

Research Article

Processing of *Pueraria montana* var. *lobata* (kudzu bean) and *Colocasia esculenta* (Taro) during the early holocene at kuk swamp in the papua new guinea highlands

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Abstract

Identifying use-related residues from stone artefacts has become increasingly important in determining starchy plant exploitation over time and in different locales. Standard methods for processing residues samples are widely available but there is no clear consensus on suitable methods for attributing unknown starch grains to known plant taxa. We revisit the case study of a flaked stone artefact (K/76/S29B) recovered from Phase 1 (c. 10,000 ka) at Kuk Swamp in Papua New Guinea (PNG). Starch grains from taro (*Colocasia esculenta*) were identified in the residue extraction, but there were other grains that could not be attributed a plant origin at that time. The new analysis applied robust statistical methods, categorical attributes and expert input. In addition to *C. esculenta*, kudzu bean (*Pueraria montana* var. *lobata*) was identified, representing the earliest use of kudzu bean in the PNG highlands. Importantly, we also determined that starch grains from *C. esculenta* and *Dioscorea esculenta* are morphologically indistinguishable. We turned to other attributes of potential contributing plant taxa in determining distinguishing features: habit/growing requirements; the sedimentary context of the archaeological find; and environmental settings. Cultural use of both plants, artefacts and artefact technologies can be critical elements in confident identification outcomes, as exemplified here.

keywords: ancient starch; New Guinea highlands; Kuk Swamp; geometric morphometrics; *Pueraria montana* var. *lobata*; *Colocasia esculenta*; *Dioscorea esculenta*; Holocene

Introduction

The processing of starchy plant foods to render them edible often demands a variety of implements and methods depending on the context and palatability and/or toxicity of the plant taxa in question (Pedley, 1992, 1993; Cosgrove et al., 2007; Messner, 2011:16). Numerous investigations around the globe have focussed on grinding and/or pounding stones to better understand function and use of both raw material and plant exploitation (Fullagar et al., 2008; Piperno et al., 2004, 2009; Liu et al., 2010; Shaw et al., 2020; Hayes et al., 2020; Field et al., 2024). In Australia and New Guinea, ethnographic studies have been important for gaining insights to starchy plant use across different environments and cultural groups, e.g. Bulmer 1964; Watson, 1964; O'Connell et al., 1983; Sillitoe, 1983. Processing methods and the associated stone tool technologies can show great variation. The keen observations of various researchers have provided a foundation on which 'ancient starch' studies have developed (e.g., Reichert, 1913; Tindale, 1977; O'Connell et al., 1983; Sillitoe, 1983; Smith, 1985; Pedley 1992).

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Cite this article: Coster, A.C.F., Field, J.H., Fullagar, R., Lovave, M., 2025. Processing of *Pueraria montana* var. *lobata* (kudzu bean) and *Colocasia esculenta* (Taro) during the early holocene at kuk swamp in the papua new guinea highlands. *Quaternary Research* 128, 45–59. <https://doi.org/10.1017/qua.2025.10022>

The physical remains from the processing of starchy plants can persist for millennia, as shown in the discovery of use-related residues on the surface of flaked and ground stone artefacts (Van Peer et al., 2003, Birarda et al., 2023). These use-related residues can sometimes be found alongside other plant fossils including macrobotanical remains such as nutshells (Fairbairn and Swadling, 2005; Fairbairn et al., 2006; Cosgrove et al., 2007; Field et al., 2016).

The study of wear traces and use-related residues on stone tools from archaeological contexts have the potential to reveal activities and plant food choices that may otherwise remain unknown (Fullagar et al., 2006, 2008; Shaw et al., 2020; Field et al., 2024). Plant-related use residues occur as starch grains, raphides (calcium oxalate crystals), phytoliths and other plant cell tissues (Van Peer et al., 2003; Fullagar et al., 2008; Piperno et al., 2009; Field et al., 2016, 2020), providing the opportunity for a multifaceted approach to identifying specific plant taxa.

Our interest has principally been in starch grain identification using objective criteria to develop a diagnostic tool, as highlighted by Cortella and Pochettina (1994). Now over a century ago, Reichert (1913) published the first images of starch grains from an array of plants and plant parts. The discipline of ancient starch studies has grown quickly, with reports of starch grains as residues on archaeological finds and in calculus on teeth, now representing an important and routine component of archaeological research

(Pearsall, 1989; Piperno, 2006; Torrence and Barton, 2006; Tromp et al., 2020; Hayes et al., 2021).

Attributing unknown starch grains to plant taxa has proven to be a significant challenge (Wilson et al., 2010). Various approaches have claimed success in this endeavour, mainly through the identification of diagnostic grain shapes, comparison of gross morphologies, and maximum dimensions through the hilum (growth centre of the starch grain). Some approaches have involved qualitative assessments supported in part by starch grain metrics and visual confirmation (Louderback et al., 2022), while others have applied statistical methods, such as Discriminant Function Analysis (DFA) (Allen and Usher, 2013) as well as Geometric Morphometric approaches (GMA) (Coster and Field, 2015, 2018). More recently, Birarda et al. (2023) have combined optical and scanning electron microscopy with Fourier Transform Infrared Spectroscopy (FTIR) to assess ancient starch residues.

Robust statistical methods such as GMA, have successfully attributed unknown starch grains to plant taxa in different contexts and environments (Field et al., 2016, 2020; Owen et al., 2019; Hayes et al., 2021). Our methodology for identifying unknown starch grains has been evolving over the last decade (Coster and Field 2015, 2018, Field et al., 2016, 2024; Hayes et al., 2021) and has now moved beyond a strictly GMA approach. While the long-term aim has been to develop a quantitative approach to starch grain identification in concert with expert input, a diverse approach to the topic remains across different research groups.

The primary aim of this paper is to present the most recent developments in our approach to starch grain identification by revisiting the analysis of material from Kuk Swamp in the PNG highlands (Denham et al., 2003; Fullagar et al., 2006). We also examine whether it is possible to discriminate between starch grains of similar size and morphology from different plant species and discuss the implications for starch analyses going forward.

Background

Quantitative approaches to starch grain analysis have expanded our understanding of the breadth of plant use in different environments where starch is preserved (see also Field et al., 2020, 2024; Hayes et al., 2021). Establishing a consensus on a clear and systematic approach to investigating starch as use-related residues on artefacts remains one of the significant problems in ancient starch studies from discovery to analysis, including handling methods and the laboratories in which starches are analysed (Haslam, 2004; Crowther et al., 2014). In our laboratory at the University of New South Wales (UNSW), careful handling of artefacts and the stringent use of controls during sampling and processing has been effective in identifying and eliminating potential contamination that may affect our analyses.

The ability to correctly identify plant taxa in use-related residues or sediments has important implications for discussions of plant use in any context. The timing of introductions into new environments, the adoption of plant processing strategies, including complex processing, and the antiquity of certain plant species use, all feed into global debates about plant domestication and exploitation, as well as technological developments through time (e.g. Denham et al., 2009; Matthews et al., 2018; Ahmed et al., 2020; Shaw et al., 2020).

The first human arrivals in Northern Sahul (New Guinea) occurred around 50,000–65,000 years ago and was followed by

a rapid human dispersal across Sahul (Pleistocene Australia-New Guinea landmass) (Bowler et al., 2003; Denham et al., 2009; Clarkson et al., 2017). The rapidity of colonisation has been attributed, in part, to the dynamic nature of human adaptation to new environments which, in Sahul, included a suite of previously unknown flora and fauna (Denham et al., 2009).

Over the last few hundred years, sweet potato (*Ipomoea batatas*) has dominated the diets of people in the New Guinea highlands due in part to its potential for cultivation at higher altitudes. Developing an understanding of the exploitation of plant resources in the time periods preceding the introduction of sweet potato has largely relied on inferences from pollen and phytolith records (Denham et al., 2003; Haberle, 2003; Hope, 2009). Macrobotanical remains have also provided empirical support for the antiquity of specific plant use such as bananas and *Pandanus* (Denham et al., 2003; Fairbairn et al., 2006; Summerhayes et al., 2010; Lentfer et al., 2013).

Ancient starch studies have now confirmed the widespread exploitation of tree nuts across the highlands, along with a range of subterranean storage organs such as tubers and yams. The evidence is derived from formally manufactured mortars and pestles from the PNG highlands that were dated to the mid-Holocene. These included Joe's Garden in the Ivane Valley, and at Waim (Shrader Range) and Imbiben in the Upper Kaironk Valley of the Madang Province (Field et al., 2020, 2024; Shaw et al., 2020). Speculation about the use of other starch-producing plants first proposed in the early 1960s can now be addressed through these new methodologies (Bulmer, 1964; Field et al., 2020; Hayes et al., 2021).

The Kuk Swamp artefact K/76/S29B and ancient starch.

Artefact K/76/S29B is the distal end of a broken flake tool, recovered from Phase 1 of the Kuk Swamp sediments dated to c. 10,000 cal yr BP (Figure 1). Usewear traces and residue extractions for Artefact K/76/S29B were first studied more than three decades ago—initially by Tom Loy, then by Richard Fullagar and later with Judith Field, Michael Therin and Carol Lentfer (Denham et al., 2003; Fullagar et al., 2006; Fullagar and Golson, 2020).

Fullagar identified retouch and use-scars along two edges, striations oriented perpendicular to the edge, and a reticular polish typical of woodworking. The level of confidence in interpreting tool function is high: definite use for scraping hard siliceous woody tissue (possibly palm). Woody plant fibres, starch grains, raphides and phytoliths were observed under incident light on the artefact surface. The stone raw material was identified by David Ellis, Philip Hughes and Marjorie Sullivan as ignimbrite, a pyroclastic igneous rock (hardened tuff) (Fullagar and Golson, 2020:396).

To facilitate the identification of starch grains to plant taxa, the residue study required access to a modern comparative reference collection. For the Fullagar et al., (2006) study we were able to access the reference material collected by Carol Lentfer, Lisa Kealhofer and Michael Therin from Garu village, West New Britain. The 165 plant specimens in that collection had their identifications confirmed/verified at the Botanical Gardens in Lae, PNG (Therin et al., 1997).

The 2006 study determined that the use of Artefact K/76/S29B (perhaps after the tool broke), was to slice or scrape raw taro (*C. esculenta*) (Fullagar et al., 2006:605). Other starch residues of different morphologies documented in the original residue

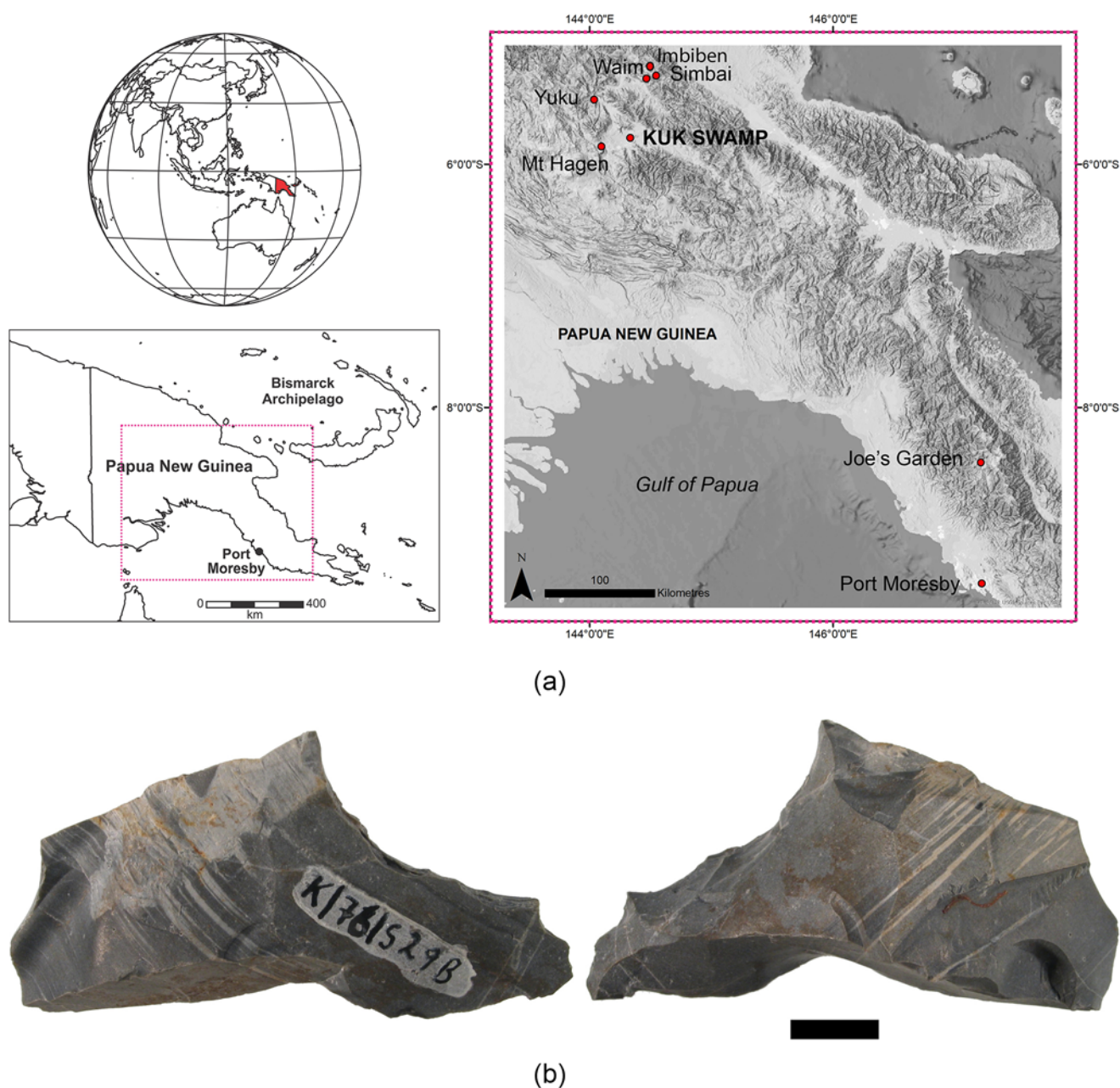


Figure 1. **A.** Location of Kuk Swamp in the Papua New Guinea Highlands and other sites mentioned in text. **B.** Stone artefact K/76/S29B from the Phase I context (see Golson et al., 2017).

preparation were never attributed to a plant taxa, reflecting the limitations of the original qualitative study.

Methods

The original slide preparation was mounted in Karo syrup and has been stored for 20 years. To enable a re-examination of the slide preparation, the original nail polish that had sealed the coverslip was removed with a scalpel blade and distilled water was introduced to the sample by capillary action. The slide was resealed with clear nail polish.

The methodological approach to identifying unknown starch has undergone significant changes since the studies described

above. For the present study, an algorithm was developed for the analysis of the unknown starch assemblage isolated from the K/76/S29B artefact surface (Figure 2). The five main stages of the analysis were to:

1. Establish a modern comparative reference set from the UNSW starch database.
2. Compile previously unpublished data on the technology and usewear traces of artefact K/76/29B that was analysed by RF.
3. Examine the original K/76/29B slide preparation (Fullagar et al., 2006) and re-photograph the starch assemblage.
4. Execute a Geometric Feature Analysis (GFA) of the unknown starch grains observed on the slide preparation.

Ancient Starch Analysis Algorithm

- Assemble a species list of potential contributor starchy plants from the area of interest.
- Document (digital images) the archaeological sample from total slide scans.
- Digitise outline and hilum position for all starch grains in the archaeological and reference set (from database).
- Extract selected metrics from archaeological sample and comparative reference set.
- Prepare the normalised shapes and determine self-similar subgroups.
- Exclude non-contributing species by comparing macro-features and normalised shape.
- Examine the categorical features to assess similar features and to quantify correspondence with subgroups.
- Exclude non-contributing species and quantify the correspondence between the archaeological assemblage and reference subgroups as populations.
- Refer to the geographic/habitat, etc., context to assess the likelihood of discrimination between reference species, where overlaps occur (e.g., altitudinal limits, growing conditions, etc.).
- Reassess the archaeological and reference species with reference to compound vs. single grains and other features likely to assist in discrimination between species.

Figure 2. Ancient starch analysis algorithm used in the study of starch of Kuk Swamp Artefact K76/S29B.

5. Review the archaeology, residues, archaeobotany and ethnobotany (e.g., Pardoe *et al.*, 2019).

The starch database

The UNSW modern comparative starch reference collection has been developed over the last 20 years with material collected during field trips, from herbarium collections or material shared by other researchers. Plant material was cut as hand sections and/or partially pulverised with water in a glass mortar and pestle before mounting on a slide.

The comparative reference collection sub-set used in this study was compiled based on our current knowledge of the flora of the New Guinea highlands, ethnographic reports, local informants and herbaria records (e.g., Paijmans, 1976; Gardner, 2010) (Table 1, Figure 3). Note that some plant species are not currently in our UNSW database (including *Elaeocarpus womersleyi* and *Finschia chloroxantha* and we have not yet established if they are starchy).

Starch grains were viewed with a Zeiss Axioskop II transmitted brightfield microscope with Nomarski optics and images collected with a Zeiss HRc camera. Images were stored as .zvi files using Zeiss Axiovision software. Starch grain outlines and hilum positions were digitised from micrographs using either a graphical user interface (GUI) developed in MATLAB (MATLAB Release 2014b, The MathWorks, Inc., Natick, MA, USA), and a WACOM Intuos Pen Tablet (CTH-480) or a mouse (Logitech Pebble M350). A minimum of 100 starch grains were digitised per sample. Other features that were noted include presence/absence of lamellae, fissures/cracks at hilum, vacuoles and the presence of faceting. The individual starch grain outline is referred to as the region of interest (ROI) (see Coster and Field, 2015, 2018; Field *et al.*, 2020).

The starch grains in the residue extraction from the Artefact K/76/S29/B were photographed and digitised using the same method as for the comparative reference set. Examples of starch grains from Artefact K/76/S29/B are presented in Figure 4.

Geometric feature extraction and analysis

The method used here is fundamentally a ‘shape analysis’ (microscopic geometric features) determined from the traced starch grain outlines (ROI) and the hilum position. Starch grain metrics extracted from the ROI include the hilum position within the shape, perimeter, area, maximum length through the hilum (maxD), and the Fourier signature of the grain outline (*i.e.* a radial decomposition of the shape) (see Coster and Field, 2015). Histograms of the metrics and the distances between the artefact sample and the reference set were compared for overlaps.

The measures used for the Artefact K/76/S29B starch assemblage were maxD (maximum length through the hilum), area, perimeter, and hilum position. The two strongest discriminatory metrics for this process were maxD and hilum position. Grain shapes are examined at their original size and as ‘normalised’ shapes. Normalised shapes are determined by scaling the size of individual grains such that the average radius around the hilum is one. The shapes are then rotated and aligned around the hilum, and a distance measure between the shape’s proportional to the absolute area difference was determined (Figure 5). The aligned normalised shapes were clustered hierarchically into self-similar groups based on their average pairwise distance. A common cut-off between the comparative reference and archaeological assemblages was used to identify sub-groups and to ensure the same levels of self-similarity between the different sub-groups.

The distributions of the metrics (maxD, area, perimeter, hilum position) were then determined for each of the sub-groups to analyse the overlaps with those of the archaeological assemblage.

The categorical features of the grain shapes of the overlapping reference sets were compared to the archaeological assemblage grains and ranked in distance in normalised shape. The categorical features and visual assessment of grain shape correspondence were used to classify whether the reference species could match each grain from the artefact. The correspondence to each reference was then quantified, noting that the grains could align with more than one reference species.

Table 1. Plants known to be used and those that were possibly scraped or pounded in the Papua New Guinea highlands, with starch-producing species known from the Wahgi Valley, Western Highlands Province, Papua New Guinea, also included.^a

Sample name	Common name	Altitudinal range (asl)	n	Plant part	Processed	Size range (μ)	Median
K76 S29B	Artefact	(1580 m)	139			3.52–34.69	10.45
<i>Castanopsis acuminatissima</i>	Castanopsis (Saway)	570–2440m	233	Fruit/nut	Raw/roasted	5.06–49.61	20.53
<i>Colocasia esculenta</i>	Taro	0–2760m	458	Tuber	Roasted/baked	2.53–9.87	5.16
<i>Dioscorea alata</i>	Greater yam	0–2100m	199	Tuber	Roasted/baked	10.53–68.18	29.36
<i>Dioscorea bulbifera</i>	Bitter/hairy yam	0–2110m	534	tuber	Cooked/ leached	6.33–60.75	28.34
<i>Dioscorea esculenta</i>	Lesser yam	0–1620m	284	Tuber	Roasted/baked	2.28–9.29	5.56
<i>Dioscorea nummularia</i>	Common yam	0–2050m	114	Tuber	Roasted/baked	19.18–55.37	32.43
<i>Dioscorea pentaphylla</i>	Five leaflet yam	0–1620m	146	Tuber	Roasted/baked	14.60–110.77	65.02
<i>Gnetum gnemon</i> ^b	Tulip nut	0–1330m	125	Nuts	Raw/roasted	3.50–21.29	12.58
<i>Homalomena</i> sp.	—	2000m	103	Root	—	6.49–43.78	16.22
<i>Hydriastele</i> sp.	Palm	2000m	102	Root	—	2.24–23.02	5.90
<i>Musa acuminata</i>	Banana	0–2350m	94	Fruit	Raw	1.53–19.52	3.46
<i>Musa ingens</i>	Banana	0–<2000m	160	Fruit	Raw	4.66–18.11	9.61
<i>Musa peekelii</i>	Banana	0–<2000m	121	Fruit	Raw	2.49–22.22	5.26
<i>Psophocarpus tetragonolobus</i>	Winged bean	0–2070m	151	Tuber	Baked/roasted	5.15–35.95	11.37
<i>Pueraria montana</i> var. <i>lobata</i>	Kudzu bean	0–2740m	278	Tuber	Baked/roasted	2.93–25.08	10.07
<i>Saccharum officinarum</i>	Sugar cane	0–2760m	105	Root	Raw	4.82–19.42	9.42
<i>Zingiberaceae</i>	Ginger	0–2200m	144	Root	—	2.18–20.14	7.31

^aSome of the plant species are common across the highlands, although other species such as *D. esculenta* are rarely grown above 900 m asl (Bourke, 2010). The two species discussed in this paper are shaded in the table.

^bCultivated in the present day as a supplementary food (Paijmans, 1976).

Expert input is essential in these analyses as the geometric feature extraction basically works on a 2-dimensional basis. A review of the starch grains and correlated attribution to plant taxa was important to assess the other features (3D shape, vacuoles etc) not captured in the digital tracing.

Results

Artefact K/76/S29B starch grain assemblages

A range of starch grain shapes and sizes were identified in the rehydrated sample, with a total of 139 grains documented and digitised. The clumps of very small compound grains observed (see Figure 3) were similar in size and morphology to those illustrated in Fullagar et al. (2006: 606). Boxplots of the metrics for all the artefact and reference set starch grains are presented in Figure 6. The reference sets that overlapped with the artefact sample are shown in Figure 7, and those that did not in Figure 8. Note: it would be expected that the within-reference and within-artefact distances would be similar to the between-sample distances if the reference and artefact grains showed similar normalised shape characteristics.

It was found that 40% (n=48) of the 120 unknown grains could correspond to *D. esculenta*-5, 39% (n=47), to *C. esculenta*-3, and 18% (n=22) to *P. montana* var. *lobata*-2. An example of the correspondence of the unknown grains to *P. lobata*-2 is shown in Figure 9. Of the 48 grains that could correspond to *D. esculenta*-5 and the 47 grains corresponding to *C. esculenta*-3, 34 were in common. An example of the micrographs and overlapping outlines of the grains is shown in Figure 10. Thus, the likely contributing species for 64% of the sample (77 grains) was reduced to just 2: *C. esculenta*-3 and *D. esculenta*-5.

Based on the 'geometric feature' approach undertaken in this study, we cannot distinguish between these two species. Other characteristics of the two species need to be considered, and may include geography, altitudinal limits, and growing requirements.

Discussion

There are three important findings in the study of starch residues from Artefact K/76/S29B:

1. We can confidently conclude that *P. montana* var. *lobata* (kudzu bean) was exploited in the Phase I Kuk Swamp sequence dated to c. 10 kya;

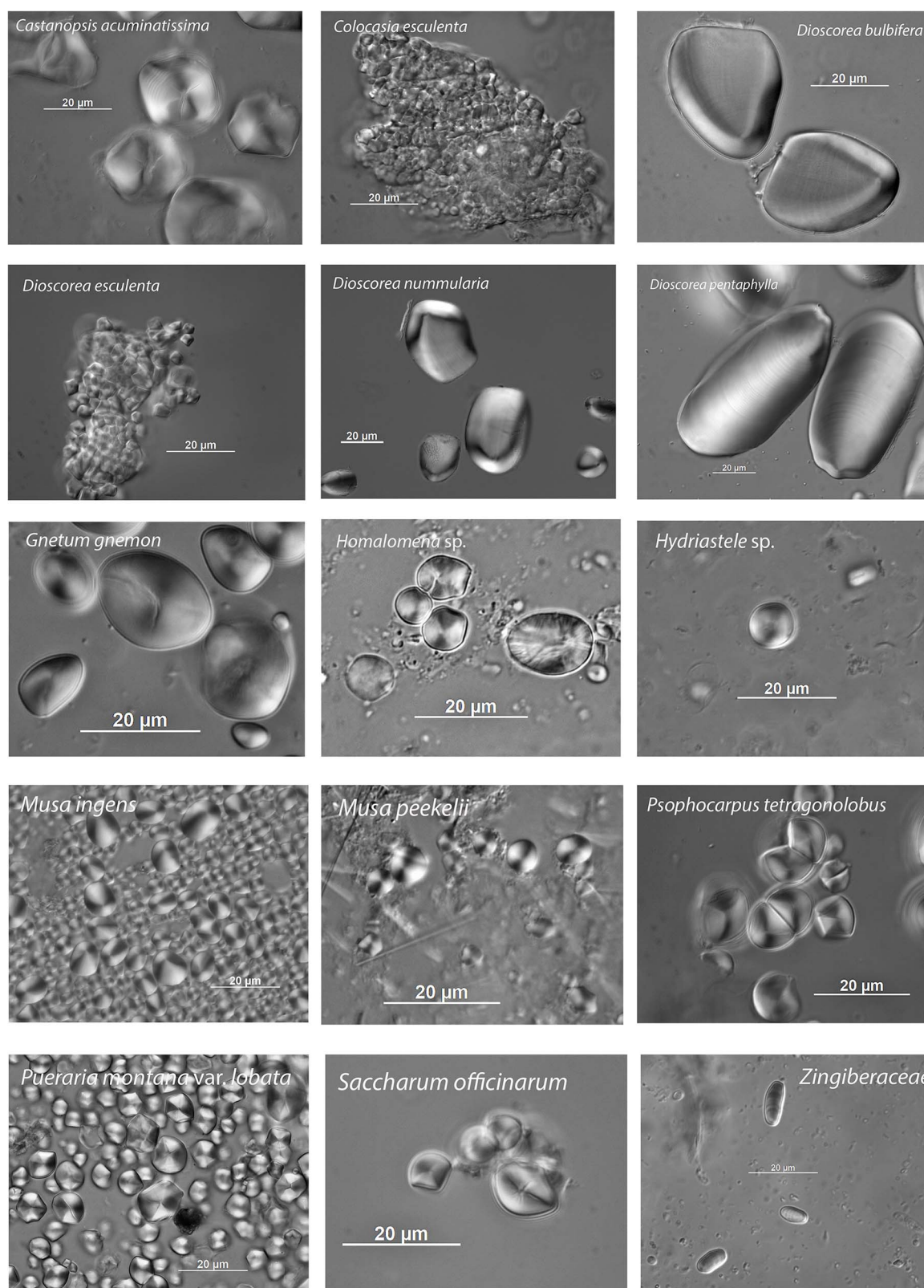


Figure 3. Examples of starch grains from plant taxa included in the comparative reference set, as listed in Table 1. Images were photographed using the Differential Interference Contrast (DIC) method.

2. Notably, the lesser yam (*D. esculenta*), and taro (*C. esculenta*) grow in very different habitats but are effectively

indistinguishable microscopically, as demonstrated by the metrics and correspondence analysis (Table 2); and,

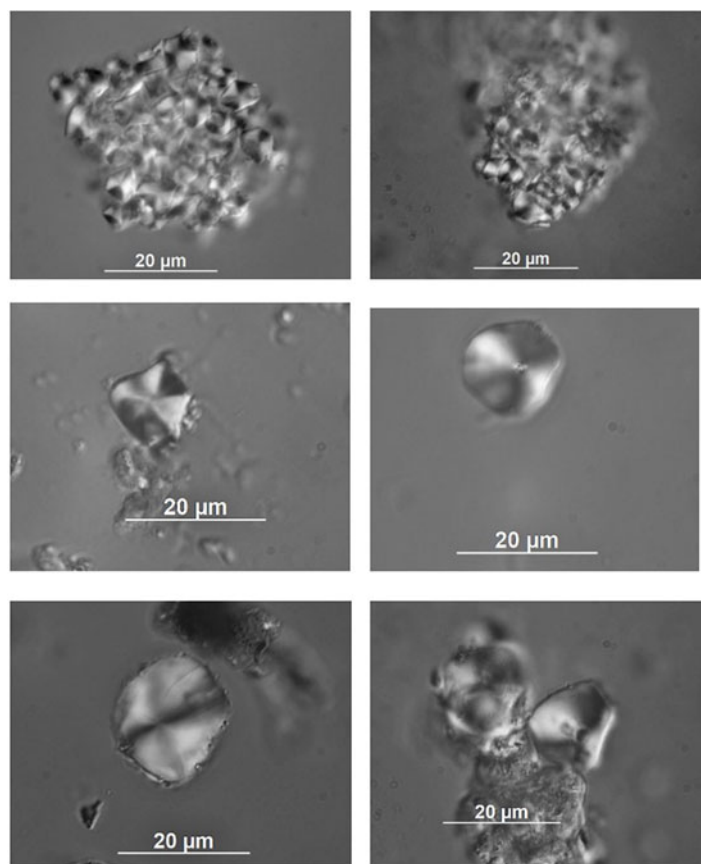


Figure 4. Examples of starch grains recovered in the aqueous sample extracted from the surface of ignimbrite flake K/76/S29B from Phase I at Kuk Swamp.

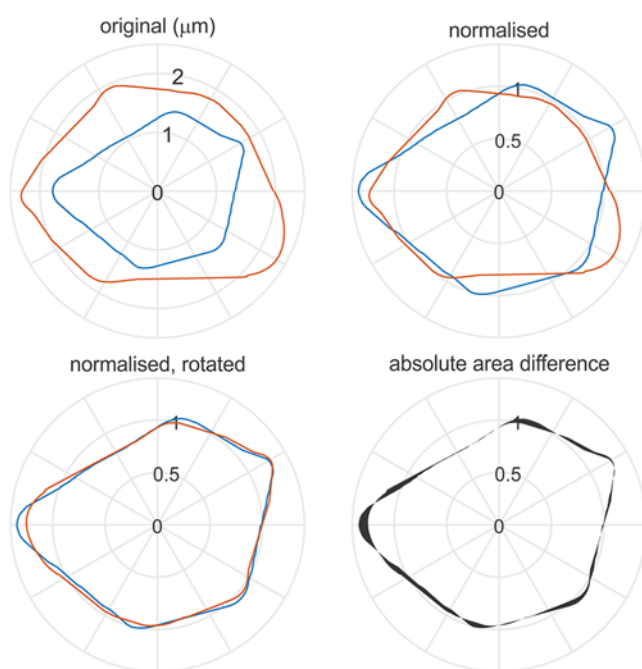


Figure 5. Traced outlines of two *D. esculenta* starch grains from the reference collection. The grain shapes are centred at the hilum. The starch grain outlines are shown, left to right, at their original size and orientation as extracted from the micrographs; normalised in size such that their average radius about their hilum is one; rotated so that they best align, then the difference between the normalised grains is shown as an absolute area difference, which is proportional to the distance measure.

3. The species identification of *C. esculenta* (taro) from Phase I sediments at Kuk Swamp has been confirmed, following consideration of the various growing requirements, altitudinal limits and other factors discussed below.

P. montana var. *lobata*/kudzu bean (previously *P. lobata*)

Kudzu bean is considered a famine food by modern day highlanders, though numerous researchers had flagged the potential for it as an important staple of some antiquity (Watson, 1964, 1968; Barrau, 1965; Paijmans, 1976; Sillitoe, 1983). Strathern (1969) suggested that the term 'oka' which can apply to both kudzu bean and sweet potato may signify the importance of kudzu bean in some highland diets prior to sweet potato. Kudzu bean tubers are known to be longer lasting than *I. batatas* both prior to and after harvesting. It is a semi-woody vine and produces a large edible (but fibrous) tuber up to 1 m long that grows laterally from the main stem just below the surface. Paijmans (1976) has noted that the tubers may weigh up to 32 kg.

Sillitoe (1983) reported that, in the present day, only men (in the Wola clan) grow kudzu bean, and this 'male concern' is reflected in planting practices elsewhere (Watson, 1964). It is propagated vegetatively (see also Strathern, 1969), "taking the tuberous apex where the roots join, together with 15cm or so of stem...they plant it at the same times as beans...following the planting of sweet potato, taro and pitpit" (Sillitoe, 1983:48). In some places it is also planted near houses as it only needs a tree trunk (or pole) to grow around. Strathern (1969) also observed that Kudzu Bean may have been interspersed with taro, yam and other garden plants. It was seen as a journey food and kept well after being cooked (Watson, 1968).

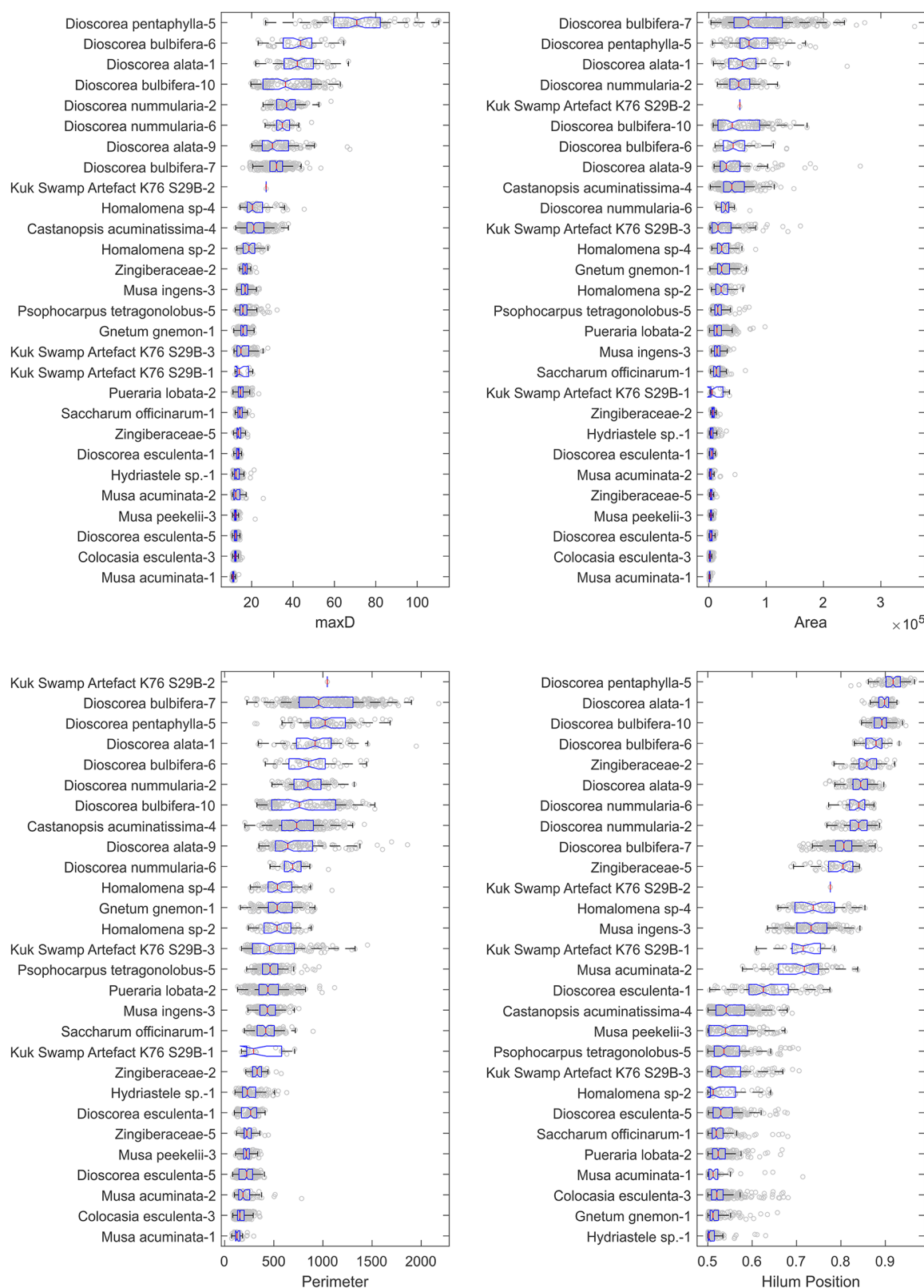


Figure 6. Boxplot graphs of archaeological and reference set grains for the metrics used in this study: maxD, area, perimeter and hilum position. The data is presented as subgroups which are determined following the normalisation of the starch grains (see Field *et al.*, 2020).

Furthermore, the large size of the tubers meant that kudzu bean was suitable for feeding large congregations of people and is perhaps why it has been associated with large ceremonies.

The discovery of kudzu bean starch grains in the Phase I context at Kuk Swamp supports the suggestion that it was an important staple prior to the introduction of sweet potato, around 300 years ago

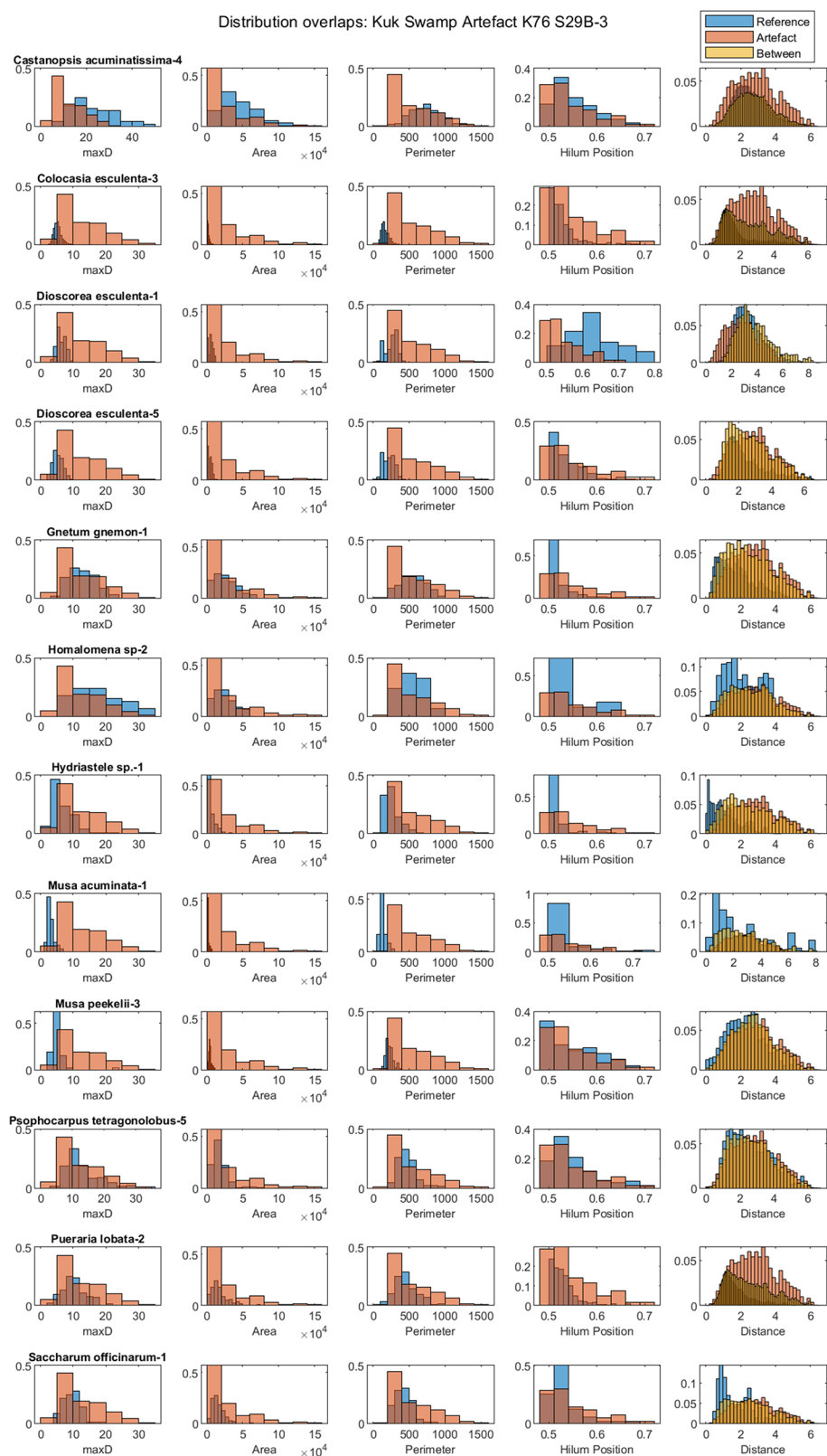


Figure 7. Histograms for the reference set samples plotted against the entire archaeological sample with the four metrics used in the analysis. The correspondence of the normalised grains shapes is also shown. The reference sets shown in this figure overlap with the unknown archaeological assemblage under consideration.

(Roullier et al., 2013). Like taro, kudzu bean was easily replanted and is likely to have been a significant adjunct to taro during the Early Holocene in the New Guinea Highlands.

C. esculenta vs D. esculenta in ancient starch assemblages.

The ability to discriminate between starch grains of similar size and morphology is challenging. In the past few decades, reports

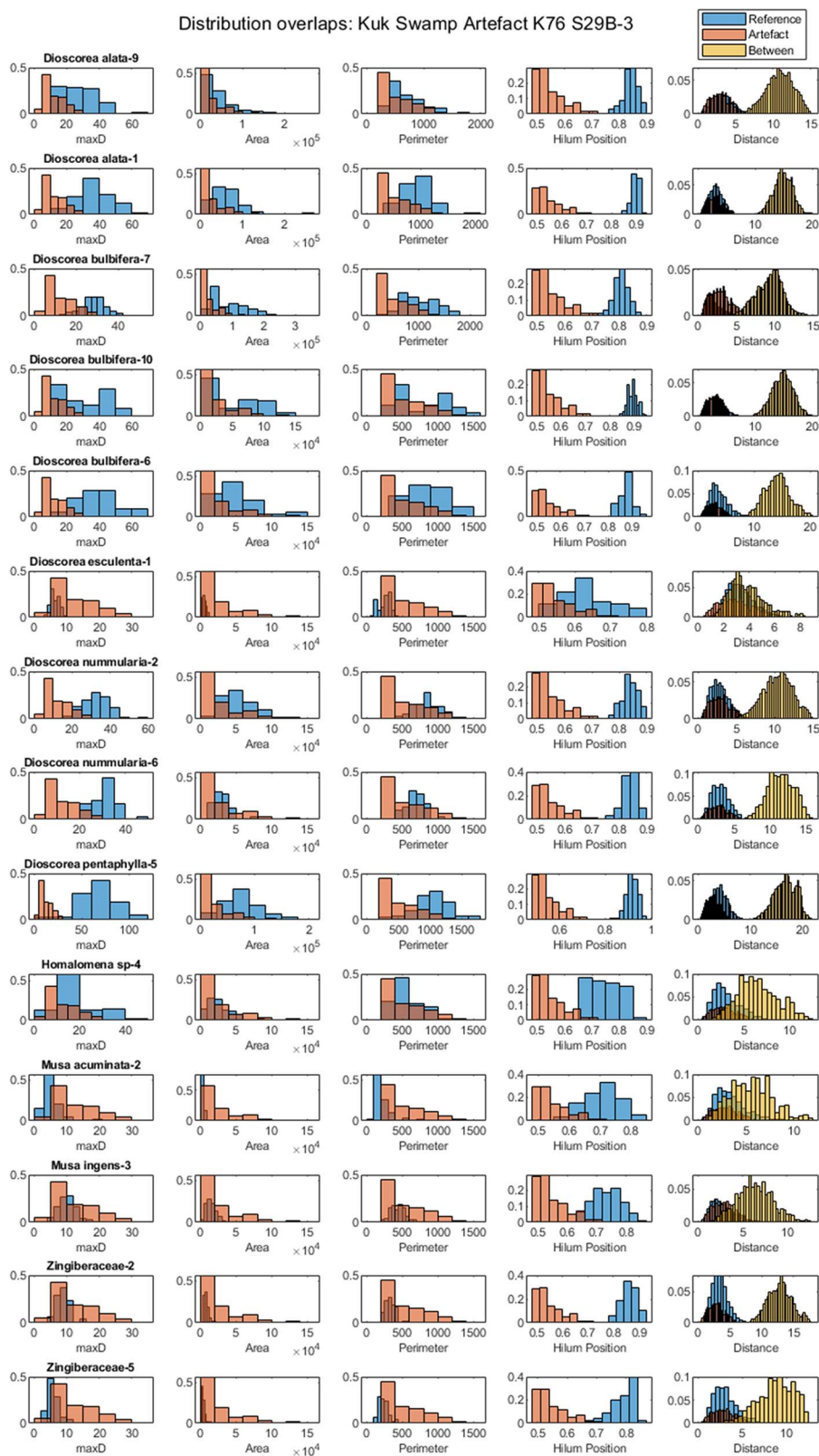


Figure 8. Examples of reference sets that did not overlap with the unknown archaeological assemblage under consideration. For instance, in the last row, while the maxD, area and perimeter overlapped, the hilum position did not correspond.

have claimed to be able to attribute starch grains to specific plant taxa, notably *C. esculenta* (taro) and *D. esculenta* (purple yam). Taro starch grains have been described as having a diameter of

1–6 μm , ‘more-round’ in shape, and with ‘shorter’ raphides that are square in cross-section and pointed at one end. Purple yam starch grains have been described as 2–10 μm in diameter, ‘more oval’ in

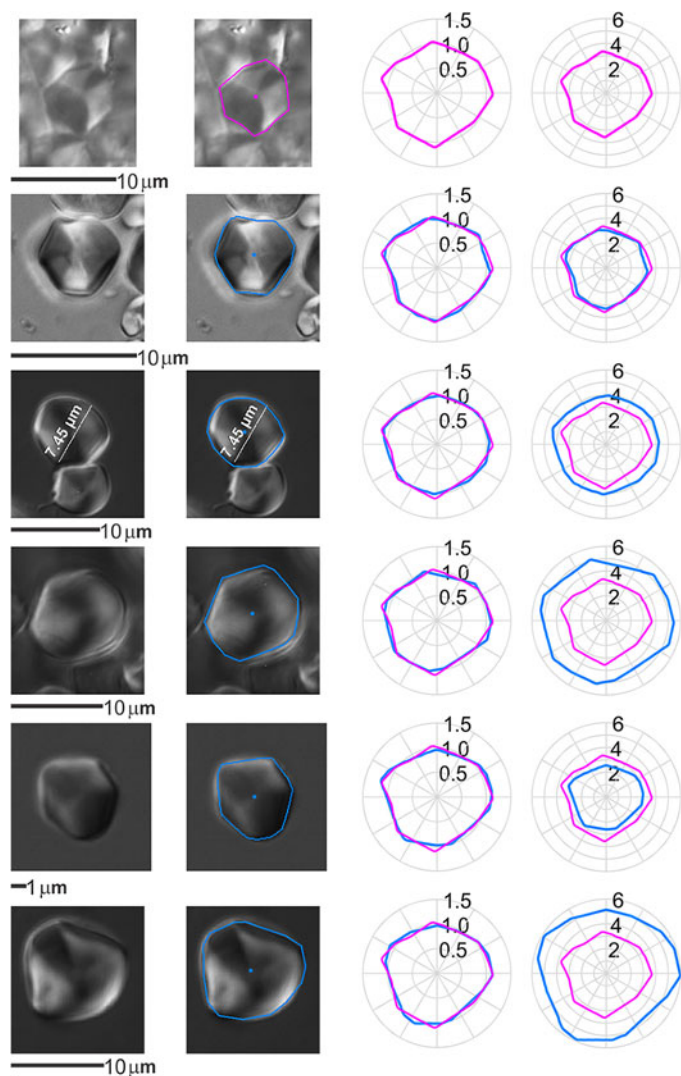


Figure 9. An example of the shape of an individual grain from K/76/S29B (first row, magenta) associated with *P. lobata* 2 (remaining rows, blue). The first column shows the micrographs, second column the grain outline as traced over the micrograph, third column overlaid and rotationally aligned normalised grain outlines, fourth column overlaid and rotationally aligned grain outlines at original scale (μm). Note that there is no significant difference between the starch grain sizes or shapes and this was repeated across the component of the assemblage associated with *Pueraria montana* var. *lobata*.

shape, with 'longer' raphides that are circular in cross-section with tapered points at both ends (see also Loy et al., 1992; Fullagar et al., 1998).

Horrocks and Weisler (2006:1190) (citing Loy et al., 1992) argued that *C. esculenta* starch has a mean size of $<5 \mu\text{m}$ with most grains $<3 \mu\text{m}$, then asserted that the identification of *D. esculenta* could be distinguished from *C. esculenta* on size, shape, and the morphology of the xylem elements (bordered ellipsoid pits), as well as the shape and size of raphides. The same rationale was used to identify *D. esculenta* in deposits at Yuku Rockshelter in the PNG highlands, *C. esculenta* and *D. esculenta* at Viti Levu Island in Fiji, and in cave deposits in New Caledonia (Horrocks and Nunn, 2007; Horrocks et al., 2008a, 2008b:293–294). Allen and Ussher (2013) also reported the presence of *C. esculenta* based on this rationale, though their measurement of starch grains showed a large overlap in size between *D. esculenta* and *C. esculenta*.

Starch grains from *C. esculenta* and *D. esculenta* are indistinguishable from each other based on their size and morphology. The identification of starch grains as *C. esculenta* in this study was not dependent just on the grain morphology but followed consideration of a range of other factors (Fullagar et al., 2006) as outlined below:

- Context: Artefact K/76/S28B was recovered from the Phase I palaeosurface which was consistent with cultivation (including digging and staking), and inter-cropping as proposed by Denham et al. (2017: 190–196).
- Archaeobotany: Macrobotanical remains identified as *C. esculenta* in previous studies included putative seeds of an aroid recovered from the same channel near to where the artefact was recovered (Lentfer and Denham, 2017:166–167). At least one raphide was observed (by Fullagar) on the original slides, though none were found on the rehydrated preparations.
- Habitat: Taro prefers growing in wetland environments, in contrast to *D. esculenta* which prefers dry and well-drained soils. Furthermore, *D. esculenta* while having been recorded as high as 1620 m asl, is rarely found growing above 900 m asl (Bourke, 2010). The altitudinal trends for growing *D. esculenta* do not preclude yams being transported into the Wahgi Valley from lower elevations, though we think it is unlikely in this context.

The study undertaken here has conclusively shown that *D. esculenta* and *C. esculenta* are indistinguishable at the microscopic level. Contrary to earlier qualitative descriptions which suggested size-shape differentiation, our study shows that the starch grains of both

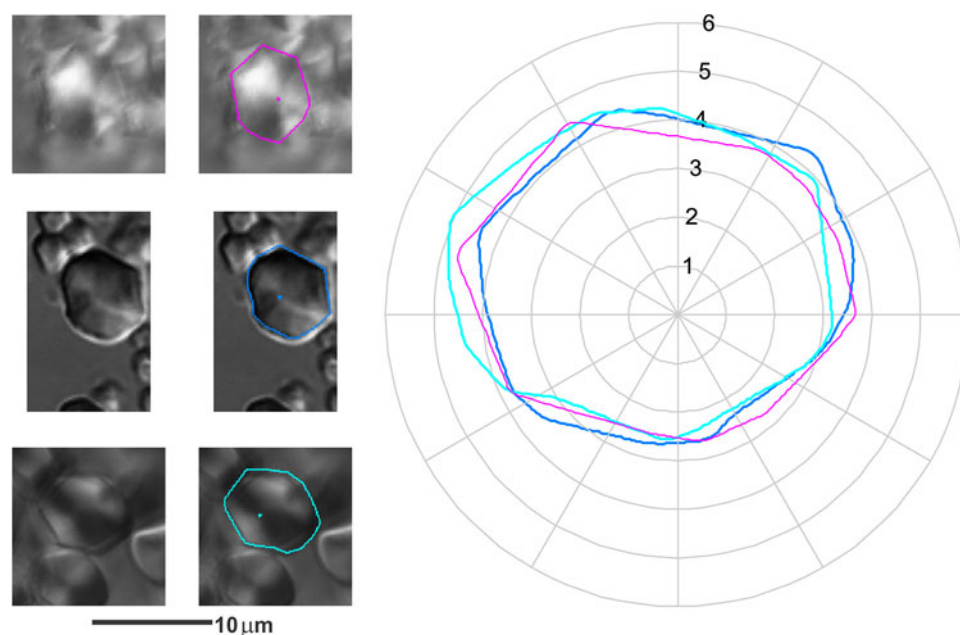


Figure 10. An example of the shapes of individual starch grains from K/76/S29B (first row), *C. esculenta* (second row) and *D. esculenta* (third row). Note that there is no significant difference between the two starch grain size or shapes and this was repeated across the component of the assemblage associated with these reference species. The overlaid and rotationally aligned grain outlines are shown at the right (magenta K/76/S29B, blue *C. esculenta*, cyan *D. esculenta*; scale in μm).

Table 2. Comparative reference material and archaeological sample subgroups.^a

Species	No. of grains	Species	No. of grains
<i>Castanopsis acuminatissima</i>	233	<i>Gnetum gnemon</i>	125
<i>Castanopsis acuminatissima</i> -1	2	<i>Gnetum gnemon</i> -1	125
<i>Castanopsis acuminatissima</i> -2	1	<i>Homalomena</i> sp.	103
<i>Castanopsis acuminatissima</i> -3	1	<i>Homalomena</i> sp-1	1
<i>Castanopsis acuminatissima</i> -4	223	<i>Homalomena</i> sp-2	46
<i>Castanopsis acuminatissima</i> -5	4	<i>Homalomena</i> sp-3	1
<i>Castanopsis acuminatissima</i> -6	2	<i>Homalomena</i> sp-4	55
<i>Colocasia esculenta</i>	458	<i>Hydriastele</i> sp.	102
<i>Colocasia esculenta</i> -1	1	<i>Hydriastele</i> sp.-1	97
<i>Colocasia esculenta</i> -2	5	<i>Hydriastele</i> sp.-2	1
<i>Colocasia esculenta</i> -3	452	<i>Hydriastele</i> sp.-3	4
<i>Dioscorea alata</i>	199	<i>Musa acuminata</i>	94
<i>Dioscorea alata</i> -1	51	<i>Musa acuminata</i> -1	36
<i>Dioscorea alata</i> -2	18	<i>Musa acuminata</i> -2	58
<i>Dioscorea alata</i> -3	2	<i>Musa ingens</i>	160
<i>Dioscorea alata</i> -4	1	<i>Musa ingens</i> -1	9
<i>Dioscorea alata</i> -5	1	<i>Musa ingens</i> -2	22
<i>Dioscorea alata</i> -6	1	<i>Musa ingens</i> -3	127
<i>Dioscorea alata</i> -7	1	<i>Musa ingens</i> -4	2
<i>Dioscorea alata</i> -8	11	<i>Musa peekelii</i>	121
<i>Dioscorea alata</i> -9	101	<i>Musa peekelii</i> -1	20
<i>Dioscorea alata</i> -10	12	<i>Musa peekelii</i> -2	2
<i>Dioscorea bulbifera</i>	534	<i>Musa peekelii</i> -3	99
<i>Dioscorea bulbifera</i> -1	4	<i>Psophocarpus tetragonolobus</i>	151

(Continued)

Table 2. (Continued.)

Species	No. of grains	Species	No. of grains
<i>Dioscorea bulbifera</i> -2	1	<i>Psophocarpus tetragonolobus</i> -1	2
<i>Dioscorea bulbifera</i> -3	1	<i>Psophocarpus tetragonolobus</i> -2	2
<i>Dioscorea bulbifera</i> -4	4	<i>Psophocarpus tetragonolobus</i> -3	1
<i>Dioscorea bulbifera</i> -5	21	<i>Psophocarpus tetragonolobus</i> -4	3
<i>Dioscorea bulbifera</i> -6	35	<i>Psophocarpus tetragonolobus</i> -5	143
<i>Dioscorea bulbifera</i> -7	333	<i>Pueraria montana</i> var. <i>lobata</i>	278
<i>Dioscorea bulbifera</i> -8	1	<i>Pueraria lobata</i> -1	1
<i>Dioscorea bulbifera</i> -9	12	<i>Pueraria lobata</i> -2	277
<i>Dioscorea bulbifera</i> -10	121	<i>Saccharum officinarum</i>	105
<i>Dioscorea bulbifera</i> -11	1	<i>Saccharum officinarum</i> -1	105
<i>Dioscorea esculenta</i>	284	Zingiberaceae	144
<i>Dioscorea esculenta</i> -1	79	Zingiberaceae-1	1
<i>Dioscorea esculenta</i> -2	1	Zingiberaceae-2	48
<i>Dioscorea esculenta</i> -3	2	Zingiberaceae-3	6
<i>Dioscorea esculenta</i> -4	5	Zingiberaceae-4	2
<i>Dioscorea esculenta</i> -5	197	Zingiberaceae-5	46
<i>Dioscorea nummularia</i>	114	Zingiberaceae-6	1
<i>Dioscorea nummularia</i> -1	1	Zingiberaceae-7	1
<i>Dioscorea nummularia</i> -2	79	Zingiberaceae-8	16
<i>Dioscorea nummularia</i> -3	1	Zingiberaceae-9	23
<i>Dioscorea nummularia</i> -4	1		
<i>Dioscorea nummularia</i> -5	2		
<i>Dioscorea nummularia</i> -6	30		
<i>Dioscorea pentaphylla</i>	146		
<i>Dioscorea pentaphylla</i> -1	10		
<i>Dioscorea pentaphylla</i> -12	3		
<i>Dioscorea pentaphylla</i> -2	1		
<i>Dioscorea pentaphylla</i> -3	1		
<i>Dioscorea pentaphylla</i> -4	5	<i>Kuk Swamp</i>	139
<i>Dioscorea pentaphylla</i> -5	80	<i>Kuk Swamp Artefact K76 S29B</i> -1	17
<i>Dioscorea pentaphylla</i> -6	1	<i>Kuk Swamp Artefact K76 S29B</i> -2	1
<i>Dioscorea pentaphylla</i> -7	4	<i>Kuk Swamp Artefact K76 S29B</i> -3	121
<i>Dioscorea pentaphylla</i> -8	3		
<i>Dioscorea pentaphylla</i> -9	1		
<i>Dioscorea pentaphylla</i> -10	20		
<i>Dioscorea pentaphylla</i> -11	17		

*Groups (in italics) and subgroups after hierarchical clustering with a cutoff equal to 0.25 maximum distance. Note that the archaeological starch assemblage effectively sorted into three subgroups, of which two comprised 17 and 121 grains.

taxa overlap in shape and size and we suggest that previous claims may need review and revision.

Questions remain over the identification of *D. esculenta* and *C. esculenta* in other published studies from across the Pacific region. The widespread distribution of both plant taxa and their indistinguishable morphologies does mean that other factors must be considered before attributing confident identifications.

Misidentification has the potential to skew our view of plant use over time, as both taxa are known from contrasting environmental contexts and require different growing conditions. We would argue that the accurate attribute measurement data that was collected, with the methods described here, bring into question the utility of qualitative measurements and subsequent conclusions drawn from those datasets.

In summary, it is perhaps unsurprising that both taro and kudzu bean starch grains were identified on the small, flaked tool recovered from Phase I sediments at Kuk Swamp. It has been well documented that taro plants are trimmed by scraping prior to replanting, as is the kudzu vegetative apex (e.g., Sillitoe, 1983:39, 48). Our interpretation is that the flake tool was used on taro and kudzu in preparation for replanting in the Kuk Swamp sediments.

Conclusion

The identification of *P. montana* var. *lobata* in the starch assemblage from Artefact K/76/S28 is an important addition to the range of plants known to have been exploited at Kuk Swamp in the Early Holocene. The presence of *P. montana* var. *lobata* in a 10 kyka cal BP context is the oldest known age in Papua New Guinea and provides support for earlier arguments that kudzu bean was a significant staple in highland New Guinea diets. The identification of *P. montana* var. *lobata* builds on previous discoveries at the Joe's Garden site in the Ivane Valley in the Mid-Holocene and highlights what appears to be a long history of exploitation in highland contexts.

Of considerable methodological importance is demonstrating that the identification of *C. esculenta* and *D. esculenta* in starch assemblages cannot rely on quantitative size-shape criteria alone. Consideration of other features such as xylem element and raphide morphology, habitat requirements and cultural activities is critical to the correct attribution of species identification. A detailed understanding of the archaeological context from which these finds are recovered is essential.

Acknowledgments. We are grateful for support from the University of New South Wales, the Forest Research Institute in Lae, and to Tim Denham for permission to re-examine the Kuk Swamp artefact studies here and for reading a previous draft. JF is grateful to Carol Lentfer for the reference slides of *Musa* spp. We dedicate this paper to the late Dr Beth Gott AM (1922–2022) who was instrumental in assisting JF in the early stages of her starch research. We also thank the two anonymous reviewers for their detailed comments. A huge thank you to Dr Anthea Mitchell for preparing the topographic map in Figure 1A.

Competing Interests. The authors declare that they have no competing interests that could interfere with the objectivity or integrity of this publication.

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