Hafted Tool-use Experiments with Australian Aboriginal Plant Adhesives: Triodia Spinifex, Xanthorrhoea Grass Tree and Lechenaultia divaricata Mindrie

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V. Rots (BE),
E. Hayes (AU),
K. Akerman (AU),
P. Green (AU),
C. Clarkson (AU),
C. Lepers (BE),
L. Bordes (FR),
C. McAdams (AU),
E. Foley (AU) and
R. Fullagar (AU)

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Hafted stone tools commonly figure in Australian archaeology but hafting traces and manufacture processes are infrequently studied. The Aboriginal processing of resin from *Xanthorrhoea* (Sol. Ex Sm.) grass tree, *Triodia* (R.Br.) spinifex and *Lechenaultia divaricata* (F.Muell.) mindrie, is reported with experiences and observations about the performance of resin mixtures in hafted tool-use experiments. Pure mixtures of winnowed *Triodia* grass, though soft, were more effective as a sticky adhesive than lumps collected from ant nests or the ground following bushfires. *Xanthorrhoea* resin mixed with kangaroo dung and charred wood was effective, though brittle, and re-heating made it less sticky and more brittle. Mindrie root mixed with kangaroo dung and ashes proved highly effective. *Triodia, Xanthorrhoea* and *Lechenaultia* resins have different adhesive properties, and the resin sources, additives and processing techniques all affect how and when hafts break.

Introduction

Although hafts or handles are not necessary for most functions, stone tools were frequently modified by adding a grip to comfortably secure the tool for handheld use or by attaching a handle for mechanical or other advantages. Other tasks necessarily require hafting—e.g., stone lacerators and spear tips, being fixed to shafts, are by definition ‘hafted’, and stone hatchet heads are often designed for particular types of handles (e.g., socketed, cleft stick or wrap-around). Suitable adhesives, fillers and bindings are all essential considerations when constructing an effective handle or haft for stone tools.

Reliable identification of hafting traces in the archaeological record is important, particularly for evaluating the evolution of human cognition and also for understanding the range of human needs and responses to tool stone availability, specific environmental conditions and climate change (e.g., Stordeur 1987; Mazza et al. 2006; Rots, 2010; 2015; Iovita and Sano, 2016; Lombard, 2016). Barham (2013) argued that the invention of hafting by early hominins marked a revolution in technological development, requiring a certain level of ingenuity that encouraged social interaction and learning. Hafting also provided a means to enhance supplies of food and other resources. Aside from the timing when hafting was invented, there is a need to understand the associated technologies (e.g., heating and mixing adhesives, fibre technology, haft configurations, stone tool technology, organic tools) to explain how, where and why hafting was adopted in particular contexts.

Hafting has been an important concept in the construction of typological phases in Australian prehistory, particularly in the Holocene (e.g., Mulvaney and Kamminga, 1999) - yet analyses of hafting traces by integrating usewear and residue traces, tool technology and the refitting of stone artefacts are not common in Australia (but see Akerman, Fullagar and van Gijn, 2002; McDonald et al., 2007). In an experiential study, observations are reported from a hafting workshop (December 2016), designed to gain experience in utilising experimental tools hafted with

Aboriginal adhesives, and to broaden the focus of hafting studies in Australia by examining the effectiveness of adhesive mixtures, hafting arrangements, breakage and traces (usewear and residues) linked with production and use. The aims here are to: (1) review Aboriginal processing of three recorded adhesives (*Triodia*, *Xanthorrhoea* and *Lechenaultia*); and (2) summarise observations about these resins as hafting media. Further details of the experimental usewear and residue patterns will be reported in a later paper.

Aboriginal Hafting Adhesives

Australian Aboriginal people hafted stone tools using adhesives harvested or extracted from plants in various forms (e.g., resins, gums) or animal products (e.g., beeswax); and bindings, which were also made from either plant (e.g., root and bark fibres) or animal products (e.g., sinews). The extraction and processing of some of these hafting components have been described previously (e.g., Dickson, 1981, 65ff, 163ff; see below), but determining reliable details about specific processes can be complex (See Appendix). Philip Green has documented 78 plant species (28 genera) that are potentially utilised by Aboriginal people in Australia for hafting adhesives (See Table 1; see also Boot, 1990). Green (nd) also compiled various methods of harvesting, and has processed at least 22 plant species adhesives, detailing recipes for mixing fibres (e.g., dried macropod faeces), sediment, ash and other additives that act as a temper or agent for controlling brittleness and pliability.

Genera	**Species**
Acacia	*craspedocarpa*
Acacia	*dealbata*
Acacia	*elata*
Acacia	*harpophylla*
Acacia	*homalophylla*
Acacia	*irrorata*
Acacia	*loderi*
Acacia	*mearnsii*
Acacia	*minyura*
Acacia	*oswaldii*
Acacia	*peuce*
Acacia	*pycnantha*
Acacia	*rivalis*
Acacia	*salicina*
Acacia	*victoriae*
Agathis	*microstachya*
Agathis	*robusta*
Allocasuarina	*leuhmanii*
Araucauria	*bidwilli*
Araucauria	*cunninghamii*
Brachychiton	*populneus*
Callitris	*bailyei*
Callitris	*canescens*
Callitris	*columellaris*
Callitris	*endlicheri*
Callitris	*glaucophylla*
Callitris	*gracilis*
Callitris	*intratropica*
Callitris	*macleayana*
Callitris	*preissii*
Callitris	*rhomboidea*
Callitris	*verrucosa*
Canarium	*australanium*
Ceratopetalum	*gummiferum*
Corymbia	*eximia*
Corymbia	*gummifera*
Corymbia	*maculata*
Eremophila	*galeata*
Erythrophleum	*chlorostachys*
Eucalyptus	*camuldulensis*
Eucalyptus	*crebra*
Eucalyptus	*microcarpa*
Eucalyptus	*radiata*
Eucalyptus	*sideroxylon*
Flindersia	*maculata*
Ficus	*virens*
Grevillea	*robusta*
Grevillea	*striata*
Hakea	*gibbosa*
Hymenosporum	*flavum*
Lechenaultia	*divaricata*
Melicope	*elleryana*
Melicope	*bonwickii*
Myoporum	*platycarpum*
Nuytsia	*floribunda*
Owenia	*acidula*
Pittosporum	*angustifolium*
Polycias	*murrayi*
Syncarpia	*glomulifera*
Triodia	*pungens*
Xanthorrhoea	*acanthostachya*
Xanthorrhoea	*acaulis*
Xanthorrhoea	*arborea*
Xanthorrhoea	*australis*
Xanthorrhoea	*drummondii*
Xanthorrhoea	*glauca*
Xanthorrhoea	*johnsonii*
Xanthorrhoea	*latifolia*
Xanthorrhoea	*malacophylla*
Xanthorrhoea	*media*
Xanthorrhoea	*platyphylla*
Xanthorrhoea	*preissii*
Xanthorrhoea	*quadrangulata*
Xanthorrhoea	*resinosa*
Xanthorrhoea	*semiplana*
Xanthorrhoea	*tateana*
Xanthorrhoea	*thorntonii*
Wollemi	*nobilis*

Table 1. Australian plants with adhesive exudates (Green nd).

Aboriginal use of *Xanthorrhoea*, *Triodia* and Lechenaultia Resins

Xanthorrhoea Sol. ex Sm.
Xanthorrhoea resin was used widely by Aboriginal people in Australia (e.g., Maiden, 1889; Cribb and Cribb, 1982; Kamminga, 1982) and has been identified on recently collected items in museums (e.g., Blee et al., 2010; Bradshaw, 2013; Matheson and McCollum, 2014) and reported on archaeological tools (e.g., Boot, 1990).

The Atlas of Living Australia lists at least 30 species of *Xanthorrhoea* (a monocot, although commonly called 'grass tree'), which is widespread in eastern and southwestern Australia (especially on coastal margins) with a very patchy distribution in the arid zone and absent in most northern areas (See Figure 1). Green collected resin from 17 species of *Xanthorrhoea* (See Table 1, Figure 2). Some of the other species do not have above ground caudexes (trunks) and are not useful for resin collection. The name *Xanthorrhoea* means 'yellow flowing', referring to the yellow resin typical of the genus. The species in early records are often uncertain. Moore (1884, p.6) refers to at least two utilised varieties in the Southwest, including one that is apparently stronger (*Xanthorrhoea drummondii* Harv.):

"*Barro, s.—The tough-topped Xanthorea [sic] or grass-tree, from which the strongest resin, the Kadjo, exudes; that which the natives use for fastening on the heads of their hammers …"*

Most species of *Xanthorrhoea* were likely utilised by Aboriginal people in the past. In 1865, Oldfield (2005, p.46) published an account of *Xanthorrhoea* collection and processing near the Murchison River mouth, Western Australia:

"*… These flints fit into a cavity formed in the end of the stick, and to keep them firmly in their places, the natives use a cement made from the gum of the Grass tree (Xanthorrhoea). In the manufacture of this substance (called Ty-a-lo by the Watchandies), as in the practice of all their other simple arts, much time and labour are consumed. Having collected a quantity of the crude gum-resin (which being liquified by the bush fires, is accumulated at the bases of the plants), they return to the camp and proceed to fit it for use. The gum, as collected, is of a dark brown red colour, very nearly opaque, and exceedingly brittle. The first operation consists in making it sufficiently hot that it may be kneaded by the hands, and this process of warming and kneading, varied occasionally by drawing it into long strings and then making it up into a ball, is continued until the substance entirely changes its appearance, becoming of a bright brick-red colour and perfectly opaque, and in this state also it is rather brittle, and is only used for finishing off the points of their fishing spears. It undergoes no farther manipulation until in immediate requisition as a cement. When required for fixing the flint into the do-wak, the peg into the wamra, or for any similar purpose, for which, a cement of great tenacity is required, the final operation is as follows: -A sufficient quantity being taken from the mass prepared as above, it is again melted and a quantity of finely powdered charcoal gradually worked into it, the substance being kept in a nearly fluid state during the whole operation, and applied to the required purpose while in that condition. When cold, it is very hard and tenacious, and almost metallic in its appearance, nor does it again fuse readily after being once perfectly set*."

Nyungar people of southwest Australia collected balls of *Xanthorrhoea* and pounded them with rocks to create powder that was then mixed with kangaroo dung and crushed charcoal. Mixing *Xanthorrhoea* with charcoal or ashes is reported in several early accounts (e.g., Moore, 1884, p.70; Curr, 1886, p.329; Hammond, 1933, p.37) while mixing with other additives (e.g., fine dust, sand and beeswax) was reported by Cribb and Cribb (1982, p.89), expressly for hafting stone axe heads to handles and stone spear tips to shafts. The resin mixture was built up on heated rocks, moulded firmly to the stone and attached to the handle. Clarke (2015) noted that while the mixing of *Xanthorrhoea* resin with animal fats and beeswax have been reported, he thought it more likely '*… that powdered charcoal, human hair, animal fur or dry kangaroo dung was used, as these are materials that act as fillers reinforcing the binding medium'* (Clarke, 2012, pp.134,137).

Triodia R.Br.
Triodia spinifex (including plants formerly classified as *Plectrachne*) is a versatile grass that provides food (in the form of seeds), fibre (from leaves) and resin (leaf cell exudate) (Gamage et al., 2012; Pitman and Wallis, 2012; Powell, Fensham and Memmot, 2013; Hayes et al., 2018). *The Atlas of Living Australia* lists 72 species of *Triodia*. The 'soft' resin-producing spinifex species occur in the northern half of Australia and dominates plant communities in the northwestern areas and, despite some overlap, is mostly found in inland and northwestern areas where *Xanthorrhoea* is absent (Fig 1 and Fig 3). Early use of *Triodia* resin is suggested at Carpenter's Gap 1, in the form of basal culms of grass stems identified as *Plectrachne* genus, by about 40 ka (O'Connor and McConnell, 1997; McConnell, 1998, pp.26–27).

Black ants, recently re-classified as *Ochetellus flavipes* (Kirby), have a symbiotic relationship with the Triodia and coccid larvae that exude lerp (Morton and Christian, 1994), which accumulates on the leaves as a white mass, signallingthat the plant is a good source of resin. Details of *Triodia* resin processing vary, but threshed and winnowed *Triodia* leaves provide the best adhesive qualities (See Appendix). The use of ant-derived *Triodia* resin for an adhesive probably became common only recently, and yields an inferior adhesive because of the mixing with sand and over-heating (see also Latz, 1995). Nevertheless, burnt and unburnt ant-derived resin was probably used in the past (notably in the Pilbara), although it would have been more suitable as filler or for protecting sinew lashings than for use as an adhesive.

Lechenaultia divaricata F.Muell.
Lechenaultia divaricata occurs in Central Australia (Atlas of Living Australia), and is known as 'mindrie', 'tangled leschenaultia' and 'wire-bush' (See Figure 4; see Clarke, 2012, p.147). A botanical specimen of the root, documented in Museum of Arts and Applied Sciences (https://collection.maas.museum/object/222916), was collected by Professor Ralph Tate during the Horn Expedition to Central Australia, 1894. Horne and Aiston (1924, p.102), referred to mindrie (1924, pp.102–106):

"*…mindrie is a wiry, bush-like plant that grows in the swampy holes on the plains. To get the gum the blacks dig up the roots, scrape them down with a stone knife until they are all scraped away; then they put the result (it looks like wet sawdust) in the hot ashes. Sometimes they hold the frayed-out roots over the fire. The gum then forms in small lumps, and these are carefully raked out of the ashes to be pressed up into a ball with a mixture of kangaroo dung…* (p.106, Figure 76)"

"…The roots are then held over a fire until a black, pitchy substance oozes out. This is scraped off with a stone knife into a pirrha (wooden bowl) until enough for the work in hand is collected. The whole lot is then mixed with ashes and kangaroo dung and heated in the ashes until well mixed. It is then made into a ball and left to cool. When cool it is almost stone hard. For use this is again warmed up in the ashes, and sufficient is taken from the ball for the work needed. The mindrie softens with heat. It is heated until workable, and a strip is placed over the end of the koondi ; by this time it has hardened up again, so it is returned to the ashes. Directly it is soft enough it is taken out and worked into a ball on top of the koondi. The worker licks his hands all the time to prevent the mindrie from sticking to them. The selected tuhla is now held ready, and when the mindrie has softened sufficiently the base of the stone is pushed into it until it rests on the end of the koondi; it is usually too hard again by this time, so is given a final heating to finish it off; this is done by wetting the hands with spittle and rubbing gently all around the tuhla, pressing the mindrie tightly into any inequalities that may be in the stone. The tool is now ready for use and is called a koondi tuhla … (pp.102–3)."

Hafting Experiments

Tool-use experiments (See Tables 2–5) focused on the two hafting media (*Triodia* and *Xanthorrhoea*) and utilised a range of fine and coarse-grained microcrystalline tool stones, including grey flint from the South Australian coast (Nene Valley); yellow chert from the Barkly Tableland, Queensland; silcrete from the south coast New South Wales; quartzite cobbles from the Clyde River (Yadboro Flats, New South Wales); and some exotic fine grained stone from the southern USA (uncertain provenances). The edge-ground hatchet heads were made of fine-grained basalt from the Moondarra quarry, Queensland.

Tools*	**Flint / Chert**				**Silcrete**	
Hafting media	*Xanthorrhoea*	*Triodia*	*Xanthorrhoea* + *Triodia* repair	*Lechenaultia divaricata*	*Xanthorrhoea*	*Triodia*
Knives	8	4	0	0	3	4
Transverse	6	1	0	0	5	0
Drills	3	4	0	1	0	2
Tula	4	4	1	0	0	1
	21	**13**	**1**	**1**	**5**	
Projectiles	31	34				
Grip		3				
Hatchets (basalt)		3				

Table 2. Tool use experiments and hafting media.
*Handheld tools in experiments comprise 14 flakes without grips or handles and were used to remove bark and scrape wooden handles.

Experimental tools consisted of several implement classes known archaeologically and, with the exception of backed microliths, also known ethnographically in Australia. They included: unretouched handheld flakes (n=14, Table 3), unretouched flakes with a resin grip (n=30), backed microliths (n=34, Table 4), tula adze flakes (n=10), retouched points (n=60, Table 5) and edge-ground hatchets (n=3) (See Figure 5 and 6). Tools were used to process a range of materials, including wood (*Toona Australis,* tea tree) and kangaroo (*Macropus fuliginosus*) tail, skin and bone (See Figure 5). Tools were used until they broke or the edges became ineffective.

The backed microliths were hafted on wooden sticks for use in three orientations: (1) Chord exposed and transversely hafted on the end of a stick (used for cutting and scraping (i.e., low angle pushing motion) tasks) (See Figure 6a); (2) A portion of the tip and chord exposed and hafted longitudinally on the end of a stick (used for drilling or as projectiles) (See Figure 6b); (3) Chord is fully exposed and hafted singly or in adjacent pairs along the longitudinal edge of a stick (used for cutting) (See Figure 6c).

Tool ID	**Activity**	**Duration h:m:s**	**Worked material**	**Use details**	**Raw material**
1.01	cutting	3:00:00	wood	cutting groove for hafting	silcrete
1.02	de-barking	0:55:00	wood	stripping bark from wood, 90° angle	grey flint
1.03	cutting	2:00:00	wood	cutting groove for hafting	yellow flint
1.04	cutting	2:00:00	wood	cutting groove for hafting	white flint
1.05	whittling		wood	preparation of handle	grey flint
1.06	scraping	1:00:00	wood	preparation of handle	grey flint
1.07	cutting/ grooving	2:00:00	wood	preparation of handle	grey flint
1.08	de-barking	2:00:00	wood	stripping bark from wood, 90° angle	grey flint
1.09	grooving	2:00:00	wood	widen and deepen grooves in handles	silcrete
1.10	sawing	3:00:00	wood	saw notched on extremity of handle	yellow flint
1.11	de-barking	2:00:00	wood	stripping bark from wood	grey flint
1.12	de-barking	0:55:00	wood	stripping bark from wood, 90° angle	grey flint
1.13	bidirectional scraping	0:15:00	wood	preparation of axe handle	grey flint
1.14	scraping	0:05:00	fresh hide on wood	scraping fat off hide	yellow flint

Table 3. Handheld tool use experiments.

Projectile tips (See Table 5) included unifacial and bifacial retouched points (n=65) hafted to wooden foreshafts that were affixed to several spear shafts with *Xanthorrhoea* (n=31) or *Triodia* (n=34) resin, in one of three ways: (1) Points were glued at the extremity of the foreshaft, in contact with the wood, but not inserted into it and not in juxtaposition; (2) Points were inserted in a split in the foreshaft and glued; (3) Points were inserted in a split in the foreshaft, secured with sinew bindings and covered with glue. Spears were launched with a wooden spear thrower by a single experienced shooter into a uniform target (a termite mound, ~1 m high) to test the quality and resistance of the hafting arrangement (See Figure 7). Success and failure were documented by recording whether the point directly hit the target, whether the hafting broke and the number of shots per point.

Tool	Tool type	Activity	Duration h:m:s	Worked material	Use details	Raw material
3.01	tula	adzing	0:20:00	wood	preparation of handles	grey flint
3.02	tula	adzing	0:10:00	wood	preparation of handles	grey flint
3.03	tula	adzing	0:15:00	wood	preparation of handles	yellow flint
3.04	tula	adzing	0:35:00	wood	preparation of handles	yellow flint
3.05	tula	adzing	1:00:00	wood	preparation of handles	yellow flint
3.06	tula	adzing	1:00:00	wood	preparation of bowl	yellow flint
3.07	tula	adzing	1:00:00	wood	preparation of bowl	yellow flint
3.08	tula	adzing	1:40:00	wood	preparation of bowl	yellow flint
3.09	tula	adzing	1:40:00	wood	preparation of bowl	yellow flint
3.10	tula	adzing	3:00:00	wood	preparation of bowl	silcrete
4.01	ground hatchet	chopping	0:50:00	wood	chopping	quartzite
4.02	edge-ground hatchet	chopping	0:50:00	wood	chopping	quartzite
4.03	edge-ground hatchet	chopping	0:50:00	wood	chopping	dolerite
5.01	microlith	cutting	0:10:00	hide	cut tail to extract sinew	yellow flint
5.02	microlith	cutting	0:00:01	hide	fell out upon use	yellow flint
5.03	microlith	cutting	0:31:00	hide	cutting strips	yellow flint
5.04	microlith	cutting	0:55:00	hide	strip hide from tail	grey flint
5.05	microlith	cutting	0:55:00	hide	strip hide from tail	grey flint
5.06	microlith	cutting	0:00:08	hide	strip hide from tail	grey flint
5.07	microlith	cutting	0:05:00	hide	cut tail to extract sinew	grey flint
5.08	microlith	cutting	0:25:00	hide	remove inner membrane	grey flint
5.09	blade	cutting	0:23:00	hide	cut strips	yellow flint
5.10	microlith	cutting	0:03:00	hide	cut strips	grey flint
5.11	microlith	cutting	0:08:00	hide	cut strips	grey flint
5.12	microlith	cutting	0:35:00 0:25:00	hide hide	skinning de-fleshing	flint
6.01	microlith	scraping	0:45:00	hide on wood	remove inner membrane	grey flint
6.02	microlith	scraping	1:10:00	hide on wood	remove inner membrane	grey flint
6.03	microlith	scraping	0:00:10	hide on	remove inner membrane	flint
6.04	microlith	whittling	0:00:10	wood		flint
6.05	microlith	whittling	1:00:00	wood		yellow flint
6.06	microlith	scraping	0:33:00	hide on wood	scrape fat from hide	grey flint
6.07	microlith	scraping, whittling	0:40:00	wood		yellow flint
6.08	microlith	scraping	0:02:00	wood	bark shaving	silcrete

6.09	microlith	shaving	0:02:00	wood	bark shaving	silcrete
6.10	microlith	shaving	0:28:00	wood	bark shaving	silcrete
6.11	microlith	shaving	0:25:00	wood	bark shaving	silcrete
6.12	microlith	shaving	0:07:00	wood	shaving	silcrete
7.01	microlith	drilling	0:16:00	bone	piercing bone	yellow flint
7.02	microlith	drilling	0:01:00	bone	piercing bone	yellow flint
7.03	microlith	drilling	0:08:00	bone	piercing bone	grey flint
7.04	microlith	drilling	0:07:00	bone	piercing bone	grey flint
7.05	microlith	drilling	0:54:00	bone	piercing bone	yellow flint
7.06	microlith	drilling	0:15:00	bone	piercing bone	flint
7.07	microlith	drilling	0:35:00	bone	piercing bone	yellow flint
7.08	microlith	drilling	0:20:00	bone	piercing bone	yellow flint
7.09	microlith	drilling	1:53:00	bone	piercing bone	silcrete
7.10	microlith	drilling	0:30:00	bone	piercing bone	silcrete

Table 4. Hafted tool use experiments.

Adhesive recipes

Xanthorrhoea (probably *Xanthorrhoea preissii*) resin was collected as globular balls 1–3 cm diameter from near the base of plants in the Perth area. The resin balls were pounded between rocks to create powder, mixed with dried kangaroo dung (in varying proportions) and heated on rocks near an open fire (See Figure 8a–b). Stones and handles (with a carved end to receive the stone) were gently heated near an open fire and rolled in the powdered mixture that melted and stuck to the hot tools (See Figure 8c–d). The process was repeated until sufficient resin had built up on the handle and stone. The hot soft resin was then firmly moulded into shape with bare hands and pressed with the ends of burning sticks (See Figure 8e–f). In another process, to scale up production, the *Xanthorrhoea* resin was heated in a frying pan on a low gas flame. The molten resin from the frying pan was collected on a stick and held over an open flame causing droplets to fall on to the heated stone tool where it was pressed to the wooden handle with bare hands and the ends of burning sticks.

Triodia resin was collected from various parts of northern Australia in six forms: (1) as black ant-made shelters on the stems of leaves with lerp accretions; (2) as black ant ground tunnels; (3) as burnt black ant nest; (4) as active unburnt black ant nest; (5) from threshed and winnowed *Triodia* leaves; and (6) as lumps on the ground that had melted in bushfires—the latter being the most abundantly available for the workshop. All six forms of *Triodia* resins were mixed with different proportions of dried macropod faeces and beeswax to improve pliability and stickiness.

Resin lumps were pounded with stone to get them an even consistency and formed into cakes and heated in a pan (See Figure 9a–d). The resin cakes were then re-heated over a low flame to become malleable and placed around the tool and handle using sticks and gently moulded with bare hands around the stone (See Figure 9e).

Lechenaultia divaricata mindrie resin was recovered from a whole plant, collected in central Australia by Philip Green, who prepared roots that were used in the experiments (See Figure 4, Table 1).

Handles and bindings

All handles and spear shafts were made from 2–3 cm diameter branches of *Leptospermum obovata* growing locally near the Clyde River—a species listed by Kamminga (2002) as one used for making spears and clubs. Bindings for spear shafts included sinews extracted from macropod tails, bought frozen from an Adelaide pet food distributor. Wrap-around bindings for hafting hatchet heads were harvested from vines, 0.5–1 cm diameter stems (a native *Cissus hypoglauca* and an introduced species *Wisteria* sp.).

Results

Heated *Xanthorrhoea* resin was fast and easy to apply when in a molten state, but overheating and re-heating created a less sticky and more brittle adhesive. Parr (1999) explained that heating of *Xanthorrhoea* resin initiates loss of volatiles and chemical changes (that would also complicate identification of archaeological specimens) and suggested that over-heating might affect its viability as an adhesive—the heating regime is thus critical. Slow application of crushed and powdered resin, by rolling heated tools into the mix, tended to make a less brittle adhesive. A smouldering coal at the end of stick and wet hands were successful for final moulding and shaping of the adhesive on the hafted tool.

Lumps of *Triodia* resin collected after bushfires only softened at higher temperatures and were more brittle (probably owing to repeated bushfire burning and their high sand content) and lacked the high degree of stickiness typical of *Triodia* gathered from leaves or threshed and winnowed. Heating of the burnt resin lumps at lower temperatures with ~10% unburnt resin increased its pliability and stickiness markedly. For *Triodia* resins derived from ant-beds, the addition of ~10% beeswax increased the pliability and stickiness of the resin markedly, and the addition of the right mix of winnowed *Triodia* resin eventually made the lumps soft and pliable. Adding dried kangaroo dung to the mix tended to make application to a haft easier by holding the adhesive together as a lump. The *Triodia* resin collected from fresh black ant bed proved to be a better quality source of resin and was most suitable for hafting the projectiles.

In general, *Xanthorrhoea* resin mixtures were more brittle than the *Triodia* resin mixtures and tended to break more often in tasks used to process harder materials. Transversly hafted backed microliths used for wood-working and hide-scraping tasks hafted with *Xanthorrhoea* tended to break in the early stages of use when the resin was applied as a single lump. *Xanthorrhoea* resin was significantly more effective when built up from ground powder and added to the tool in multiple stages. This procedure was also effective for the preparation and application of *Triodia* resin and resulted in increased hafting strength, notably with drilling experiments. *Xanthorrhoea* resin was effective for hafting hide-working knives, but was less effective in these tasks when beeswax was added. *Triodia* resin proved very effective, unless it had a grainy texture resulting from over-heating. Tula adze flakes detached more frequently from the more brittle *Xanthorrhoea* adhesive mixtures and required frequent repairs. Tula adzes hafted with *Triodia* resin were long-lasting and effective in percussive wood whittling tasks for over 2 hours—without de-hafting. Edge-ground hatchets, which were bound with wrap-around vine handles and fixed firmly in place with *Triodia* resin filler, were effective in wood-chopping experiments. The *Triodia* filler could be gently reheated to renew haft tightness, after prolonged use.

All hafting problems were caused by limitations with the adhesives, notably cracking owing to brittleness. None of the wooden handles broke (except during projectile experiments). All grip handles worked well, regardless of the adhesive type, and the tools could be used for extensive durations without any particular effect on the grip.

Projectiles
The results of the tool experiments outlined above were used to inform on the preparation of the *Xanthorrhoea* and *Triodia* resins used for hafting the projectile armatures. Given the observed brittleness of *Xanthorrhoea* resin, beeswax was added to the mixture in order to improve the elasticity and to absorb shock during projectile impact. Of the *Triodia* varieties, only the fresh black ant nest was used, as it performed very well and was available in sufficient quantity to haft half of the projectiles.

Table 5 outlines the occurrence of tip damage (both head-on and lateral), and transverse breaks documented on the stone points after use, but attention is devoted to describing the resistance of the hafting arrangement. *Xanthorrhoea* resin was too brittle to be an effective fixative, even with beeswax additives. Some of the end-hafted points de-hafted in flight, and those that did not immediately detached upon contact with the target with their tips remaining intact. All energy was absorbed by the fracturing of the haft, leaving too little residual energy to be transferred to and damage the points. *Triodia* performed distinctively better for end-hafted points.

Hafting type	**Hafting resin**	**Hafted points**	**No. of throws**	**Target contact**			**Hafting success**			**Point recovery**		**Macrosco**
				Target direct hits	**Glanced target**	**Missed target**	**De-hafted before impact**	**De-hafted upon impact**	**Intact hafting after impact**	**Lost points (all de-hafted)**	**Point embedded in target**	**Transver breaks**
End-hafted	*Triodia*	13	14	10	2	2	1	11	1	0	5	0
	Xanthorrhoea	11	13	9	1	3	3	8	0	3	0	0
Split haft	*Triodia*	10	11	10	0	1	0	10	0	0	2	1
	Xanthorrhoea	10	11	10	0	1	0	10	0	1	0	1
Split haft + sinew bindings	*Triodia*	11	13	10	0	3	0	11	0	0	1	0
	Xanthorrhoea	10	11	8	0	3	0	10	0	2	1	0
TOTAL		**65**	**73**	**57**	**3**	**13**	**4**	**60**	**1**	**6**	**9**	

Table 5. Projectile experiments.

Xanthorrhoea proved to be a more effective fixative when applied to split hafts and its performance improved even more when combined with sinew bindings. However, compared with *Triodia*, *Xanthorrhoea* was less effective overall. Only one *Xanthorrhoea* hafted point embedded in the target (split haft with bindings). The poor performance of *Xanthorrhoea* contrasts with the general success of *Triodia*; even an end-hafted system, which provides a less resistant joint than a split haft, succeeded in embedding five points into the target. For the other hafting modes, more *Triodia* hafted points were embedded in the target than *Xanthorrhoea* hafted points. When a point was not deeply embedded in the target, *Triodia* hafting generally resulted in greater penetration into the target than *Xanthorrhoea*. Based on these results, it is clear that the *Triodia* mixture used in experiments provides a stronger hafting medium that is more resistant to impact shock than the *Xanthorrhoea* mixture used.

Discussion and Conclusion

Ethnographic recipes and controlled experiments for mixing *Xanthorrhoea* and *Triodia* adhesives are important for understanding patterns of haft breakage and preferences for task-specific hafting arrangements used in the past. Understanding adhesive recipes is also important for interpreting archaeological residues and potential origins of haft components via chemical characterisation. Other additives, not directly linked with gluing components together, may further complicate the identification of hafting recipes (Akerman, Fullagar and van Gijn, 2002). For example, smearing of hafted spear tips with poison (Hedley 1888; Parker 1905) or ochre adds to the complex of residues that might be found on archaeological specimens.

The distributions of *Xanthorrhoea* and *Triodia* in parts of southern and northern Australia respectively, and *Lechenaultia*in central Australia, likely affected access and their exploitation for particular tasks. It may be that limited access to a higher quality product or the disadvantages of using a locally widespread but inferior adhesive, may have been overcome in the past by determining the best recipe for mixing less optimal forms of resin; persevering with frequent breakage, because repairs are easy; utilising alternative animal or plant adhesives; and/or redesigning hafting arrangements less dependent on or not requiring an adhesive. The options are complex because Aboriginal people in Australia could access a remarkably high number of plant taxa with adhesive exudates.

The main conclusion, drawn from the workshop experiments, is that resin source, heating regimes/temperature controls, additives, mixing processes (grinding, crushing and pounding) and methods of application all play important roles in creating an effective haft. As an adhesive, *Xanthorrhoea* resin is more brittle than *Triodia* resin but this advantage may be reversed if the *Triodia* resin is not mixed in optimal ways. The combination of different experimental tool uses shows that hafting adhesive performance affects the efficiency of tool use and the formation of wear traces, particularly in the case of projectile tips. The way an adhesive reacts in flight and upon impact largely determines whether and how the stone point will be damaged (in combination with other variables not tested here). This is a pattern that has been observed during previous experiments (e.g., Coppe and Rots, 2017; Tomasso et al., 2018), and is essential knowledge for any projectile experiment that is performed. As others have noted, it can be a deliberate design feature for some spear tips to release from the shaft at impact (Akerman, 1978, p.488; Akerman, Fullagar and van Gijn, 2002). This experiential study reinforces the need for a thorough reflection on the experimental design and relevant variables for understanding hafting traces in the Australian archaeological record.

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About the Authors

Veerle Rots is a Research Professor (FNRS) at the University of Liége (ULiège) in Belgium and director of TraceoLab. She manages projects in Africa and Europe that focus on understanding prehistoric hafting technologies and stone tool function.

Richard Fullagar is Honorary Professorial Research Fellow at the University of Wollongong (UOW) and studies the function of stone tools in Eastern Asia, Southeast Asia, America and Australia.

Elspeth Hayes is an Honorary Research Fellow at UOW and studies the function of grinding stones and other artefacts in the Australian region.

Kim Akerman is an anthropologist and Adjunct Professor of Archaeology and member of the Advisory Board for CRARM at The University of Western Australia (UWA).

Chris Clarkson is a Professor at the University of Queensland (UQ) and Research Associate in the ARC Centre of Australian Biodiversity and Heritage (CABAH) and studies lithic technology in Africa, Eurasia and Australia.

Philip Green is a naturalist and an educator, and has special interest is in Aboriginal use of gums, resins and other adhesives and how they were harvested, mixed and used.

Christian Lepers is a technologist and an expert stone knapper at TraceoLab, ULiege. He replicates prehistoric tools for experimentation with skills in the use of projectile weaponry.

Luc Bordes is from CNRS, Toulouse, France. He specializes in Raman Spectroscopy and studies usewear and residues on stone tools.

Conor McAdams is a PhD student at UOW studying geoarchaeology with a focus on early southeast Asian sites.

Elizabeth Foley is PhD student at La Trobe University studying Aboriginal land use in semi-arid regions of Australia during the Last Glacial Maximum.

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