18

Ancient starch and usewear analyses of an excavated pestle fragment from the Upper Kaironk Valley, Madang Province, Papua New Guinea

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Abstract

During archaeological survey and excavation along the Kaironk and Simbai Valleys of the New Guinea Highlands in 2016, a ground and pecked tool fragment was recovered from a subsurface context immediately adjacent to the Imbiben (JRQ) open area excavations where a well-preserved cultural deposit including hearth stones and a flaking floor has been dated to the mid-Holocene (4.4–4.3 cal. ka (ka: thousands of years ago). Technological and usewear analyses of the fragment identified a formally manufactured surface shaped by pecking, with minimal traces of use but consistent with the side of a pestle, on which starch residues were preserved. Ancient starch analysis identified *Castanopsis acuminatissima* as the primary contributing species in the residue sample. *C. acuminatissima* is an upper canopy tree found in primary forest across the highlands. It belongs to the acorn family (Fagaceae) and produces an edible starchy nut that can be eaten raw or roasted. The Imbiben pestle fragment is the fourth formally manufactured artefact with pecked and/or ground surfaces recovered from subsurface sediments during the current project, all of which date to the mid-Holocene. The other artefacts include two pestle fragments and a fragment of a carved face excavated at the Waim site. Pestles, mortars and carved stones are widely known from unprovenanced contexts across the Kaironk/Simbai Valleys, New Guinea and the Bismarck Archipelago. The functional study of the Imbiben pestle fragment described here aids in our understanding of the range, antiquity and use of these formally manufactured stone tools to process starchy plant foods.

Introduction

The enigmatic mortar and pestle complex of formally manufactured ground, pecked and sometimes exquisitely carved stone objects from New Guinea and neighbouring islands has a remarkable range of form and decoration, providing a unique opportunity to investigate the role of these objects in traditional societies across different landscapes and language groups (see Swadling 1986, 2013, 2021; Swadling et al. 2008). The vast majority of stone mortars and pestles currently known are from poorly provenanced contexts with no associated chronological information (Swadling 2021). Local communities have no knowledge about their manufacture or intended use. Despite much speculation among researchers for over 100 years, the primary function of these implements is only now becoming clearer (Barton 1908; Bulmer 1964; Field et al. 2020; Seligman and Joyce 1907; Shaw et al. 2020; Swadling and Hide 2005; Watson 1968). The recent discoveries of mortar and pestle fragments from securely excavated and dated contexts in widely separated geographic locations, and the significant advances in ancient starch studies over the past two decades, and in combination with usewear analyses, have yielded much-needed new information on the associated uses of these tools (e.g. Coster and Field 2015, 2018; Field et al. 2016, 2020; Hayes et al. 2021). As mortars, pestles and carved objects are found across New Guinea and the Bismarck Archipelago (see Swadling 2021:Fig. 1), it is highly likely that the function and use of these implements also varied according to resource availability and subsistence patterns, as well as locale and context of their manufacture (e.g. Ambrose 1964; Berndt 1954; Chappell 1964). The study presented here adds to the growing corpus of archaeological knowledge about the past uses of these remarkable tools, especially the range of plants that were being processed.

Functional studies of pestles and mortars in New Guinea

Usewear residue studies have previously been undertaken on one excavated mortar fragment from the Joe's Garden site in the Ivane Valley (Central Province), and on two excavated pestle fragments from the Waim site in the Schrader Range (Madang Province) (Field et al. 2020; Shaw et al. 2020). The starch grains identified on all three artefacts were attributed to *Castanopsis acuminatissima,* a forest tree species that is ubiquitous across the highlands, occurring between 570–2440 m asl (above sea level) and documented in the vegetation histories of the region (e.g. Haberle 2007). *C. acuminatissima* produces small hazelnut-size starchy kernels which are abundant between November to April. The starchy nuts can be eaten either raw or roasted and are likely to have been processed by pounding. *C. acuminatissima* starch grains were identified along with starch grains from the geophytes of *Dioscorea alata* and *Pueraria lobata,* these latter species considered to have considerable antiquity as important plant foods prior to the arrival of the sweet potato (*Ipomoea batatas*) (Roullier et al. 2013; Watson 1964, 1968). Bulmer (1964:149) has argued that *C. acuminatissima* may have been considered important across the New Guinea Highlands because of its edibility, abundance and size. While it has been documented from mid-Holocene contexts, it is likely to have been exploited over a longer period (Bourke 1996; Field et al. 2020; Shaw et al. 2020).

C. acuminatissima (*sawey*—pronounced 'sar-way', Gardner 2010:36) is just one of 13 plants identified by Ralph Bulmer (1964) when he canvassed the range of edible tree nuts likely to be processed in the mortars and pestles in the Kaironk Valley (Table 18.1). *C. acuminatissima* trees were observed in village gardens in the Ivane Valley, while in the Kaironk Valley a grove of *C. acuminatissima* has been set aside as a reserve in recognition of the importance attributed to the annual availability of these edible tree nuts during the wet season. The *C. acuminatissima* reserve is on the northern side of the Kaironk River on the Schrader Range, though Bulmer (1964) described almost pure stands

of *Castanopsis* on exposed ridge crests on the southern side of the valley on the Bismarck Range at around 2100 m asl (c. 7000 feet) (see also Paijmans 1976). There has been, and continues to be, considerable clearing of forests across the Kaironk/Simbai system leading to a severe contraction of their availability. Local population increases have resulted in considerable pressure for more land clearing to develop new gardens.

Table 18.1: A summary of the 13 tree taxa identified by Bulmer (1964) and updated by Gardner (2010), including local names and judged by Bulmer to likely be processed in mortars and pestles in the Kaironk Valley.

No.	Family	Species	Kalam name(s)	Ethnographic notes
1–3	Pandanaceae	*Pandanus* sp.	*algaw, gdi/gdl, kmi*	3 categories, roasted, cooked in ground oven
		P. brosimos (cf. *julianettii*)	*alngaw*	>2250 m,[a] oily nuts roasted and eaten; 1800–3300 m asl[b]
		P. cf. *julianetti*	*kumi, snay*	to c. 2400 m,[a] nuts eaten roasted or raw; 1450–2800 m asl[b]
4–6	Elaeocarpaceae	*Elaeocarpus* sp.	*ymges*	3 species, eaten raw or roasted, tedious to extract
		E. leucanthus	*kodjop*	Grows to higher altitude than *kodlap*, single edible kernel
		E. womersleyi	*kodlap*	to c. 2100 m,[a] eaten raw or roasted
		E. schlechterianus	*ttaman*	tree of mid-altitude forest, kernels eaten
7	Elaeocarpaceae	*Sloanea archboldiana* (syn. *tieghemii*)[a]	*tlum, tlm*	to c. 2400 m,[a] not recorded as eaten by Kalam, though Maring people do; 1100–2300 m asl[c]
8	Fagaceae	*Castanopsis acuminatissima*	*sawey, kabj, wusij, kabi nqem*	eaten raw or roasted; 570–2440 m asl[b]
9	Moraceae	*Artocarpus* sp. 1	no known Kalam name	not in Kalam area but adjacent groups. Seeds eaten roasted; 0–1450 m asl[b] (*A. altilis*)
10		*A. lacucha*	*abok*	Shrader Range at 1800–2100 m,[a] nuts eaten
11	Proteaceae	*Finschia chloroxantha*	*sog*	roasted and then pounded with a rock; 0–2000 m asl[b]
12	Malvaceae	*Sterculia* sp. cf. *monticola*	*dkpn, dkbn*	tree to c. 1800 m,[a] seeds from bean-like pod, roasted and eaten: up to 2150 m asl[d]
13	Pittosporaceae	*Pittosporum pullifolium*	*slknuw**	Shrub, pod roasted, seeds extracted and eaten, bitter taste

Notes: * not documented by Gardner (2010); powo.science.kew.org/taxon/324460-1; [a] Bulmer (1964); [b] Bourke (2010), extreme altitudinal range in PNG; [c] Coode (1983); [d] uses.plantnet-project.org/en/Sterculia_monticola (PROSEA). asl = above sea level. Further Kalam names for the various species can be found in Pawley and Bulmer (2011). (Also note *E. schlechterianus* has been added following Gardner (2010).)

Source: See sources listed throughout notes.

Other important tree nuts include *Elaeocarpus womersleyi*, the nuts known locally as *kodlap,* while *Elaeocarpus leucanthus*, which grows to a higher altitude, is known as *kodjop* (Gardner 2010:28). It is not clear whether these nuts are starchy, and although we encountered carbonised remains of both types of seeds in excavated sequences (identified by local collaborators), we have not yet been able to acquire any fresh reference samples for study. *Finschia chloroxantha* (*sog,* Gardner 2010:39) is also

widely eaten and numerous trees were observed in the Kaironk and Simbai Valleys. Unfortunately, prepared slide samples from field collections did not contain any starch. *Pandanus* species (*alngaw/kumi* Gardner 2010:12) are common in the Kaironk Valley, as they are across the highlands. *Pandanus* sp. seeds are high in protein and oil (Hyndman 1984) but yield low quantities of starch. While *Pandanus* drupes are pounded in some contexts, the number of starch grains may consequently be under-represented in archaeological contexts. Although *Pandanus* drupes were recovered from the Kosipe Mission excavations (in the Ivane Valley) and dated to around 35 ka (Fairbairn et al. 2006), no *Pandanus* sp. starch was identified in tool residues. *Pandanus* kernels (endosperm) and the pulp (mesocarp) (Hyndman 1984:295) may be cooked and consumed away from the villages, as observed elsewhere in the Ivane Valley (Summerhayes et al. 2010).

Functional analyses of mortars and pestles likely to be associated with food processing have provided important insights into the range of foods exploited over time in domestic contexts, and into the types of plant materials that are pounded and/or ground. The residues recovered from these artefacts contribute important functional and contextual information that supplements other microfossil records, such as those preserved in sediment cores. The study discussed here is no exception, as the aim of this paper is to present a functional study of an excavated formally manufactured stone artefact recovered from subsurface sediments of probable mid-Holocene age from the Kaironk Valley in the Papua New Guinea.

Study area

The Upper Kaironk Valley, in the Madang Province, is part of the Kalam-speaking territory of the Papua New Guinea Highlands (Field et al. 2021). Anthropological, linguistic and botanical research in the Kaironk Valley has been undertaken since the 1960s (Gardner 2010; Majnep and Bulmer 1997, 2007; Pawley and Bulmer 2011). The initial archaeological investigations were pursued by Sue Bulmer at the Wañelek site (JAO) and elsewhere in the Kaironk Valley in the 1970s (see Bulmer 1975).

The archaeological survey and excavation described in this paper are part of an Australian Research Council – funded project titled 'Pathway to the Highlands Project' (see Field et al. 2021; Shaw et al. 2020), aimed at investigating whether the highland fringe valleys were conduits for the movement of people, plants and technology, between the coastal lowlands and highland valleys, and ultimately to develop a more nuanced model for the peopling of Sahul and New Guinea. Previous research by Pawel Gorecki had explored the human record in the adjacent, but lower-lying, Jimi Valley (<500 m asl). Notably, these valleys are less than 100 km from the Wahgi Valley and the Kuk Swamp records (Golson et al. 2017; Gorecki and Gillieson 1989). In 2015, a survey of the Upper Simbai and Kaironk Valley was undertaken to identify past settlements and whether areas of cultural activity in the form of subsurface cultural materials were present and in concentrations justifying excavation (Field et al. 2021).

Imbiben (JRQ), Upper Kaironk Valley, Madang Province

During a survey of the Alvan Spur in the Upper Kaironk Valley (Figure 18.1), a range of surface finds were recovered at Imbiben, while some were observed in the Alvan village museum (Figure 18.2). Similar artefacts are often revealed during garden construction, emerging as the soil is turned over for planting. The small museum at Alvan was only recently constructed to house a range of artefacts collected by locals.

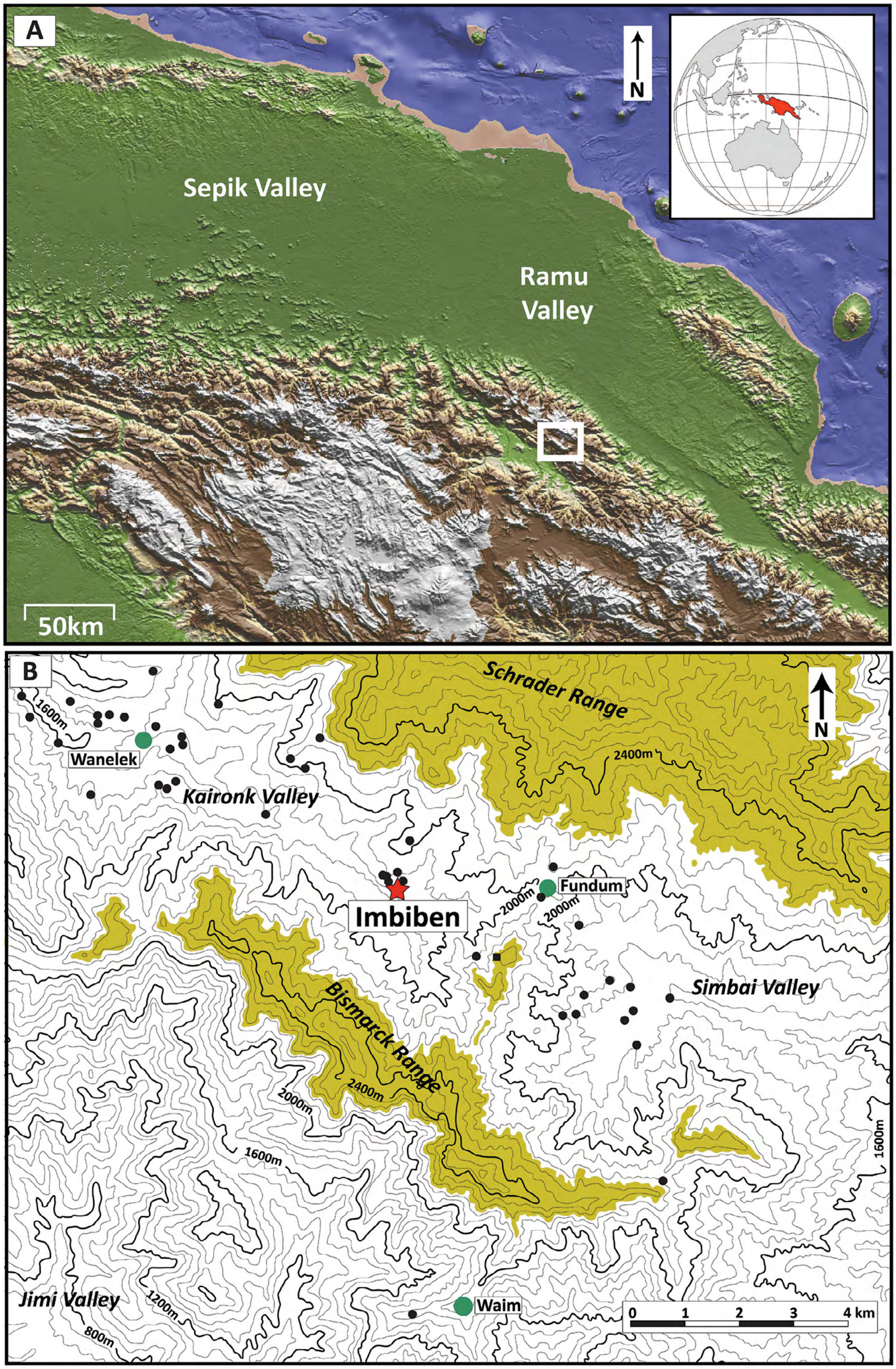

Figure 18.1: The location of the Simbai–Kaironk Valleys.

Notes: B. KAI-25 (JRQ,* red star) is associated with a cluster of other recorded sites below the Alwan village on a prominent spur system. The map shows 80 m contours. Fundum (JQQ,* green dot) lies on the saddle between the Kaironk and Simbai River valleys. * National Museum and Art Gallery site codes.

Source: Illustration by Ben Shaw.

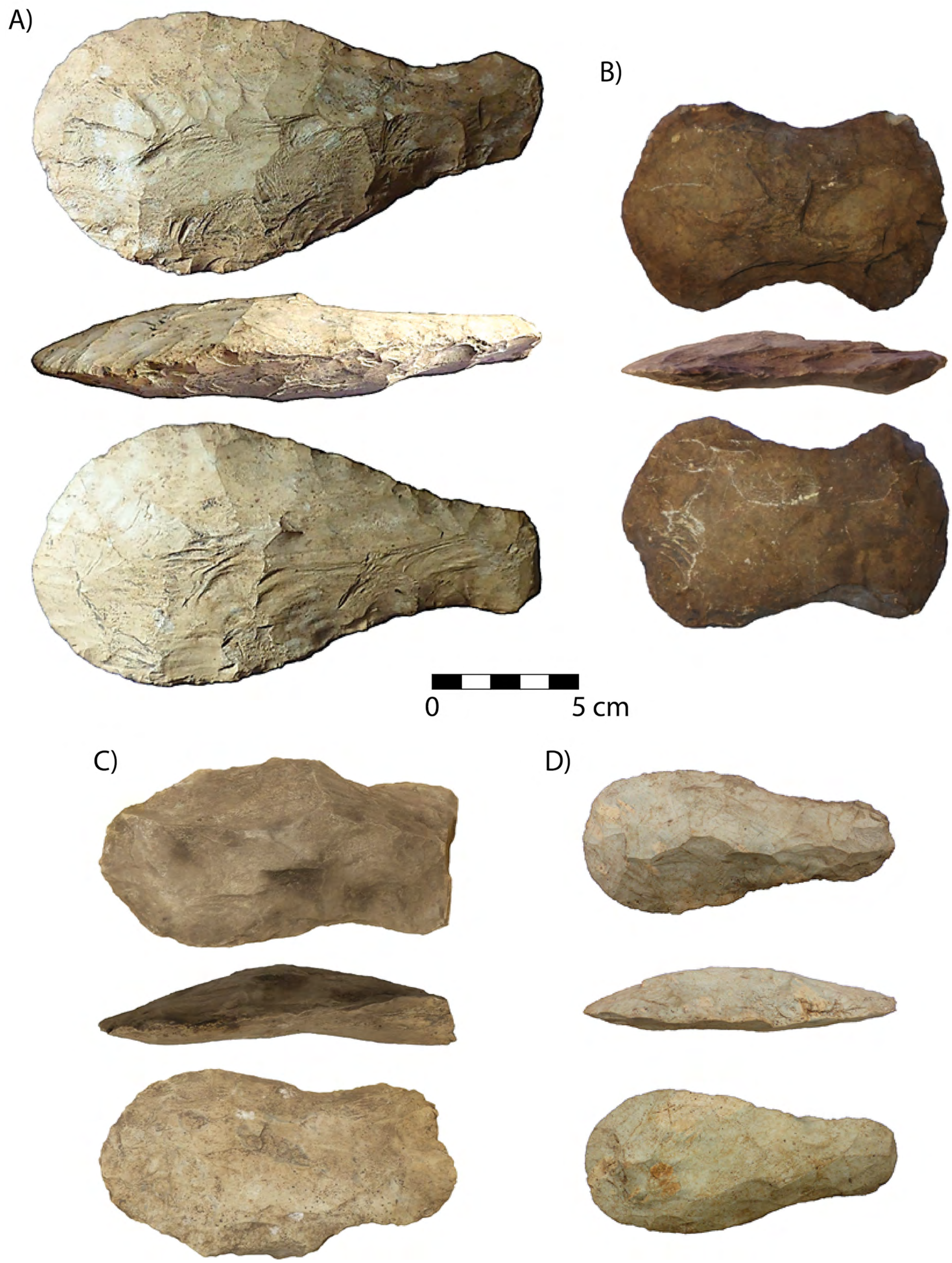

Figure 18.2: Waisted chert artefacts as surface finds from the Upper Kaironk Valley.

Notes: (A) From the local Alvan collection; (B) Skow (KAI-6); (C) near Alvan (KAI-22) above Imbiben. All three artefacts had a weathered cortex overlying a green chert interior; (D) Fundum (SIM-11).

Source: Illustrations by Ben Shaw.

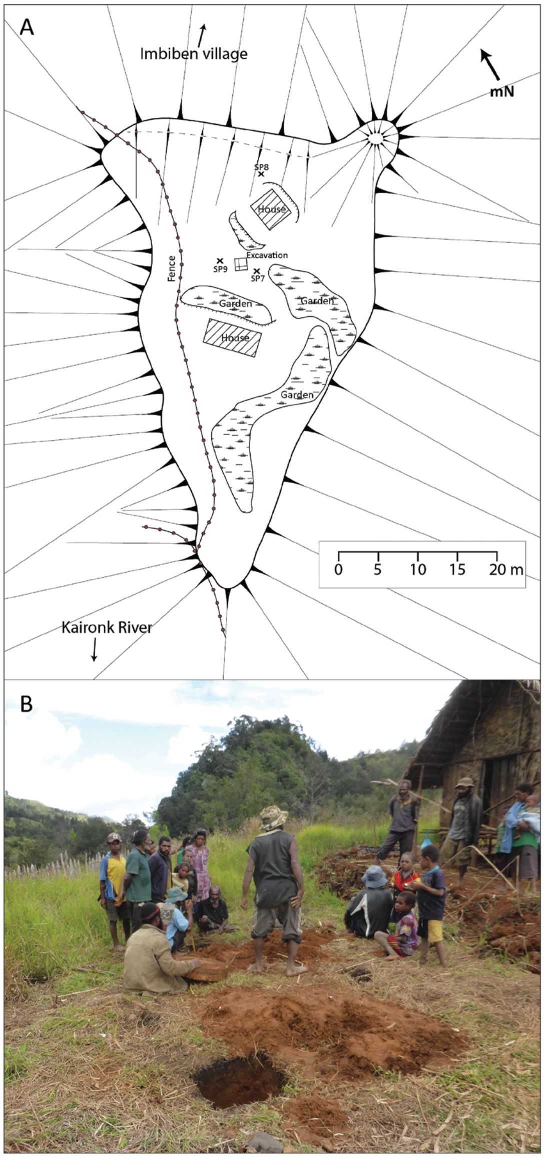

Figure 18.3: Alvan spur excavation.

Notes: (A) Survey plan of the flattened part of the Alvan spur where systematic archaeological investigations were undertaken; (B) test pit excavations in progress (SP9), with spade pit 7 (SP7) open in the foreground. The artefact KAI25-SP7-20cm-bs was recovered from SP7 and is immediately adjacent to the later systematic excavation (Field et al. 2021). The Kolkop limestone outcrop covered in dense vegetation can be seen in the background to the southwest.

Source: Illustrations and photo Ben Shaw.

Prior to systematic and targeted subsurface investigations at Imbiben (JRQ) in 2016, a series of nine spade pits were excavated down the Alvan spur, with three (SP7–SP9) dug across a 1300 m^2 triangular area of relatively flat ground (JRQ: Imbiben site, 1860 m asl), ~ 40 m above and 100 m north of the Kaironk River, to ascertain the nature and extent of any cultural remains and their correlation to sediments and stratigraphy (Figure 18.3). The highest concentration of flaked lithic artefacts was in SPs 7–9, including a fragment from SP7 (Layer 2, 20 cm below the surface (bs)) with a smooth, rounded surface that appeared to be similar to those found at Waim (WAA), where they were recovered from excavation, in addition to several samples held by the local community (see Shaw et al. 2020). To better understand details of its manufacture, use and breakage, a technological and functional analysis was undertaken.

The three stratigraphic layers identified in SPs 7–9, and confirmed in later systematic excavation, include an organic topsoil (Layer 1, 0–15 cm), a dense cultural horizon (Layer 2, 15–40 cm) and an underlying compact, culturally sterile basal clay (Layer 3). Bedrock was not reached. Two radiocarbon determinations from the systematic excavation situated between the two spade pits, and adjacent to SP7, bracket Layer 2 between 5460–5070 cal. BP (OSV218, 4595±30 BP, 50–60 cm) and 4510–4240 cal. BP (OZV217, 3930±30 BP, 20–30 cm). The latter date was associated with a well-defined stone cooking area (*mumu*) and a dense scatter of flaked and ground stone artefacts, revealing the remarkable preservation of a mid-Holocene cooking place and associated knapping floor (Field et al. 2021). A radiocarbon determination from SP9 of 1690–1410 cal. BP (OZU286, 1645±25 BP) from 37 cm bs is inconsistent with the established age of Layer 2, and is likely to have been deposited within an intrusive pit feature from Layer 1, as identified in the section of the spade pit. The date is therefore not considered further here.

Methods

Technological and usewear analysis

A 3D scan of the artefact was generated using a Polyga Compact C210 3D scanner with FlexScan3D software (Version 3.3). The 3D image and snapshots of the artefact were viewed and obtained in MeshLab (Version 1.3.4BETA).

Wear traces were documented under low and high magnification. Low magnification examination (up to ×45) was undertaken using an Olympus SZ61 stereo-zoom microscope with an external fibre optic, 150-watt halogen light source (Olympus LG-PS2). High magnification examination was undertaken using an Olympus metallographic microscope (model BX53M) with vertical incident light (brightfield and darkfield) with objective lenses of ×5, ×10, ×20 and ×50 and various polarising filters. Microscopic images were captured with an Olympus Infinity 2 camera attachment (TIF files). Multifocal images of the artefact surface were taken with both microscopes and stacked to create a focused image using Helicon Focus software Version 7.6.3.

A reference library of experimental usewear patterns from grinding/pounding a variety of materials is available (e.g. Hayes et al. 2018), the results of which contributed to our functional interpretations.

Residue analysis

Residue extraction and documentation

The pecked dorsal surface was immersed in an ultrasonic bath of deionised water for two minutes to remove adhering residues. The solution, including residues, was then reduced in volume by centrifugation. Starch and phytoliths were isolated using heavy liquid separation (sodium polytungstate, S.G.2.35) by centrifugation at 1000 RPM for 15 minutes. The sample was then rinsed with water by centrifugation, dried in acetone and mounted in water. A negative control sample was processed in parallel with the archaeological sample and subsequently checked for modern starch contamination.

Modern comparative reference collections

The principal aid in identifying from which plant taxa the unknown starch gains originate is a modern comparative collection of starchy plants parts known to be exploited and possibly pounded or ground, from the region of interest (see Field et al. 2016, 2020; Hayes et al. 2021). Plant parts were sampled, visualised, documented and digitised (Coster and Field 2015, 2018) (Table 18.2).

Table 18.2: Comparative reference starch and archaeological sample.

Sample name	Common name	Altitudinal range	*n*	Plant part	Processed	Size range (μ)	Median (μ)
KAI25-SP7-20cm-bs pestle frag	–	(1860 m)	121	–	–	6.62-43.21	15.65
Castanopsis. acuminatissima	Castanopsis	570–2440 m	233	Fruit	Raw/roasted	5.07–49.6	20.52
Colocasia esculenta	Taro	0–2760 m	458	Tuber	Roasted/baked	2.53–9.9	5.15
Dioscorea alata	Greater yam	0–2100 m	199	Tuber	Roasted/baked	10.53–68.18	29.44
D. bulbifera	Bitter/Hairy yam	0–2110 m	207	Tuber	Cooked/leached	8.29–51.00	28.33
D. esculenta	Lesser yam	0–1620 m	284	Tuber	Roasted/baked	2.27–9.3	5.56

Sample name	Common name	Altitudinal range	*n*	Plant part	Processed	Size range (μ)	Median (μ)
D. nummularia	Common yam	0–2050 m	114	Tuber	Roasted/baked	19.20–53.37	32.45
D. pentaphylla	Five leaflet yam	0–1620 m	146	Tuber	Roasted/baked	14.60–110.78	65.07
Gnetum gnemon	Tulip nuts	0–1330 m	125	Nuts	–	3.51–21.32	12.58
Homalomena sp.	–	2000 m	103	Root	–	6.49–43.79	16.29
Hydriastele sp.	Palm	2000 m	102	Root	–	2.24–23.02	5.93
Musa acuminata	Banana	0–2350 m	94	Fruit	Raw	1.53–19.52	3.46
M. ingens	Banana	0–<2000 m	160	Fruit	Raw	4.66–18.11	9.65
M. peekelii	Banana	0–<2000 m	121	Fruit	Raw	2.49–22.22	5.25
Psophocarpus tetragonolobus	Winged bean	0–2070 m	151	Tuber	Baked/roasted	5.15–35.95	11.42
Pueraria lobata	Kudzu bean	0–2740 m	278	Tuber	Baked/roasted	2.93–25.07	10.05
Saccharum officinarum	Sugar cane	0–2760 m	105	Root	Raw	4.83–19.45	9.50
Zingiberaceae	Ginger	0–2200 m	144	Root	–	2.18–20.14	7.21

Notes: '*n*' indicates the number of digitised grains in the analysis. *Musa acuminata* has numbers less than 100. Many of these plant taxa are often roasted and baked while others are eaten raw. It is well known that some foodstuffs are pounded when feeding the elderly and the young, though there may be other reasons why they are processed, perhaps to improve palatability or combining less abundant resources.

Source: Table prepared by Judith Field, Michael Lovave and other sources cited in text (e.g. Bourke 2010).

Microscopy and documentation

The residue sample and modern reference samples were viewed using a Zeiss Axioskop II transmitted brightfield microscope with Nomarksi optics. Total slide scans were undertaken for the archaeological sample. For the reference set, a minimum of 100 starch grains were documented. Starch grains were photographed using a Zeiss HRc camera as .ZVI files with Zeiss Axiovision software.

The outline and hilum position of individual starch grains from the archaeological sample and the reference starch assemblages were digitised (from the micrographs) using custom Matlab (Mathworks R2018b) code and a Wacom Intuos Pen Tablet (CTH-480). Damaged starch grains were not included.

Analysis of starch assemblages

A range of quantitative macroscopic geometric features were determined for each starch grain from the digitised grain outlines. In this analysis, area, perimeter, maximum length through the hilum (MaxD) and hilum offset measurements were used. The individual grain shapes were assessed at their original (actual) size and as 'normalised' grain shapes.

Normalised shapes are determined by scaling the size of individual grains whereby the average radius about the hilum of each grain is one. The shapes can then be rotationally aligned and compared. The use of normalised shapes controls for growth stage or inherent variations in size across each assemblage. The aligned normalised shapes of each reference species and the archaeological assemblage were hierarchically clustered into self-similar groups, using a common cut-off to ensure the same levels of self-similarity between the different subsets.

The grain shapes (original and normalised) were analysed for similarity by rotationally aligning pairs about their hilum positions and minimising the area between the two shapes. The area between shapes provided a distance measure for pairs of shapes. The distribution of the distances between the normalised shapes and the distributions of the macro-scale geometric features within each reference subset were then analysed for overlaps with those of the assemblage. If any of the comparative reference subset distributions did not overlap with the distributions of the unknown (archaeological) assemblage, then those reference subsets were removed from subsequent analyses.

Independent expert visual verification

Once the geometric analyses have removed non-contributing reference species, then the closest grains from the reference set are established for the unknown grains. More than one species from the reference set may be identified for one unknown grain. As the quantitative geometric measures used in the first stage of the analysis derive from the (2D) digitised outline of the grain and the position of the hilum, other morphological features may need to be considered to identify the reference species. Thus, the second stage of the analysis is the expert visual verification: comparing the digitised outlines and the categorical features of the grains in the micrographs. The categorical starch grain features considered in the verification process were presence/absence of fissures, presence/absence of lamellae, presence/absence of facets, open/closed hilum and compound/single starch grains.

Results

Technology and usewear traces

The Imbiben artefact (KAI25-SP7-20cm-bs) appears to be a broken flake made from coarse-grained gabbro. It has a pecked/ground dorsal surface, which has two partial flake scars, and a slightly weathered ventral surface, which has a hackly fracture and lacks a clear bulb of percussion or striking platform (Figure 18.4A). The morphology suggests an abrupt lateral break at the (possible) proximal margin, although we cannot be certain of its orientation since there is no remnant of the platform or any clear indication of an impact zone. Consequently, it is uncertain whether the flake is the result of deliberate or accidental breakage. On the pecked/ground dorsal surface, there is a group of shallow grooves or scratch marks which are not typical of grinding/pounding; and it is uncertain whether these are cultural (e.g. damage caused by past tool handling), or the result of post-depositional alterations (taphonomic) (Figure 18.4B).

Microscopic examination of the dorsal surface indicates that the original surface was shaped by pecking. Under low magnification, individual grains on the dorsal surface are angular and don't appear to be smoothed or levelled, with the exception of a few isolated areas (Figure 18.4C, D). Under high magnification, many grains on the dorsal surface appear to have relatively fresh fracture surfaces (Figure 18.4E–I). These fracture surfaces are considered to be wear resulting from pecking during manufacture to shape the artefact. Pecking and minimal abrasive smoothing are the only techniques documented. The abrasive smoothing could have formed during manufacture and diagnostic traces of use are absent.

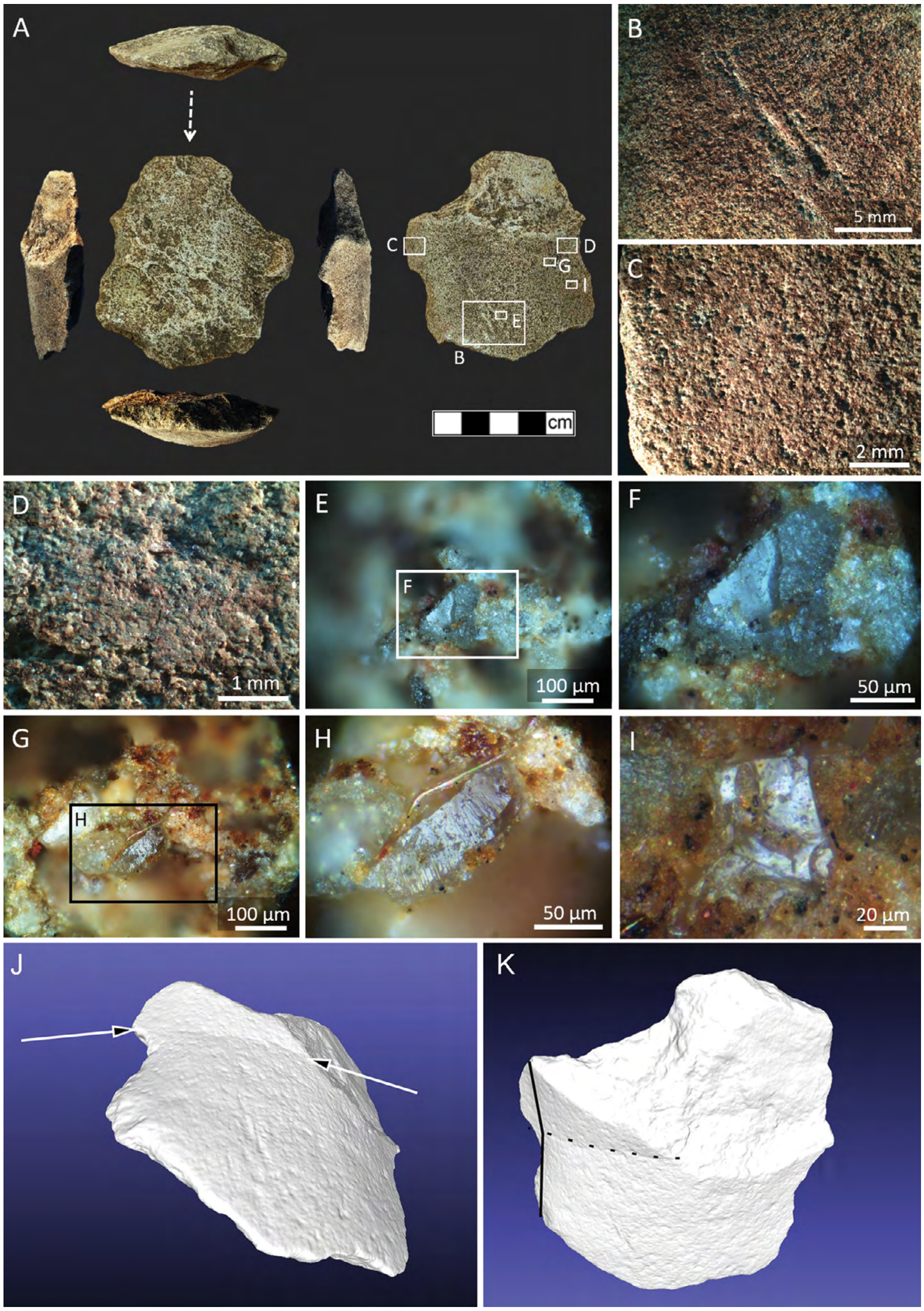

Figure 18.4: Microscopic wear documented on artefact KAI25-SP7-20cm-bs.

Notes: (A) KAI25-SP7-20cm-bs views: ventral (left) and dorsal (right), orientated with the proximal end up. The dashed arrow indicates the likely direction of force that detached the flake. White squares show locations of the microscope images D–I; (B) macroscopically visible scratch marks on the dorsal surface (stereo-zoom stereomicroscope); (C–D) isolated zones of levelled grains, indicating grinding and smoothing (stereo-zoom stereomicroscope); (E–I) individual crystal grains in the stone matrix lack scratch marks or striations and mostly have natural fracture features that are likely the result of hard impact, probably from hard hammer percussion—pecking to shape the pestle (metallographic microscope); (J–K) 3D model snapshots of the dorsal surface of KAI25-SP7-20cm-bs (proximal end up), showing possible inflexion or waist; (J) a possible waist on the artefact indicated by arrows; (K) alternate view of the artefact with inflexion indicated by solid lines and waist indicated by dotted lines. Note that curvature at the proximal end appears to get wider in diameter more steeply than at the distal end, possibly indicating that the missing proximal end would be pestle base.

Source: Illustration by Richard Fullagar and Elspeth Hayes.

It is difficult to reconstruct the diameter or general shape of the complete artefact prior to breakage but a partial 'waist' is discernible in a rotated 3D image (Figure 18.4F, G). The waist may indicate deliberate widening at the working end or base, as seen on the base of some formally manufactured pestles (e.g. Shaw et al. 2020:Fig. 4e). But we cannot determine whether the working end or base of the artefact is 'above' or 'below' the apparent waist. If the working end or base of the artefact is 'above' the waist—that is, beyond what we identify as the possible proximal end—then only a small portion of the working end has survived. Either way, the flake is from near the junction of a handle and the base, and the wear is mostly from manufacture (stone on stone). It is possible that the force of pounding, when using the artefact as a pestle, caused the flake to be detached from the side. The lack of impact percussion marks perhaps makes it less likely that the artefact was deliberately broken as part of some ritual (e.g. Adams 2008).

Only minimal abrasive smoothing was noted, and the general lack of usewear is intriguing. Is the flake from near the working end of an implement or part of a carved stone object that was not a utilitarian tool? A change in surface morphology was noted on the carved head fragment from Waim, though it was not considered to be part of a pestle (see Shaw et al. 2020:Fig. S14a–b). Many other formally manufactured implements also bear elaborately carved surfaces, but in this case, the artefact is most likely a combination of both: a pestle with a carved handle (see Swadling 2021).

The original function/use of the artefact could not be determined from the microscopic usewear analysis alone, reinforcing the advantage of a multidisciplinary approach. A lack of distinctive usewear could be related to several factors:

1. We have concluded that the flake represents part of a pestle and is likely to derive from near the junction of the handle and not directly from the working end of the implement. As such, usewear is expected to be minimal, while residues from use are present. If the flake is from a stone carving, then we would expect no usewear or residues.
2. The pestle is made from coarse-grained gabbro (see also Shaw et al. 2020). The hardness of the raw material means that usewear may be slow to develop and hard to recognise. Moreover, the artefact studied here may have been detached very early on in the life-history of the object.
3. It is possible that weathering of the stone surface may have removed or obscured wear traces. The presence of slight but uniform edge-rounding on the flake margins and fracture ridges on dorsal and ventral surfaces indicates partial weathering. However, the microscopic fresh fracture features on the dorsal surface are typical of the deliberate stone-on-stone pecking technique with minimal abrasive smoothing. Chemical alterations were not observed on those surfaces.

Ancient starch

A total of 134 starch grains were analysed from the artefact's pecked surface, of which 121 starch grains were digitised for analysis (Table 18.2, Figure 18.5). Those starch grains which were not digitised (n = 13) and therefore excluded from the analysis were damaged, did not have complete margins or were partially obscured by other tissues/detritus in the slide preparation.

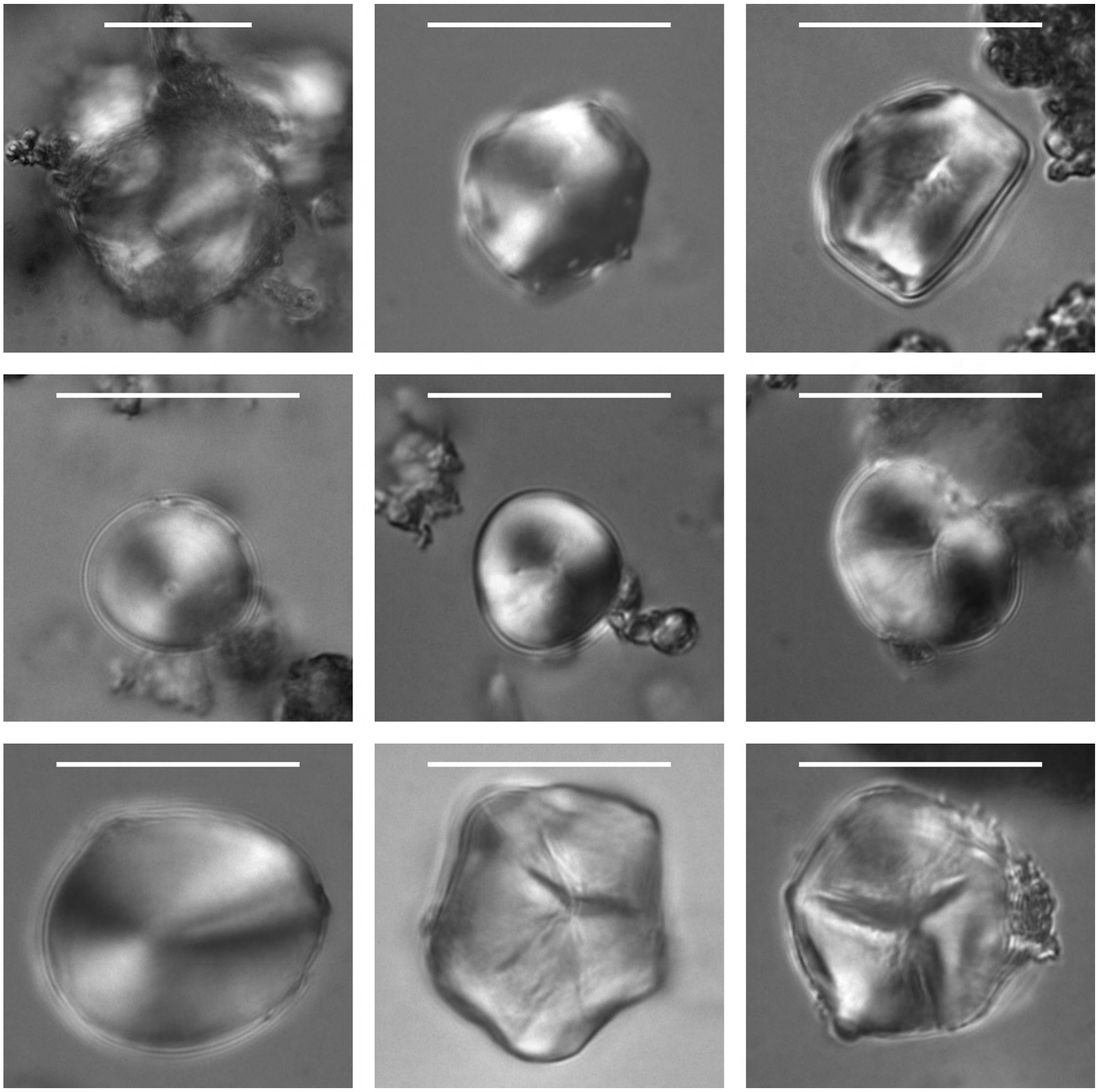

Figure 18.5: A sample of the starch grains recovered from the surface of KAI25-SP7-20cm-bs.

Notes: There is notable dominance in the assemblage of faceted grains with either fissures or pits/vacuoles/open hila. Scale Bar = 20 microns.

Source: Images J. Field.

Modern comparative reference set

A modern comparative reference collection is essential to canvas the size, shape and variability of starches from plants known to be culturally and economically important in the Kaironk Valley and surrounding highland landscapes, which can then be compared with the starch assemblage recovered from the pestle (cf. Field et al. 2020; Shaw et al. 2020) (Table 18.1). The reference collection included plants that are known to be exploited and possibly pounded or ground (see Field et al. 2016, 2020; Hayes et al. 2021). Various sources were used to construct the plant list, and importantly, plants known to have been used in the past, as well as those important in the present day, were included (Coster and Field 2015, 2018). Many plant species that have been exploited by people in the past are still commonly used across the highlands (Bulmer 1964; Gardner 2010; Watson and Cole 1977). The sweet potato (*Ipomoea batatas*), which was introduced c. 300 years ago, is now ubiquitous in the

highland landscape (Roullier et al. 2013). Over the last decade, a database of starch isolated from field collected specimens or from herbaria from Australia, New Guinea and North America has been created at the University of New South Wales Ancient Starch laboratory. Over 32,000 starch grains from a range of plant taxa and archaeological samples have now been added to the starch database, of which c. 23,000 are from 432 samples of modern comparative reference species.

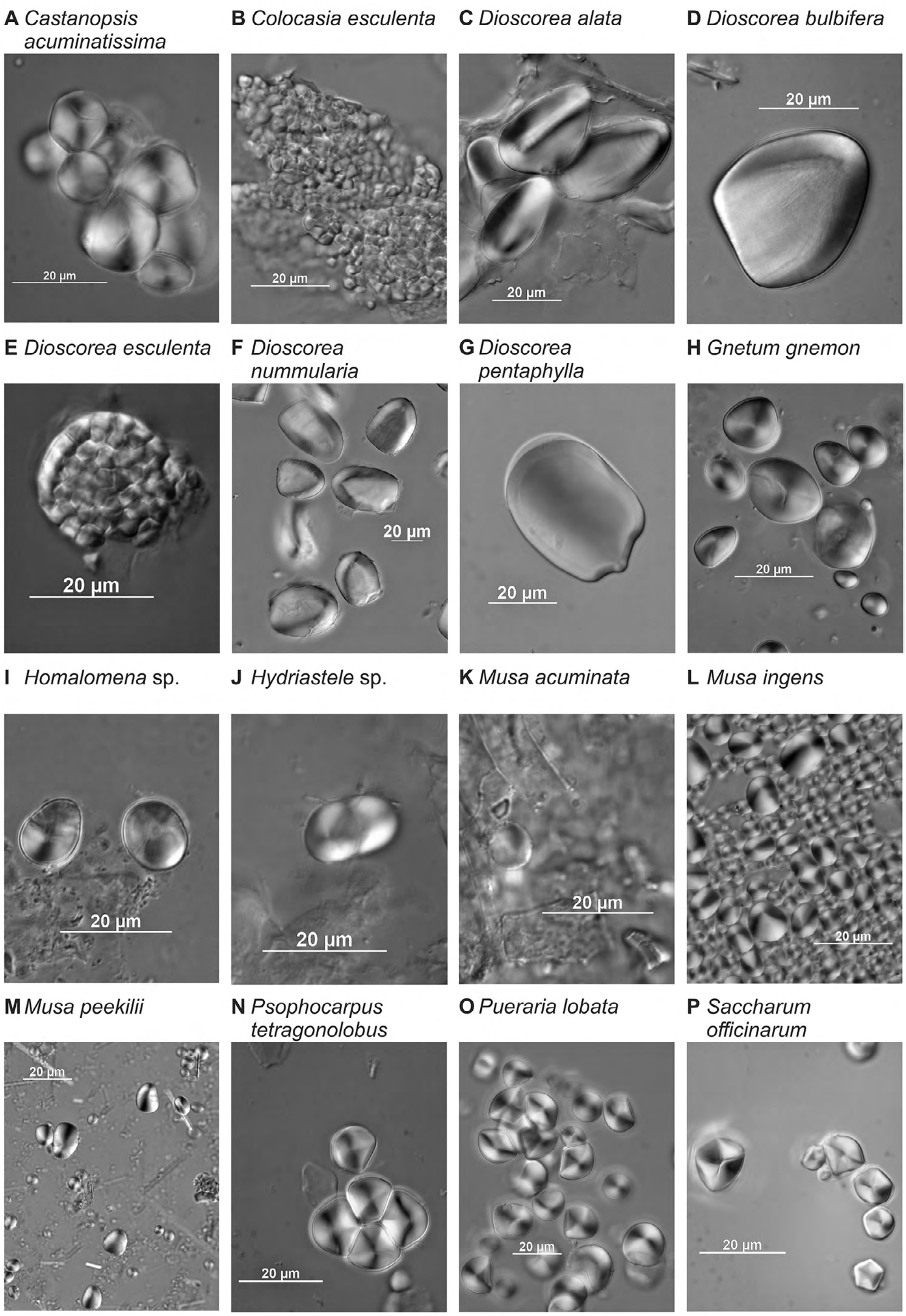

Figure 18.6: Representative examples of starch grains from the comparative reference set used in the analysis of the pestle fragment (KAI25-SP7-20cm-bs), Kaironk Valley, Madang Province, PNG.

Source: Images J. Field.

The inclusion of 17 plant species in this study is based on our general knowledge of starchy plant use in the highlands, and more specifically the flora in the Kaironk/Simbai Valleys (Gardner 2010) (Table 18.1; Figure 18.6). The comparative reference set is conservative, in the sense that the plant list reflects the most likely candidates for the region of interest. As the Simbai–Kaironk are highland fringe valleys, some flexibility was required to account for the potential movement of plants and people between the coastal lowlands and the highland fringe. *Gnetum gnemon* was included as it is a tree species that produces a starchy nut and has an altitudinal range close to the elevations documented in the Simbai–Kaironk Valleys (see also *Dioscorea esculenta* and *D. pentaphylla)*. Sago (*Metroxylon sagu*) was not included, despite the proximity of coastal lowlands where it is used, primarily because it has very distinctive and diagnostic morphologies and that were not observed in the starch residues recovered from the pestle fragment.

Refining the comparative reference set

The range of metrics plotted for all the starch grains in the study are presented in Figures 18.7 and 18.8. Of these metrics, the maximum diameter through the hilum (MaxD) (Figure 18.7) assessed in the first pass through the data, often facilitates the elimination of non-contributing reference species (see Coster and Field 2015). For this study, the range of starch grain attributes identified in the KAI25 sample meant that further refining of the comparative reference sample was required.

To further reduce the number of potential contributing plant species to the unknown sample, the analysis of normalised grain shapes was undertaken. It allowed us to explore overall grain shape variability independent of size in both the reference set and for the unknown archaeological sample. The normalisation of grains shapes effectively reduces anomalous within-species variations due to small differences in growth stage and size and was determined by scaling each grain so that the average radius about the hilum was one. The normalised grain shapes were then rotationally aligned about the grain hila, minimising the radial distance between the grains within each of the species and unknown archaeological sample.

Variability in normalised starch grain shapes was further explored by the identification of within-sample subgroups across the archaeological and comparative reference set (see Hayes et al. 2021). Normalised grain shapes were compared within-species using hierarchical clustering (average distance between radii about the shapes) to determine whether there were distinct subgroups of grain shapes within the sample. Subgroups of the sets were determined using a cut-off equal to 0.25 of the maximum separation across all grains (from all reference species and archaeological samples). All starch grains (reference species and archaeological samples) were subgrouped using this cut-off to ensure uniform within-subgroup similarity. Subgroups were denoted by adding the subgroup number to the end of the sample name, such as KAI25-SP7-20cm-bs pestle frag-1, KAI25-SP7-20cm-bs pestle frag-2 and KAI25-SP7-20cm-bs pestle frag-3. The same suffix labelling was used for the reference species.

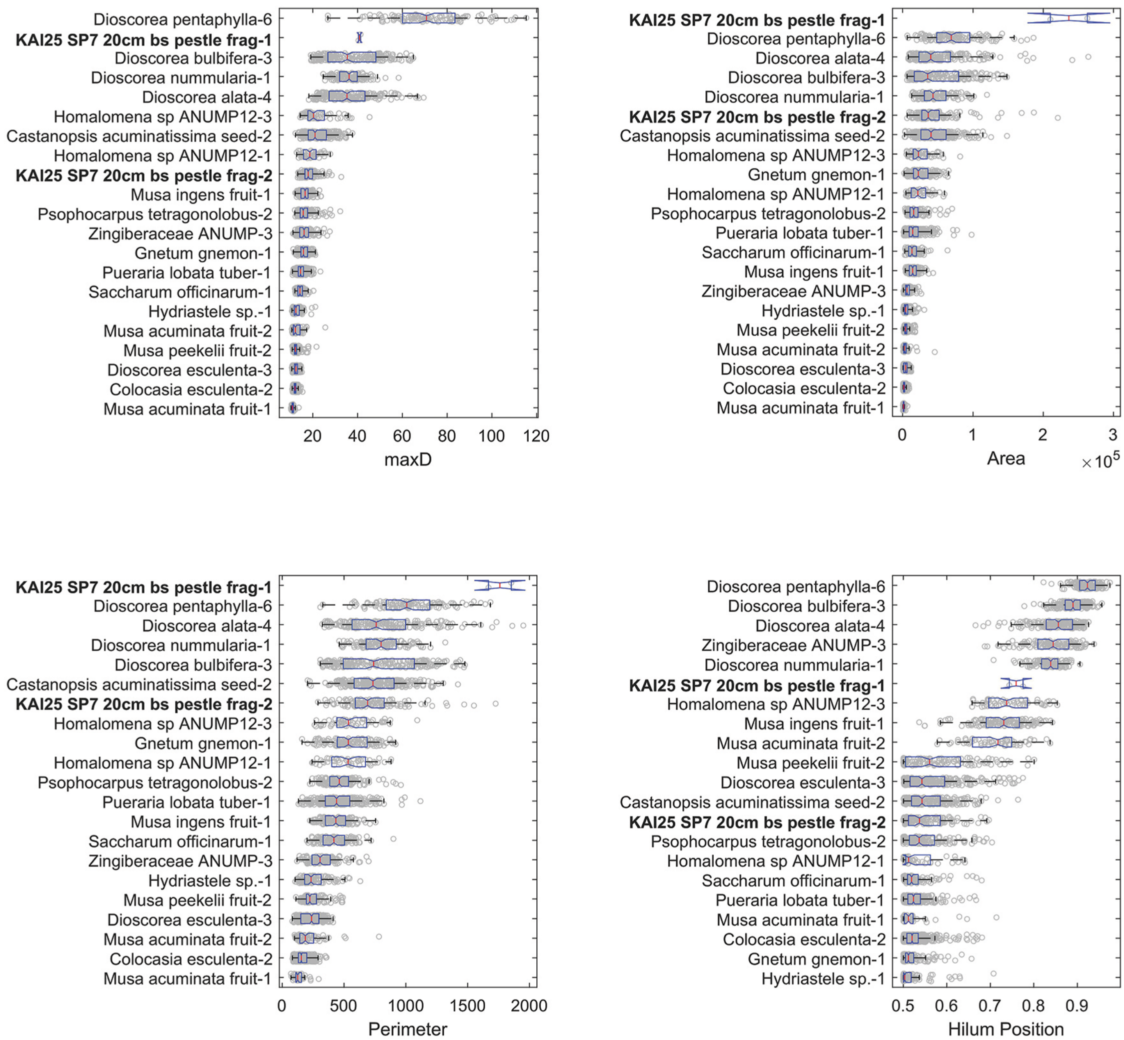

Figure 18.7: Box plots of maximum diameter through the hilum, MaxD, starch grain area, starch grain perimeter and starch grain hilum position for the comparative reference set and the archaeological samples KAI25-SP7-20cm-bs (indicated in bold).

Notes: The subgroup KAI25-SP7-20cm-bs pestle frag-1 contained only two starch grains and was not further analysed. All the data points are shown. The boxes indicate the values of the data quartiles q_1, q_2 and q_3. The whiskers indicate the re-transformed range of less than $q_3 + 1.5(q_3 - q_1)$ and greater than $q_3 - 1.5(q_3 - q_1)$.

Source: Illustration by Adelle Coster.

The distributions of the macro-scale metrics (maximum diameter through the hilum, area, perimeter and hilum position—a measure of the offset of the hilum from the grain centre) for each of the reference subgroups with greater than 25 grains were compared to the archaeological samples (cf. Hayes et al. 2021) (Figure 18.7). Note the subgroup KAI25-SP7-20cm-bs pestle frag-1 contained only two starch grains and was not further analysed. The subgroup KAI25-SP7-20cm-bs pestle frag-2 however, contained 118 grains, the macro-scale metrics of which also indicate a large degree of similarity within this subgroup across these measures—and that it may be largely composed of a single species.

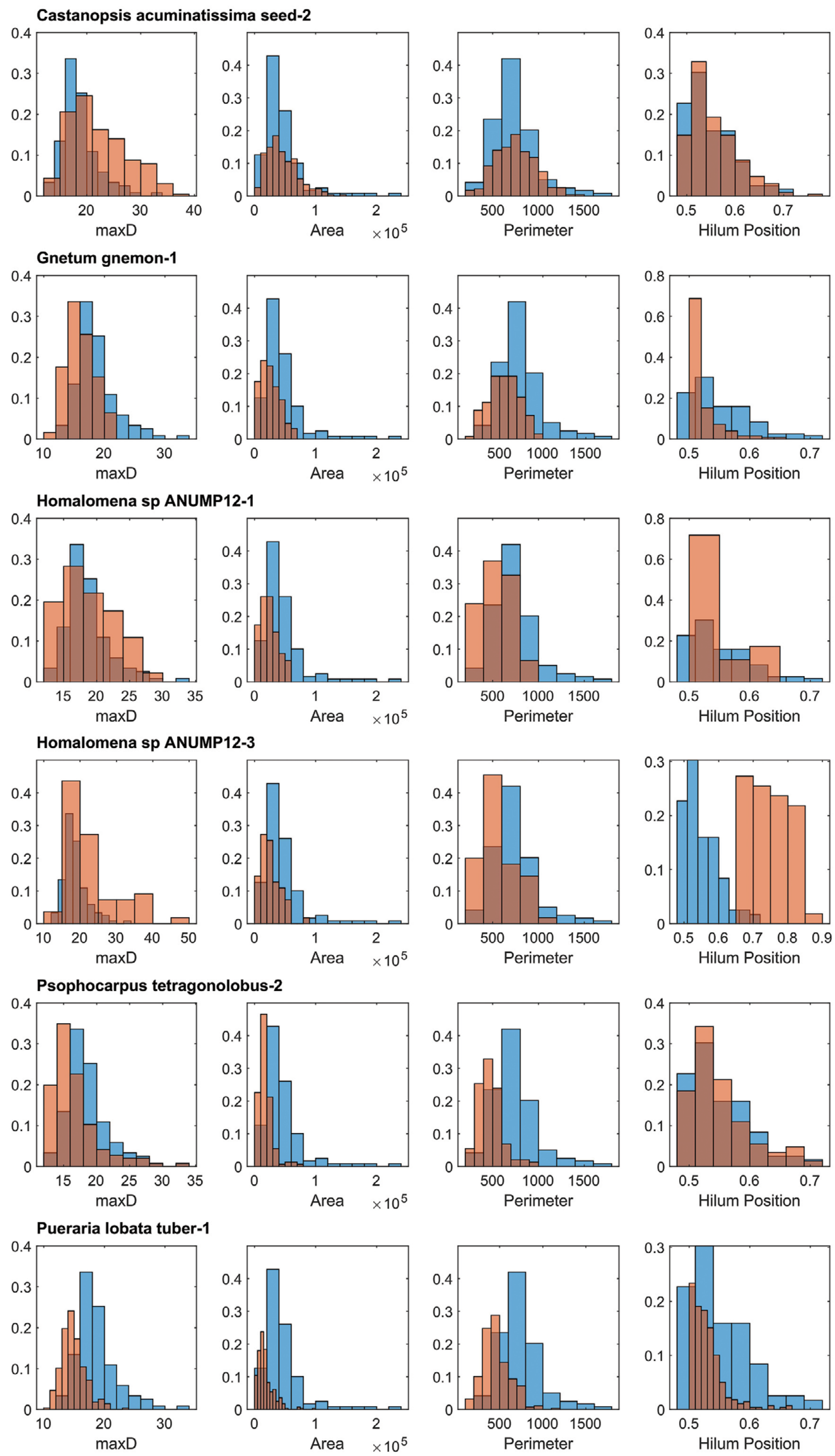

Figure 18.8: Histogram plots of size metrics.

Notes: The plots show maximum diameter through the hilum, area, perimeter and hilum position for the populations of grains comparing the archaeological sample with the five species that have the best overlap with the unknown sample: *Castanopsis acuminatissima* seed-2; *Gnetum gnemon*-1; *Psophocarpus tetragonolobus*-2; *Homalomena* sp. ANUMP12-1; Homalomena sp. ANUMP12-3; *Pueraria lobata* tuber-1. KAI25-SP7-20cm-bs is in blue, reference species in orange.

Source: Illustration by Adelle Coster.

Six subgroups were identified as having significant overlaps across all the macro-scale metrics with the larger unknown subgroup (KAI25-SP7-20cm-bs-2, 118 grains): *Castanopsis acuminatissima* seed-2, *Gnetum gnemon*-1, *Psophocarpus tetragonolobus*-2, *Homalomena* sp. ANUMP12-1, *Homalomena* sp. ANUMP12-3 and *Pueraria lobata* tuber-1.

The proximity of the archaeological (KAI25-SP7-20cm-bs) assemblage and *C. acuminatissima* across the four metrics indicate their close association and overlap. *Homalomena* sp. is also in close proximity to the KAI25 sample for MaxD. *D. pentaphylla* overlaps in the outlier grains for this metric but is unlikely to be a contributing species. There was also good correspondence in area between the archaeological sample and *C. acuminatissima*. The intervening *Dioscorea* samples do not match when compared using other attributes. The hilum position of *C. acuminatissima* and KAI25 assemblages completely overlap, whereas the large *Dioscorea* groups are clearly differentiated on this measure. *Homalomena* does overlap in hilum position as do the two *Musa* species and *D. esculenta*, however *D. esculenta* and *M. acuminata* can be excluded as dominant contributors to the archaeological assemblage due to the size of the grains.

Histogram plots of the unknown grains overlaid with the six identified subgroups illustrate the overlaps in the distributions of the macro-scale metrics (Figure 18.8). The remaining reference subgroups had distinctly different metric distributions over one or more of the attributes and were excluded from further comparison.

The six reference subgroups were then analysed to determine the similarity of characteristics with the archaeological grains. For each unknown archaeological starch grain, and each reference subgroup, the five closest matching grains, based on the normalised grain shape, were then independently verified (by JF) in which the correspondence was evaluated of the non-quantitative grain characteristics in the micrographs to those of the reference species (Note that categorical features were not used in the identification of the matching references.). The analysis focused on the removal of non-attributable species based on a population analysis of the samples (recalling that the samples were determined with uniform within-group similarity of their normalised shapes). Thus, for each reference subgroup, the proportion of unknown grains that could not be attributed to that species was determined, with some archaeological grains being attributed to more than one reference subgroup. The attributions of the KAI25-SP7-20cm-bs-2 archaeological subgroup is shown in a Venn diagram (Figure 18.9). Note that the two *Homalomena* subgroups (although distinct in shape) have been combined in this figure. Of the 118 unknown grains, 68 unknown grains (57 per cent) were attributed to *C. acuminatissima* (42 of which were to only *C. acuminatissima*), 28 were not attributed to any of the species (24 per cent), and 22 were attributed to species other than *C. acuminatissima* (19 per cent) (see Figure 18.9).

When all the metric distributions of the grains were examined (Figures 18.7–8), along with visual verification and population attribution (Figure 18.9), the best correlation of the archaeological assemblage is to *C. acuminatissima*. The species attribution does not necessarily hold for all the grains in the archaeological sample, but certainly accounts for the majority of the features documented, reinforcing the conclusion that *C. acuminatissima* is the primary contributor to the archaeological assemblage.

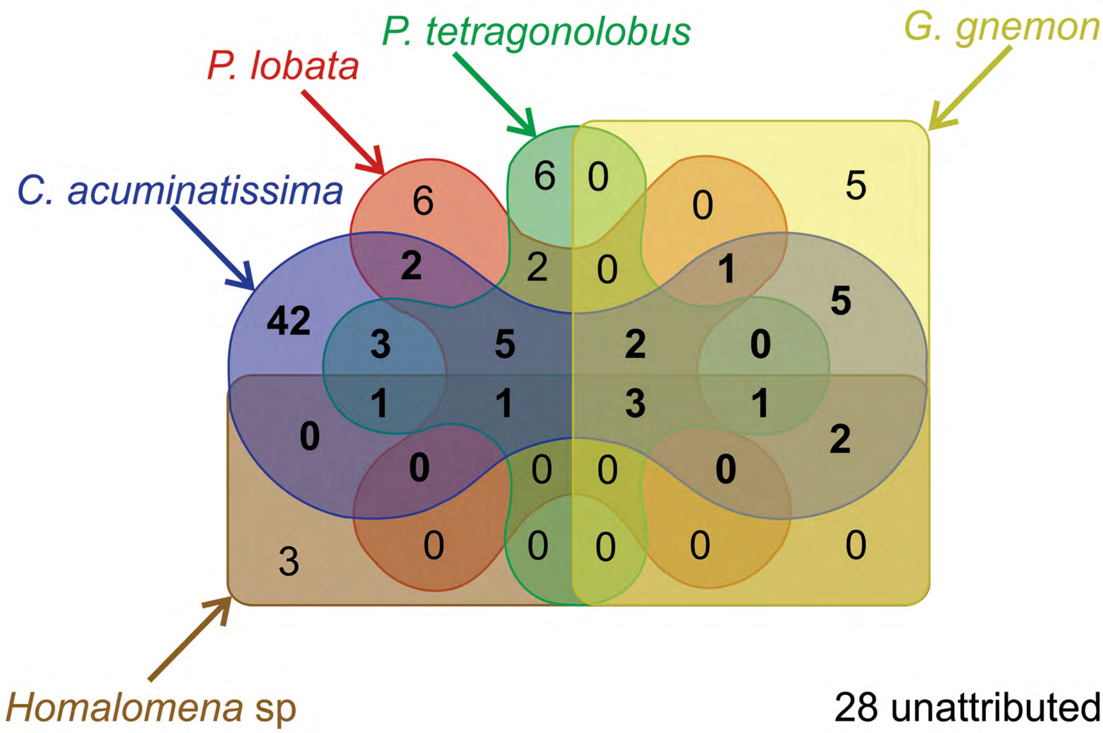

Figure 18.9: Venn diagram indicating the number of grains of the KAI25-SP7-20cm-bs-2 artefact sample attributed to species in the reference set.

Notes: *C. acuminatissima* attributions are shown in bold. The colours of the species names shown on the diagram correlate to the colours in the Venn diagram. In several cases, the starch grain features (size, hilum position, shape and surface morphologies) are shared between some species making it difficult to differentiate between them. Where a starch grain cannot be differentiated from another species, then these are shown as an overlap with that species. For example, 42 of the starch grains have been solely attributed to *C. acuminatissima*. The remaining numbers shown in the purple 'dumbbell shape' represent starch grains that are indistinguishable from *C. acuminatissima* and one or more of the other species in the reference set. For instance, two grains of *P. lobata* share common features with *C. acuminatissima* (upper left), while five grains share similarities with *P. tetragonolobus*, *P. lobata* and *C. acuminatissima* (centre left). It was found that 28 of the 118 grains analysed could not be attributed to any species in the reference set.

Source: The base intersections for the figure were adapted from output of the Venn diagram tool at and prepared by Adelle Coster.

Discussion and conclusion

Starchy tree nut use and human diet

Functional studies of stone artefacts, particularly ancient starch analyses, have opened an important window on understanding the long-term exploitation and use of starchy plant resources in a broad range of archaeological contexts (e.g. Fullagar et al. 2008; Liu et al. 2010; Nadel et al. 2012; Piperno 2004). Starchy tree nuts were widely used globally in the Holocene, some requiring either simple or complex processing to render them edible and/or palatable, and have been recognised as an important component of human diets (e.g. Basgall 1987; Liu et al. 2010; Pedley 1993; Rosenberg 2008).

The complex processing of toxic starchy tree nuts has been employed since the early–mid-Holocene in the North Queensland rainforests (Cosgrove et al. 2007). Other plant foods requiring comparable preparation methods (e.g. *Cycas* seeds) have a similar or even a greater antiquity of use in Australia (Asmussen 2011; Beck 1992; Smith 1982). Archaeological sequences in rainforest sites contain abundant carbonised shell remains (Cosgrove et al. 2007; Horsfall 1996), as the hard outer shells (endocarp) of tree nuts (primarily family Lauraceae) were discarded after baking in ground ovens and prior to pounding then leaching in running water. Ancient starch studies have demonstrated that these nuts were pounded on the formal manufactured slate pounding/grinding stones called 'morahs' (Field et al. 2009, 2016). Similarly, in North America, China and the Near East, archaeological studies have documented the use of starchy tree nuts (acorns) from oaks in the family Fagaceae, which also required complex processing to render them edible (e.g. Basgall 1987; Liu et al. 2010; Rosenberg 2008). The tradition of exploiting starchy tree nuts that contain chemicals acting as toxins or irritants appears to be common across a range of environmental contexts and continents, and New Guinea is no exception.

Tree nuts and the New Guinea Highland mortar and pestle complex

The New Guinea member of the Fagaceae (oak) family, *Castanopsis acuminatissima,* produces starchy nuts that are generally recorded as being roasted before consumption. They have been reported as eaten raw or cooked (Bulmer 1964), but Swadling has noted from other reports that if eaten raw, 'doing so can cause anaemia, emaciation and mouth ulcers' (Swadling 2021 and references therein). In New Guinea, *C. acuminatissima* nuts are widely available during the wet season and may have been exploited opportunistically and continue to have a place in modern diets. *C. acuminatissima* endocarps are thin, easily removed and discarded, and evidence of their long-term use has come from the identification of use-related residues (starch grains) on stone artefact surfaces (e.g. Field et al. 2020). The discovery of *C. acuminatissima* residues in the current and recent studies has effectively focused our attention on the importance of starchy tree nuts in highland diets from at least the mid-Holocene. When *C. acuminatissima* starch grains have been identified on tool surfaces, the indications are that they were routinely pounded, along with other starchy plants. In the study presented here, the evidence unequivocally confirms the association of *C. acuminatissima* tree nuts with the mid-Holocene Highland mortar and pestle complex.

The decline in the use of stone mortars and pestles in the Late Holocene has been argued to be a response to the decline in *C. acuminatissima* availability due to forest clearance and decreasing connectivity with the coast, the latter associated with the contraction of the Sepik inland sea (Bulmer 1964; Swadling 2021; Swadling and Hide 2005). Nonetheless, *C. acuminatissima* is still widely exploited in highland communities as a traditional food, with the potential to supplement diets in times of drought or other environmental disruptions, as observed for *Pueraria lobata* (Allen and Bourke 2009). The question remains as to whether the decline of mortars and pestles is linked to the arrival of Lapita cultural groups around 3300 years ago. The appearance of pottery and associated technologies in the region may have had a significant impact on methods of food use and preparation and appears to be broadly coincident with decline and subsequent disappearance of the stone mortar and pestle complex (see Gaffney et al. 2015).

The Upper Kaironk pestle fragment

Despite its fragmentary nature, the usewear and technology analyses of the Imbiben artefact have suggested it is part of a formally manufactured pestle, other carved stone object, or a pestle with a carved handle. However, the 'multidisciplinary' approach used here (see Fullagar et al. 1996), which considers a number of lines of evidence—stone raw material, technology, usewear, the tool's life-history and the starch residues—leads us to conclude that the artefact is indeed a fragment from a pestle.

The pestle fragment may be the result of an early break soon after manufacture, in which case usewear associated with plant processing would not have been well developed as it was not subject to high contact with a mortar or working surface. The lack of distinctive usewear is likely a consequence of the fragment origin, namely from the junction of the handle and the working end, where the dominant wear would be from manufacturing rather than use and where abundant residues might be expected with the immersion of the pestle in soft plant tissue. *Castanopsis acuminatissima* starchy nuts were processed along with other starchy plant species as seen in the Waim and Joe's Garden studies.

There are now functional studies of four examples of excavated finds of the mortar and pestle complex from the New Guinea Highlands. Three examples were recovered during the current project, supporting the proposition by Bulmer (1964) that mortars and pestles were used for pounding tree nuts, in this case *C. acuminatissima*. More recently, it was proposed that *Colocasia esculenta* (taro) may have been processed with these implements, mainly because of their co-occurrence with gardened areas (Swadling and Hide 2005). Residue studies have identified *Colocasia esculenta* on at least one flaked stone artefact (K76 S29B) recovered from the Kuk Swamp sediments (Fullagar et al. 2006), but to date there has been no empirical evidence that taro was pounded with mortars and pestles in the highlands. Functional analyses of pestles and mortars from lowland contexts will undoubtedly expand our understanding of the range of uses and associated tasks.

When Ralph Bulmer (Bulmer 1964) first published his paper speculating on the range of tree nuts that may have been processed with mortars and pestles, the notion that techniques and methodologies would be available to accomplish these identifications was beyond consideration. While these methodologies are now developing, the ancient starch analyses undertaken here are complex, time consuming and under continual development as we pursue a quantitative and transparent approach to identifying plant taxa from unknown starch grains. It is a robust and replicable method for identifying the remains of starchy plant processing on these tools. Essential to identifying the pestle fragment described here was the multidisciplinary approach. Usewear, technology and residue analysis combined can provide a high level of confidence that each method on its own may not provide.

In conclusion, the confirmed use of *C. acuminatissima* at Imbiben adds to our understanding of the role of tree nuts in the diet of highlanders from at least the Mid Holocene. Even after the changes wrought following the arrival of Lapita cultural groups just over three millennia ago, the introduction of sweet potato in the 1700s, and despite the well-documented land clearing, traditional foods such as *C. acuminatissima*, *Pandanus* sp., taro and other starchy plants have continued to be a constant in the diets and traditions of highlanders to the present day. As new research investigates the nature of plant foods and technological changes over time, a clearer picture of highland settlement and resource use will also emerge, challenging both current discourse and approaches to archaeobotanical studies in these unique environments.

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