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# The efficiency of Australian grindstones for processing seed: A quantitative experiment using reproduction implements and controlling for morphometric variation and grinding techniques

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ABSTRACT

This paper presents a controlled experimental examination of the efficiency of Australian Aboriginal grindstones with a variety of surface morphologies in milling seeds into meal. Several replicate sandstone grindstones (large and small millstones with functional surfaces ranging in length from 43 cm to 16 cm and a mortar) were employed to process three domesticated commercial grains that serve as viable proxies for native grains. These were processed in 10 min grinding sessions. Our results show that large millstones significantly outperform both the small millstones and the small mortar in the net output of ground grain. We also find that other factors may influence productivity, including the amount of wear and the seed being processed. These variations are of sufficient magnitude to have possibly influenced crucial economic decisions.

## 1. Introduction

Over past few decades a vigorous debate has emerged over the role played by grindstones in past Aboriginal lifeways; in particular, the antiquity of seed grinding, the importance of specialised tools (millstones), the role of seeds in the long-term exploitation of arid environments, the labour investment in seed collection and processing, and the extent to which seeds contributed to ancient diets (Gorecki et al., 1997; Smith, 1985, 1986, 1989, 2013). Two opposing views have emerged in this debate; one which sees intensive seed grinding economies as a late Holocene development, and the other which traces seed grinding back to the Last Glacial Maximum (LGM) or before (e.g. Fullagar et al., 2008, 2015; Smith, 1985, 1986, 1989, 2015a).While ethnographic, use-wear and residue evidence have all contributed significantly to this debate (e.g. Balme et al., 2001; Hayes, 2015), a number of fundamental questions still remain about the role of grindstone form itself in this debate (Adams, 2002). For example, what role does grindstone size, raw material type, muller type, presence or absence of a groove or type of seed processed play in milling efficiency, that is, the production of meal, labour inputs, grain wasted and so on? Are there significant differences in the efficiency of different types of grindstones when used to process the same or different seeds? If such performance characteristics make significant differences to grinding efficiency, then what might this mean for the evolution of grindstone form over time in Australia?

Addressing these questions may help understand whether intensified seed grinding at certain times in the past might have benefited from specialised equipment of some kind, thus resulting in the emergence of particular grindstone characteristics over time. This paper aims to provide a preliminary assessment of whether such fundamental issues as size, grinding action, muller type and variety of seed have significant effects on grindstone efficiency, and to employ these low-level building blocks to reflect on the Australian grindstone debate. For this purpose, 280 controlled grinding trials were undertaken on 11 grindstones and three types of commercial seeds, plus tests on two native seeds, to determine the effects of form on efficiency. In particular we compare the efficiency of 'formal' millstones versus informal 'amorphous' grindstones and mortars, since these distinctions have been paramount in the Australian seed grinding debate.

## 2. Australian seed grinding: ethnography and archaeology

Australian archaeologists are fortunate to possess a rich and varied ethnographic record documenting the use of a variety of grindstones employed in a wide range of functions. Unfortunately, few of the ethnographic studies of seed grinding provide quantitative data on processing efficiency, either for different kinds of grindstones or seeds, though a number of more detailed studies do exist (see Cane, 1984, 1987; Devitt, 1992; Gould et al., 1971; O'Connell, 1977; O'Connell et al., 1983). At present, much of our understanding of production and

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efficiency in arid seed grinding derives from O'Connell's study of Alyawarra seed grinding. O'Connell worked with Central Australian Aboriginal women informants to gather and process a range of traditionally used native seeds. Quantitative data on processing times and outputs were recorded and his calculations of from 4 to 6 h to grind a kilogram of seed have been widely accepted (O'Connell et al., 1983; Bird and Bliege Bird, 2005: 90). While the Alyawarra work was a landmark study, few if any studies have since attempted to further quantify meal production rates on a wider range of grindstones or seeds in either an ethnoarchaeological or experimental setting.

A common distinction made in descriptions of Australian grindstones is between formal grooved millstones and informal amorphous or flat grindstones and mortars. However, what is meant by this is seldom clear. In his ethnographic work of 1897, Bennett distinguished between grooved (long, narrow depression) and basin (dish like depression) millstones. Other early ethnographers such as Spencer and Gillen provided brief descriptions of the grinding process but little on the grindstones themselves (Spencer and Gillen, 1912), often merely referring to 'the usual grinding stones' (Spencer & Gillen, 1899: 22). Much later McCarthy (1976) and his colleagues provided what was accepted, until relatively recently, as the type description of many grindstones and pounders. However, it was not until the work of O'Connell (1977) and Smith (1985) that descriptions of the functional surface became the generally accepted means of classification. It is functional surface that is now used primarily to distinguish between grindstones in Australian archaeology. However, grindstone terminology remains confused and it is often difficult to be certain of the precise morphology of a grindstone under discussion.

The functional surface is a critical factor in the classification and efficiency of a millstone (O'Connell, 1977; Smith, 1985). Mauldin found the grinding surface area to be positively related to output. He considered the functional surface area of the topstone to be the best indicator of efficiency for the mill sets studied (Mauldin, 1993: 319). A further indicator of efficiency may be the degree of use-wear. Some researchers consider that unused or lightly used grindstones possess a productive advantage over well-worn examples (e.g. Gorecki et al., 1997; Veth and O'Connor, 1996). However, whilst Gorecki et al. are clear that grindstones are 'far more efficient and versatile in earlier stages of reduction than when worn' (Gorecki et al., 1997: 142), an earlier observation by Warner suggests that a grinding stone which has developed a cavity 'is sought for by a woman in preference to a new stone' (Warner, 1937: 497).

Groove development or absence also impinges on the question of formal or amorphous grindstones. Accepting for the moment that formal grindstones have well defined grooves but the surfaces of amorphous implements are flat with perhaps minor signs of abrasion (Veth and O'Connor, 1996; Smith, 1985), then the question of whether any groove is functional or merely the product of use wear is important.

From the 1940s to the 1970s, McCarthy and Tindale published a number of papers dealing with seed grinding technology and its distribution (e.g. McCarthy, 1976; McCarthy et al., 1946; Tindale, 1959, 1977). McCarthy limited his focus to the definition of a number of grindstone types and produced the first widely adopted typology of Australian implements (McCarthy et al., 1946; McCarthy, 1976). Tindale, on the other hand, proposed an evolutionary sequence of grassland use and grindstone development. He suggested that hammers and anvils were in use from the terminal Pleistocene and that 'minor abrasional surfaces' appeared from about 8000 years BP. From around 4000 years BP:

> several styles of upper and nether millstones, including ones such as were used in the wet grinding of grass seed food, appear, and culminate in the grass-seed-meal preparing mill sets characteristic of [ethnographic times] (1959:49).

Morphological details of the early millstone sets are not provided. Tindale suggested that the use of millstone sets in late prehistory identified a populous, socially advanced dry areas grass-seed culture he called the Panara (1977).

In an influential paper, Smith (1985) proposed an updated version of McCarthy's grindstone typology which divided Australian grindstones into five types on the basis of functional surface. These were: millstones, mullers, mortars, pestles and amorphous grindstones. The first four types were considered formal seed grinding implements incorporating elements of intentional design. The amorphous class, on the other hand, consisted of unmodified natural stones or slabs used expediently and lacking intentional design. He later expanded and clarified his view on amorphous grindstones as used in other areas lacking in sandstone raw materials (Smith, 2015b). In Smith's area mortars and pestles were used to dry crush hard seeds such as those of the Acacias before they were wet ground using the millstones and mullers in the same way as soft grass seeds (Smith, 1985: 24–29). For seed grinding millstones, he considered size to be critical as a 'large surface area is necessary for the long grinding action with which these implements are used and specimens smaller than 300 × 400 mm are possibly too small to use efficiently' (Smith, 1985: 26). However, Veth and O'Connor examined a large sample of grindstones from the Little Sandy Desert of Western Australia and judged them to be seed-grinders despite the maximum dimension of the largest being only 221 mm (Veth & O'Connor, 1996: 21).

A central tenet of the Smith paper was that seedgrinders could be distinguished from amorphous grindstones by their diagnostic morphological characteristics. A second tenet was that Pleistocene dates for seedgrinding could not be supported on archaeological evidence (Smith, 1985: 29 & 36). Smith later argued that seedgrinding was a mid to late Holocene 'further development of an existing technology arising out of a need to more heavily exploit certain resources' (Smith, 1986: 37). Thus Smith linked the emergence of new specialised grindstone morphology with an intensive economic reliance on seeds, implying that the new specialised technology increased the efficiency of this subsistence activity.

Smith's arguments have since received widespread support (e.g. Balme, 1991; Mulvaney, 1998). However, not all agree with his typology, nor with the conclusions drawn from the archaeological evidence. For example, Gorecki et al. (1997) countered that the specialised seedgrinding toolkit identified by Smith may only be one component of a more generalised Pleistocene grindstone/mortar technology used to process a wide range of resources and not simply seeds. Likewise, several researchers have argued that morphological variation may more simply relate to the availability of raw materials, the degree of curation or the state of preservation, rather than intentional design relating to production efficiency (Balme et al., 2001; Gorecki et al., 1997; Smith, 2015b; Veth and O'Connor, 1996). In their view, seedgrinding may not be a late Holocene development at all, but part of an economy that stretches well back into the Pleistocene in some areas (Balme et al., 2001; Fullagar and Field, 1997; Hayes, 2015).

Of the matters which can be informed by grindstone technology, two issues remain central to the debate—those of form and efficiency. For example, if it can be confirmed that the morphological variation in some grindstone types may be ascribed to accumulated use wear over time rather than design factors intended to improve efficiency, then the dichotomous distinction between formal and amorphous grindstones needs to be questioned for its usefulness (Balme et al., 2001: 5; Veth and O'Connor, 1996: 20). A flat slab classified as an amorphous grindstone could, with use, develop a groove or dish and thus be reclassified as a formal implement. If a large grooved millstone confers a significant productive advantage over other grindstones then it may be a specialised implement and its introduction into the technological toolkit may indicate a recently developed reliance on a seed based diet. However, if it only confers an incremental advantage, it may instead be merely a minor improvement to existing old and widely used practices. If grindstone types other than the specialised millstone are able to efficiently process seeds, then arguments that seeds may have been a more