potato is one of the most important members of the Andean root crop complex and it can be cultivated at this elevation[10,22]. Potato starch granules have been isolated and studied from tubers preserved on and near the arid Peruvian coast at sites dating to between ~4,000 cal yr BP and 3,000 cal yr BP (ref. 22). Although at present we cannot positively determine whether the Waynuna residues are derived from a wild or domesticated species of *Solanum*, retrieval of the starches from this context indicates that they will survive when macroremains of the tubers have decayed.

Because the lowland domesticate arrowroot does not occur in the rich macrofossil assemblages of domesticated plants preserved in arid coastal Peruvian sites (for example, see refs 1, 22), this crop most probably arrived at Waynuna from the Amazonian rainforest to the east. The nearest interzonal access route passes by contemporaneous sites that received the lithic raw material obsidian from the Alca source near Waynuna[8]. The arrowroot findings at Waynuna are the earliest empirical evidence for movement of goods and/or people from eastern lowland zones into the Andean highlands. Such transfer of products between these ecological zones has been a cornerstone of models of highland Andean civilization from the Initial period and Chavin to the Inca empire (~3,800 to 418 cal yr BP), but until now we lacked direct, early evidence from the highlands on the eve of emerging complexity[23,24]. At present, the evidence for other lowland crops (achira, peanuts, manioc) postulated to have been important

Table 2 | Starch and phytolith frequencies from sediment samples and tool fragments

Cat. level	*Maranta* sp.	Marantaceae phytoliths	cf. *Solanum* sp.	*Zea mays* cob phytoliths	*Zea mays* leaf phytoliths	*Zea mays*	*Zea mays* (soft)	*Zea mays* (hard)	*Zea mays* (damaged)	cf. *Zea mays*	Unidentified	Grand total
Soil samples												
30: 3b		P		–	A	5	14	42	22	11	3	97
31: El. 2D-2		A		P	A		6	15	25	3	2	51
32: 4		A		–	A		2	29	16		2	49
33: 5 primera		A		–	A	6	13	24	16	2	3	64
33: 5 segunda		A		C	P	1	50+	50+	50+	6	8	165+
34: 6		A		C	–	1	50+	9	16			76+
36: 7i		A		P	–	3	19	24	14	15	2	77
35: El. 2D-3		A		A	A	1	9	7	9	2	2	30
37: 7 (sterile)		A		A	A	1	6	16	16	6		45
Total ($n = 9$)	0	P		P	P	18	169	216	184	45	22	654
Lithic tools												
29: 3a							11	53	29	3	6	102
11: 3b	4						104	28	17	1	11	165
30: 3b			3				115	8	18		12	156
Total ($n = 3$)	4	–	3	–	–	0	230	89	64	4	29	423
Grand total	4	P	3	P	P	18	399	305	248	49	51	1,077

Numerals indicate the numbers of starch granules recovered. Letters indicate whether phytoliths were present (P), absent (A) or common (C) in samples.

items of exchange and/or symbolism among tropical forest and highland Andean peoples still only comes from iconographic depictions[24]. Because these plants also produce diagnostic starch grains, future microfossil work should reveal more information.

Waynuna's topographic setting, proximity to perennial water, and position at the ecotone where both maize and root crop agriculture are productive, fit traditional criteria of Andean peasant farmers for a desirable village site[25]. The archaeobotanical data indicate that this preference for settlement at the maize–tuber ecotone has considerable time depth in the region. The successful identification of starch granules damaged by grinding supports previous research[26], provides independent evidence for assessing stone tool function and plant processing strategy, and confirms that starch remains derived from sediments represent food residues. The successful recovery of the microremains of both seed and tuber crops from Waynuna, including starch granules and phytoliths from two different structures of the same food plant species, indicates that multiproxy microfossil analysis may be the most effective means for documenting crop plants and understanding their history and role in many ancient Andean contexts.

METHODS

Methods for starch extractions from soils[27] were modified from those published elsewhere, and standard procedures were used for analyses of lithic tools[14,15]. Extraction methods for phytolith analysis of soil samples followed standard procedures[13]. Microfossil identifications were based on modern reference collections of more than 2,000 Neotropical and Andean plant species housed at the Smithsonian Tropical Research Institute in Panama and the Department of Anthropology, National Museum of Natural History in Washington DC. For detailed methods, see Supplementary Information.

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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