Sweet potato (*Ipomoea batatas*) and banana (*Musa sp.*) microfossils in deposits from the Kona Field System, Island of Hawaii

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**Abstract**

Analysis of plant microfossils (pollen, phytoliths, starch grains and xylem cells) was carried out on 12 soil samples from a variety of pre-contact archaeological features in South Kona within a portion of what has been termed the Kona Field System, on the Island of Hawaii. The oldest radiocarbon ages of the sampled deposits are 1300–1625 AD and 1310–1470 AD. The pollen and phytolith evidence suggests a change from more to less trees and shrubs in the area as a result of human activity. We found phytoliths of banana (*Musa sp.*) leaves in most and starch grains and xylem cells of tuberous roots of c.f. sweet potato (*Ipomoea batatas*) in all of the samples, suggesting that the sampled features were associated with these crops and that both crops were cultivated intensively within the study area. Higher concentrations (volumetric) of starch and xylem in samples from older deposits suggest that cultivation was more intensive then. The apparent absence of starch and xylem remains of other tuberous crops archaeologically identified elsewhere in Polynesia suggests that tuberous cropping within the study area was mono-specific.

1. Introduction

During Polynesian settlement of the Pacific, agricultural practices combining tropical Asian-Pacific and American crops were adapted to a diversity of island environments. The intensity of this reached its peak in the Hawaiian Islands (Vitousek et al., 2004). A total of 26 plant species, mostly food crops, were introduced to the islands by early colonists (Whistler, 1991), who arrived between c. 300 and 600 AD (Cordy, 2000). Large areas of irrigated pond fields and of short-fallow, rain-fed dryland field systems were developed, reflecting the great environmental heterogeneity of the islands (Rosendahl and Yen, 1971; Clark and Kirch, 1983; Pearsall and Trimble, 1984; Kirch, 1985, 1994; Clark, 1987; Ladejoged, 1993; Rosendahl, 1994; Ladejoged and Graves, 2000, 2005, 2006, in press; Allen, 2001, 2004; Ladejoged et al., 1996, 2003; Burghardt and Tomonari-Tuggle, 2004; Coil, 2004; Kirch et al., 2004, 2005; Vitousek et al., 2004; McCoy, 2005; Mulrooney and Ladejoged, 2005; McCoy and Hartshorn, 2007; Meyer et al., 2007). Many of these studies focused on productive increases in relation to increased socio-political complexity.

Pond fields are restricted mainly to the geologically older islands, which have well-developed drainage networks. The dryland systems are found almost entirely on the younger islands of Hawaii and Maui, which have few streams. Their discrete locations are thought to reflect areas that represent “sweet spots” of rainfall and soil fertility (Meyer et al., 2007). Most of the dryland systems were abandoned within a few decades after significant European contact in the late 18th century as traditional Hawaiian societies were disrupted (e.g., shifts in economic focus, disease-induced population decline, demise of the traditional religious system) (Vitousek et al., 2004). The archaeological remains of the dryland systems’ stone field walls, numerous mounds and enclosures, and stone lined trails mark their former extent. The distribution of dryland fields was recorded in 1823 by Ellis (1963).

Considering the extensive amount of landscape evidence for horticulture in the Hawaiian Islands, there is no large amount of direct evidence in the form of actual remains of cultivated plants. To our knowledge, the direct evidence published to date is limited to a few sites. Macrofossil fragments of the tuberous root of sweet potato (*Ipomoea batatas*) have been identified at Kohala on the
island of Hawaii (Rosendahl and Yen, 1971; Clark, 1983b; Ladefoged et al., 2005) and at Kahikinui on Maui (Kirch et al., 2004, 2005). Also, pollen of sweet potato (Clark, 1983a) and coconut (Cocos nucifera) (Ward, 2001), seed coats of candlenut (Aleurites moluccana) and a charred stalk of Pacific Island cabbage tree (Cordyline fruticosa) (Lennstrom, 2001) have been identified at Kealakekua on the island of Hawaii.

Archaeological investigations at Ki’i’læ and Kauleoli ahupua’a in the southern part of the dryland Kona Field System on the big island of Hawaii (Fig. 1) by one of us (RR) during 2001–2007, present an opportunity to look for further evidence of introduced Polynesian crops in Hawaii, using combined plant microfossil analyses. Reported here are results of analysis of microfossils in deposits from a variety of suspected agricultural and habitation features at five archaeological sites. Twelve soil samples were examined for pollen, phytoliths and starch residues, to provide evidence of past environments, vegetation and horticulture.

2. The study area

The Kona Field System (∼140 km²) is situated on central western Hawaii Island, on the slopes of Hualalai (2100 m) and Mauna Loa (4000 m) (Fig. 1). These are currently active volcanoes and were so at the time of European contact. The field system is a narrow (∼30 × 5 km) belt with an altitudinal range of 0–2500 m extending across 100+ jurisdictionally distinct Hawaiian traditional land units (ahupua’a). Rainfall and soil age vary considerably within the Kona region. The median annual rainfall ranges from 500 mm at sea level to 2500 mm at higher altitudes (Juvik and Juvik, 1998). The ages of the frequent periodic lava flows, from which the local soils are derived, range from >5 ka to modern times (Lockwood et al., 1988; Moore and Clague, 1991).

The Kona Field System is characterised by a variety of archaeological stone structures, the most prominent of which are inland–seaward aligned field walls (kuaiwi) (Allen, 2004). Other features include terraces, mounds and enclosures. Based on early ethnographic accounts, Kelly (1983) outlined planting zones of Polynesian introduced crops at Kona based on altitudinal variation in soil, rainfall and temperature. These are: Kula with sweet potato and paper mulberry (Broussonetia papyrifera) at 0–150 m altitude, 800–1200 mm rainfall; Kalu’ulu with breadfruit (Artocarpus altilis), paper mulberry and sweet potato at 150–300 m, 800–1500 mm rainfall; ‘Apa’a with taro (Colocasia esculenta), sweet potato, sugar cane (Saccharum officinarum), Pacific Island cabbage tree and banana (Musa sp.) at 300–750 m, 1500–2000 mm rainfall; ‘Ama’u with banana at 600–900 m, 2000–2500 mm rainfall. Other Polynesian crops introduced to the Hawaiian Islands, namely yams (Dioscorea spp.), mountain apple (Syzygium malaccense), bottle gourd (Lagenaria siceraria), turmeric (Curtuma longa) and coconut (C. nucifera), are also mentioned.

Fig. 1. Map of Kona Field System showing location of study area and traditional planting zones (Kelly, 1983).
Newman (1974), who surveyed the Kona Field System primarily through aerial photography (Soehren and Newman, 1968), seems to have suggested that the fields existed as a cohesive unit. However, recent research and reinterpretation (see Rechtman et al., 2001) have described the development of collections of widely distributed agricultural fields over time and space into a loosely affiliated socio-political system. In other words, the fields expanded under the influence of individuals and small groups as the populations of Kona increased. As the Hawaiian socio-political system became more centralised, more of the agricultural produce found its way (through tribute) into the same coffers, but the fields continued to function independent of one another. Cordy (2000: 257–258) described the fields of Kona, albeit within the context of the Kona Field System, as follows:

Generally, it appears that the Kona field system gradually formed, with small clearings in the wetter uplands and some use of the kula, beginning in some ahupua‘a ca. A.D. 1000, and in others as late as the A.D. 1400’s. Then over time – with growing populations, the chiefly centers, and other factors – the fields gradually expanded and intensified. This appears likely to have taken place at different times in different ahupua‘a. By the end of the A.D. 1700’s, the fields of all these lands could be seen by the European visitors as one big complex of near continuous fields. Also these were fields of individual communities with considerable variation and differences in extent... The archaeological sites remaining probably number in the thousands.

The historically observed and archaeologically documented patterns of cultivation within the agricultural fields of Kona perhaps reflect common cultivation strategies and approaches that have developed in response to centuries of experimentation under the varied geomorphic and climatic conditions of the area. However, the concept of an agricultural system (with respect to defining the agricultural practices over a broad area) suggests that from one end of the region to the other, the agricultural features were temporally, functionally or synergistically interrelated. Clearly this was not the case; that the products of these agricultural fields may have ended up (through tribute) in the same coffers tells us more about the workings of a socio-political system than it does about an agricultural one.

Keeping in mind the diverse nature of the Kona Field System, the most comprehensive study of archaeological features within the Kona Field System published to date has been carried out at Kealakekua, one of the field systems' more productive areas (Fig. 1) (Allen, 2001). This includes the aforementioned archaeo-botanical studies by Lennstrom (2001) and Ward (2001). In a subsequent study looking at risk management strategies as well as productive increases, Allen (2004) provided a fine-grained record of agronomic change from Kealakekua and compared this with patterns from the overall region. She suggested that risk management strategies, such as innovative garden architecture, novel cultivation practices and changes in the scale of agronomic integration were initiated by 1450 AD in even the most productive localities, and a shift to productive maximising strategies occurred after 1650 AD.

Recent archaeological investigations in the southern portion of the Kona fields have focused on intensive surface survey, mapping, and excavation of selected features in Ki‘ilae and Kauloeli ahupua‘a (Rechtman et al., 2001; Loubser and Rechtman, unpublished data). Soils in the study area are characterised as stony and rocky peat, and rough broken land or exposed lava flow (Sato et al., 1973). At the time of the investigations the vegetation pattern within the study area followed the distribution of soil types. The upper portions (above 180 m elevation) of both ahupua‘a support a tree canopy of kakai (A. moluccana), mango (Mangifera indica), monkeypod (Samanea saman), guava (Psidium guajava) and avocado (Persea americana), with a few loulou (Pritchardia spp.) and citrus trees, and an under-story of Christmas-berry (Shinus terebinthifolius), coffee (Coffea arabica), air plants (Bryophyllum pinnatum), waiawi (Psidium cattleianum), cabbage tree (C. fruticosa), liliko‘i (Passiflora spp.), kakalaaloa (Caesalpinia major) and hoi or bitter yam ( Dioscorea bulbifera), along with a variety of introduced weeds and grasses. In Kauloeli, below 180 m elevation, the exposed lava flows support a tangle of koa haole (Leucaena leucocephala), opiiuma (Pithecellobium dulce) and lantana (Lantana camara), with occasional kiawe (Prosopis pallida).

Agricultural features dominate the archaeological landscape of the study area, which is within the Kalu‘u‘ulu planting zone (Kelly, 1983). Of the 4773 archaeological features recorded, 95% are thought to be agriculturally related. These features were segregated into twelve sites (Fig. 2). Six of the sites, comprised of 4312 features (95% of the agricultural features) are situated above 180 m elevation. Many of these features may be associated with nineteenth century indigenous agricultural pursuits that were a continuation of earlier practices. Archival and oral sources indicate that indigenous farming was practiced in Ki‘ilae and Kauloeli from the early 1800s to the 1900s and beyond (Rechtman et al., 2001). Five of the...
agricultural sites, accounting for only 228 features, exist below 180 m elevation. These lower features appear to be opportunistic sites taking advantage of localised soil areas in an otherwise soil poor lava landscape. All of these sites have temporary habitation features that are centrally located. These sites may represent expansion of agricultural practices into marginal areas. An alternative explanation is that these sites closest to the coast represent farmed areas proximate to coastal residential habitation.

The sampled features (n = 7) reported in this study come from five sites and include four enclosures, two platforms and a pavement (Table 1, Fig. 3). These features are dry-stacked rock constructions used for planting, processing and short-term habitation (see Rechtman et al., 2001 for detailed descriptions).

Prior to this study, standard radiometric age determinations were carried out on material associated with several of the samples by Beta Analytic Inc., Miami, United States (Table 1). The results of that analysis indicate that one feature (Site 23182, Feature 2) accounting for five of the analysed samples may date from post-contact times; and the remaining six features and their associated samples date from pre-contact times, possibly as early as the 15th century AD.

3. Methods

Numerous standard bulk archaeological sediment/soil samples were recovered in the original South Kona excavations (Rechtman et al., 2001; Loubser and Rechtman, unpublished data). We selected 12 soil samples (arbitrarily numbered 1–12) from this collection, from the seven aforementioned archaeological features, to look for evidence of past environments, vegetation and horticulture (Table 1, Fig. 3). We did this using pollen, phytoliths and starch residue analysis. Samples were given priority for analysis based on the existence of associated radiocarbon data and the presence of a stratified deposit within the features. Sampled features were typical of those within the project area and representative of the types of features found within the greater Kona Field System.

Sub-samples (2–4 c.c.) were prepared for pollen (and spore) analysis by the standard acetylation method (Moore et al., 1991). At least 200 pollen grains and spores were counted for each sample (except samples 7 and 9 which had insufficient pollen for counting). Slides were scanned for pollen types not recorded in the counts.

Sub-samples (4 c.c.) were prepared for analysis of phytoliths and starch residues by combined density separation (Horrocks, 2005). At least 200 phytoliths were counted for each sample and slides were scanned for phytolith types not recorded in the counts. Phytolith identification was carried out with the aid of a modern reference collection, which includes tissue samples from many plants known to have been cultivated in the prehistoric Pacific. Samples are from herbariums at Auckland War Memorial Museum and Landcare Research, New Zealand; Forest Research Institute, Malaysia; and National Tropical Botanical Garden, Hawaii. Previous reports of phytolith morphology were also consulted (e.g. Mindzie et al., 2001; Lentfer and Green, 2004; Ball et al., 2006; Piperno, 2006).

As well as starch grains, starch residue analysis includes calcium oxalate crystals and xylem cells, all three of which may be found together in tuberous plant material (Torrence and Barton, 2006). Starch residues in this study were identified in three forms: parenchyma storage cells densely packed with starch grains, individual starch grains and fragments of xylem cells. At least 200 of these combined forms were counted for each sample. Tablets containing a known quantity of exotic Lycopodium spores were added to samples to allow absolute counts (volumetric) of starch and associated remains. Starch grain identification was carried out with the aid of a modern reference collection, which includes tissue samples from the starch crops and many other plants known to have been cultivated in the prehistoric Pacific. Previous reports of starch grain morphology were also consulted (e.g. Reichert, 1913; Loy et al., 1992; Horrocks et al., 2007). Starch grains are normally colourless. The position of the hilum (developmental origin of the grain) can be seen under cross-polarised light; grains characteristically show bifringence with dark lines intersecting at this point (“Maltese” cross). Well-preserved starch grains generally will have retained their optical properties, however as grains degrade and lose their structure, the Maltese cross and growth rings progressively disappear. Some other types of microfossils may be visible under cross-polarised light.

4. Results

4.1. Pollen and spores

Pollen and spore preservation in the study samples ranged from good to poor, with most showing signs of corrosion. Samples 7 and 9 had insufficient pollen for counting. Samples 1–6 are overwhelmingly dominated (>95%) by pollen of Chenopodiaceae and/or Amaranthaceae, the pollen of which is difficult to identify. Small amounts of Myrtaceae, Pandanus tectorius and Cichorieae pollen were also found in these four samples.

A spore type tentatively identified as being from a truffle (hypogeous Ascoycomycota) was found in samples 8, 11 and 12 (Fig. 4). This putative truffle spore resembles those of the Australasian truffle genera Labyrinthomyces, Dingleya, and Reddelomyces but is not identifiable to any known species (Trappe et al., 1992).

<table>
<thead>
<tr>
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<th>Site no.</th>
<th>Feature no.</th>
<th>Layer/level</th>
<th>Feature type</th>
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a INTCAL98 Radiocarbon Age Calibration, Stuiver et al., 1998.
4.2. Phytoliths

Phytolith preservation was generally good, with only small amounts of corroded phytoliths in the counts. Samples 1–6 are dominated by chloridoid phytoliths (~40–80%) (Fig. 5). Panicoid phytoliths are also present (up to ~25%). Samples 7–12 are dominated by irregular verrucose (up to ~45%), spherical spinulose (up to ~75%) and bulliform (up to ~25%). Also, phytoliths of...
banana (*Musa*) leaves were found in small amounts (<5%) in samples 1, 2, 4, 7, 9, 11 and 12 (Fig. 7). Examples of banana leaf phytoliths from modern reference material are shown in Fig. 8.

### 4.3. Starch and other residues

We identified a single type of starch grain in all samples. These were up to 25 μm in diameter, spherical to sub-spherical, often bell-shaped, with a vacuole (often fissured) at the central hilum, and several flattened pressure facets, present as individuals or densely packed (several dozen grains) in ovate cell membranes. These are consistent with root of sweet potato (*I. batatas*) (Figs. 6–8). We also found a single type of xylem cell (vessel) in all samples. These have alternate slit-like pits and are likewise consistent with root of sweet potato. The microfossils showed the highest concentrations in samples 6, 8, 9, 11 and 12 (~60,000–200,000 per c.c). The remaining samples had total concentrations of ~10,000–30,000 per c.c. The densely packed cells were by far the most abundant, with individual grains and xylem cells equal to or less than 8000 and 4000 per c.c., respectively.

Morphological preservation of starch grains ranged from good to poor. Most grains showed one or more of the following: soil-staining (yellow, amber, brown), expansion and distortion of the grain and vacuole, loss of the Maltese cross, pitting and cracking (Fig. 7c,d, and g). These features have been described in detail elsewhere (Horrocks et al., 2007). Identification of this type of starch grain is based on size and shape of the grain and features of the hilum. Of the Pacific starch crops, only *I. batatas* appears to have grains with a central vacuole (Loy et al., 1992). However, although starch taxonomy of economic plants is well known and many
species have distinctive starch grain morphology (e.g. Reichert, 1913), the starch taxonomy of non-economic plants is not as well known. We therefore cannot unequivocally rule out all local plants as possible sources. Given this and the corroded nature of most of the observed starch grains, our identification is made with caution. Haslam (2006) noted that some types of fungal spores may be difficult to distinguish from starch grains because they show a similar cross under cross-polarised light. However, these are generally much smaller than starch grains of the Polynesian starch crops, with the exception of taro, which does not feature in our study. The xylem cells in our study were mostly fragmented and showed similar soil-staining, occasional cracking, cross-wise fragmentation, with wall pits becoming progressively less visible or showing distortion, expansion and coalescence (described in detail in Horrocks et al., 2007).

5. Discussion and conclusions

Theoretical processes of pollen incorporation into soils and other better-drained substrates were modelled by Dimbleby (1985). Pollen is deposited on the ground surface and carried downwards through the soil by percolating groundwater. The percolating profile mainly conforms to the chronological order of pollen deposition at the surface with older pollen found increasingly towards the bottom of the profile. Soils conforming to the Dimbleby (1985) model will most likely be acidic, as this condition reduces the activity of soil invertebrates that may homogenise profiles. The rate at which these processes operate depends on such factors as soil type and drainage, rainfall and vegetation. Preservation and movement of phytoliths and starch grains in soils have been discussed more recently (e.g. Therin, 1998; Haslam, 2004; Piperno, 2006). As phytoliths are non-organic, they often show less corrosion than organic microfossils (as in this study). Starch grains may survive for long periods by their sheer abundance (e.g. 1 g of Zea mays (maize) starch comprises 1,000,000,000 grains (Swinkels, 1985)), decreased surface area exposed to degrading agents due to clumping, and protection from degrading agents by cell walls.

In cultivated soils at archaeological sites such as ours, preservation and movement of starch grains and phytoliths may be disrupted by burial and mixing by cultivation. Thus, we assume that an undetermined degree of mixing of plant remains of different ages in the South Kona deposits has occurred by percolation, bioturbation or mechanical disturbance, or a combination of these. In conclusion, we note that our interpretations based on the microfossils, especially regarding timing of events, are made with caution.

The generally corroded nature of the pollen grains and fern spores in the study samples reflects the free-draining local soils, allowing aerobic activity by soil microorganisms and decomposition of organic material. The abundance of monolete fern spores in samples 8 and 10–12 indicates disturbed vegetation but also in large part is the result of the superior preservation of fern spores c.f. pollen (Dimbleby, 1985) (Fig. 4). Many of the Hawaiian Islands’ fern species have this spore type (bean-shaped) (Selling, 1946), a lot of which are difficult to differentiate, especially if corroded. The great abundance of Cheno-Am pollen in samples 1–6 probably reflects their generally younger age (Table 1), with major weed invasions as a result of increased forest clearance and perhaps extended fallow periods (see also phytolith and starch results, below). This disturbance-related taxon is wind-pollinated (as opposed to animal-pollinated) therefore produces abundant pollen. The indigenous Chenopodium oahuense is a likely candidate although European introduced species are also possibilities.

The Myrtaceae pollen in three of the samples may be from a number of indigenous species, with the higher values in samples 8 and 10 possibly reflecting earlier times with more trees and shrubs present (Fig. 4). The Polynesian introduced mountain apple (S. malaccense) is also a possible candidate but pollen corrosion generally precluded confident differentiation between Myrtaceae taxa. Pollen of P. tectorius, another important economic plant and possibly indigenous to Hawaii (Whistler, 1991), in samples 8 and 10 indicates that it grew and was perhaps cultivated in the area.

As Hawaii has no indigenous Cichorieae (Lactuceae), pollen of this disturbance-related taxon in samples 10 and 12 suggests either Polynesian introduction, probably accidental (although the Sonchus shoots are edible) or contamination with pollen of historical age (Fig. 4). The distribution of Sonchus in Polynesia is unclear and complicated by early confusion between Sonchus asper and Sonchus oleraceus. In Hawaii S. oleraceus was naturalised before 1871 while S. asper is thought to be a more recent introduction (Wagner et al., 1990; Leach, 2005). Ward’s (2001) pollen study from Kealakekua examined several test-pit profiles. One of these extended into very early Polynesian or perhaps pre-settlement times, with initial large amounts of grass...
(Poaceae) and sedge (Cyperaceae) pollen followed by an increase in monolete fern spores, little Cheno-Am pollen and increased vegetation disturbance. However, in the Lalamilo Field System study, Bennett (1983) found high proportions of Chen-Am, grass and Asteraceae (Compositae) pollen.

Phytoliths provide further evidence of the past vegetation within the study area. Spherical spinulose phytoliths occur in palms (Arecaceae) and bromeliads (Bromeliaceae) (Piperno, 2006). In our case these phytoliths are most likely from *Pritchardia* spp. palm, the Hawaiian Islands’ only indigenous representative of this family. However, the introduced coconut may also be a contributor. The islands have no indigenous bromeliads. The abundance of palm phytoliths in the older samples (7–12), coincident with large amounts of irregular verrucose phytoliths (probably mainly from dicotyledonous trees) supports the pollen evidence of more trees and shrubs present in earlier times (Fig. 5). The grass phytolith evidence also supports this; chloridoid, festucoid, panicoid and bulliform phytoliths are exclusively from grasses (possibly including sugar cane). As grasses are typically shade-intolerant, the large amounts of these in samples 1–6 suggest a reduction in trees and shrubs.

In a phytolith study of soil profiles within the Lalamilo Fields, Pearsall and Trimble (1984) linked disturbance to indigenous vegetation and subsequent cropping/fallowing. This was evidenced by a decline of large cell grass phytoliths (which include bulliform) and coincident increase in short cell phytoliths (which include chloridoid and panicoid). With generally larger amounts of bulliform phytoliths in older samples and higher chloridoid and panicoid phytoliths in younger samples, our results show a similar trend (Fig. 5).

Phytoliths of banana leaves are diagnostic (Mindzie et al., 2001; Lentfer and Green, 2004; Ball et al., 2006). All bananas in Remote Oceania are human introductions. They include distinctive cultivars, belonging to the sections *Musa* (formerly *Eumusa*) and *Callimusa* (formerly *Australimusa*) of the genus *Musa* that were prehistoric introductions (Simmonds, 1959; Whistler, 1991; Kennedy, 2008). The presence of these in most of the samples (58%) suggests that the sampled archaeological features were associated
Fig. 7. Plant microfossils from Kona (a, b mounted in Caedax; c–h mounted in glycerol jelly; 100×, 400× or 600×; scale bars: 20 μm). (a, b) Musa leaf phytoliths showing rectangular/squarish base with protuberances all along the sides of the base and truncated cone (c.f. Fig. 8a, b). Of the three examples shown here, two are viewed looking down into the cone (a, right panel; b) and the other (a, left panel) looking at the cone side-on. (c) Low magnification view of soil-stained dense material within ovate cell membranes (four) (c.f. parenchyma starch storage cells of Ipomoea batatas, Fig. 8c). (d) High magnification view of fragment of ovate cell showing densely packed starch grains (membrane has been lost) (c.f. parenchyma storage cells of I. batatas, Fig. 8c). Individual soil-stained starch grains are more easily seen in cells that are disintegrating than in intact cells because the grains are tightly packed in the latter. (e, f) Faceted starch grains with central vacuole (c.f. starch grains of I. batatas, Fig. 8d, e). (f) Shows the grains in (e) viewed under cross-polarised light, showing central Maltese cross. (g) Soil-stained starch grain with central vacuole (c.f. starch grains of I. batatas, Fig. 8d). Although facets are not clearly visible, two straight edges of these are. (h) Xylem vessel element with alternate slit-like pits (c.f. xylem vessel element of I. batatas, Fig. 8f).
with this crop, and that banana was cultivated intensively within the study area.

The presence of c.f. sweet potato microfossils in all of the sampled features suggests that this introduced crop was also cultivated intensively within the study area (Fig. 6). The very high concentrations of these in some of the older samples suggest more intensive cultivation in earlier times, with a later reduction possibly as a result of longer fallow periods. Identifying *Ipomoea* starch in the Hawaiian Islands (and elsewhere) is complicated by the presence of several indigenous species of *Ipomoea* (e.g. *Ipomoea indica*). However, these do not have tuberous roots like sweet potato, so the starch grains and xylem cells found in the cultural deposits with equivocal remains of another cultivated crop (i.e. *Musa*, see above) from almost certain agricultural features are most likely sweet potato. The very high concentrations of starch storage cells c.f. individual starch grains in all samples are probably due to protection from soil microorganisms by dense packing within an enclosing cell membrane.

Given the phytolith evidence of banana, we consider the possibility of banana starch within the samples. Starch grains of banana fruits (fan-shaped) are readily differentiated from those of sweet potato (Reichert, 1913; Fullagar et al., 2006). As the fruit...
ripens the starch loses its structure. We would not expect starch in aerial storage organs such as banana fruits to have the same potential for archaeological preservation that tubers and root crops have because the latter are presumably mostly already buried at time of death. This would reduce their rate of decomposition c.f. organic material such as bananas that had fallen onto the ground surface. Although the banana phytoliths are also from aerial tissue (leaves), because they are not organic they have a better chance than organic plant material of preservation and eventual incorporation in the soil if deposited on the ground surface. Relatively limited preservation of starch grains in aerial storage organs also applies to the other main starch fruit crop of the early Hawaiian Islanders, breadfruit. This has starch grains similar in shape to some of sweet potato but distinctly smaller and lacking the distinctive Ipomoea vacuole (Fig. 8d).

Apparent absence of other starch taxa in the study samples may be significant. The other major tuberous crops introduced by early Polynesians to consider in a Hawaiian context include three species of yam (Dioscorea alata, D. bulbifera and Dioscorea pentaphylla), two aroids (Araceae): taro (Colocasia macrorrhiza), turmeric (C. longa), ginger (Zingiber zerumbet) and arrowroot (Tucuma compositae) (Whistler, 1991). Starch grains of the three Dioscorea species (elongated, ovate and fan-shaped, respectively) are readily differentiated from the smaller, spherical to sub-spherical, faceted grains of sweet potato (Loy et al., 1992; Fullagar et al., 2006) and have been identified in archaeological deposits elsewhere in Polynesia (e.g. Horrocks and Lawlor, 2006; Horrocks and Wozniak, 2008; Horrocks et al., 2008). Turmeric starch grains are also fan-shaped (Reichert, 1913), as are those of ginger. Taro starch grains (at <3 µm in diameter relatively tiny) are likewise differentiated from sweet potato and although starch grains of elephant ear taro may be similar in size and shape to sweet potato, like breadfruit they lack the distinctive central vacuole (Loy et al., 1992) (Fig. 8d). Again, arrowroot has similar-sized and -shaped grains to sweet potato but lacks the vacuole. In a similar Easter Island study, abundant starch grains of D. alata and small amounts of sweet potato and taro starch were identified in dryland basaltic deposits (Horrocks and Wozniak, 2008). Thus, if yams and aroids had been intensively cultivated within the present study area, we would have expected to find their microfossils.

Regarding the xylem evidence, we use this to support the starch grain evidence; other plants have xylem cells similar to sweet potato (but not yams or arrowroot; see Horrocks and Barber, 2005; Horrocks and Lawlor, 2006). However, in our case this was the only type of xylem found. Lack of pollen of the starch crops we identified is not unexpected; fossil sweet potato (cf. Clark, 1983a) and banana pollen finds are extremely rare due to low pollen production.

The results of the current study demonstrate the potential of using combined plant microfossil analyses of archaeological deposits from the dryland field systems of Hawaii to identify crop type and range. The ubiquity and exclusivity of sweet potato and banana in our samples suggest a focus on these crops to the exclusion of other common, especially tuberous, Polynesian cultivars. These data seem to support the model of crop-specific resource zones identified in the ethno-historic record. The current study area lies within the Kalu’ulu zone (Kelly, 1983), which was reportedly dominated by the cultivation of sweet potato. The other crop that was reported as common in this zone was breadfruit; however no evidence of this cultigen was identified in the study samples. While it is possible in our case that breadfruit was visible in the archaeological record, it is also possible that local geological and climatological conditions were more favourable for the cultivation of banana. As Handy et al. (1991: 525) pointed out, “In the time of intensive native cultivation, South Kona was planted in zones determined by rainfall and moisture. Near the dry seacoast potatoes were grown in quantity... Up to 1,000 feet grew small bananas which rarely fruited... from 1,000 to 3,000 feet, they prospered increasingly. From approximately 1,000 to 2,000 feet, breadfruit flourished.”

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