Foodways in early farming societies: microwear and starch grain analysis on experimental and archaeological grinding tools from Central China

Li, W.

Chapter 2 New insights into the grinding tools used by the earliest farmers in the central plain of China

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New insights into the grinding tools used by the earliest farmers in the central plain of China

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Abstract

The site of Jiahu in the central plain of China is known for its early rice cultivation 9000 years ago. The preliminary starch analysis implies that the Jiahu grinding tools were used for processing various plants, including rice. This paper presents the use-wear analysis carried out on a sample of seventeen grinding tools from Jiahu, nine of which were previously analysed for the presence of starch. Use-wear traces associated with processing cereal and wood-like material were identified. This result confirms important evidence of cereal processing in the early Neolithic period. It also reveals the diversity of functions in the grinding tool assemblage. Furthermore, the use-wear distribution indicates that grinding slabs without feet and cylindrical rollers were mainly associated with the processing of cereals while grinding slabs with feet were mainly related to the processing of wood-like material. Quantitative analysis of the starch data also indicates that grinding slabs without feet possess more starch grains than the grinding slabs with feet. Therefore, it is argued that specific types of grinding tools were used for processing specific kinds of material. This study highlights the different roles grinding tools may have played in early farming societies.

Keywords: Neolithic archaeology; Chinese archaeology; Jiahu grinding tools; use-wear analysis; tool function

2.1 Introduction

The functional study of grinding tools is of enduring interest for archaeologists, particularly because these implements are one of the most predominant tools recovered from many Neolithic sites around the world (e.g. Tsoraki, 2007; Verbaas and Van Gijn, 2007; Hamon, 2008; Yang et al., 2015; Liu et al., 2016). Based on ethnographic analogy, Neolithic grinding tools unearthed in China were often considered to have been used to process agricultural products (i.e. rice or millet) (Chen, 1990; Song, 1997). Thus, the appearance of these artifacts was used as a proxy for the arrival of agriculture (e.g. Bellwood, 2005; Higham, 2005). However, recent studies have shown that grinding implements were not only used for cereal processing but also for processing other types of plants. For example, in the lower reaches of the Yangtze River, results of the starch analysis established that the grinding tools from the early Xiaohuangshan phase (c. 9000-8500 cal. BP) were mainly used for processing wild plants, rather than rice (Yao et al., 2016). Combining use-wear and starch analyses data from grinding tools recovered at two Peiligang Culture sites (c. 9000-7000 cal. BP) in the Middle Yellow River Valley, it is demonstrated that these tools were primarily used for processing acorns, rather than millet (Liu et al., 2010a).

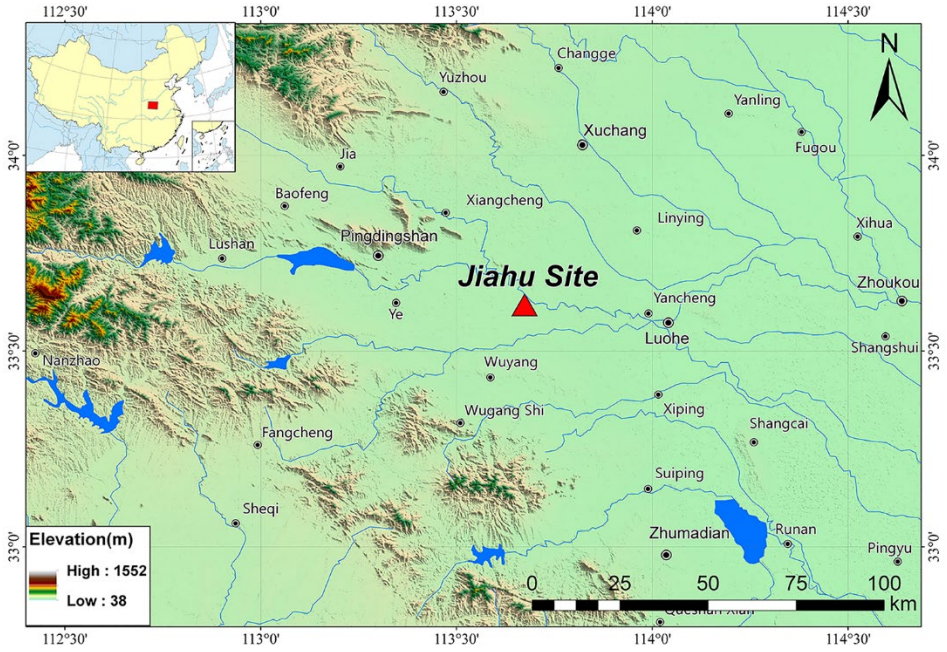

Figure 2.1 The site of Jiahu in the central plain of China

The archaeological site of Jiahu (113°40′ E, 33°36′ N) is located in the upper catchment area of the Huai River (Fig. 2.1), which was one of the major centres for the origin of rice cultivation (Wang and Zhang, 1998). About 2900 m2 of occupation area was excavated between 1983 and 2013 (Zhao and Zhang, 2009; Zhang, 2015; Yang et al., 2017). Jiahu has been radiocarbon-dated and dendro-calibrated to three sub-phases: phase 1 (ca. 9000-8500 cal. BP), phase 2 (ca. 8500-8000 cal. BP), and phase 3 (ca. 8000-7500 cal. BP) (Zhang, 1999). At Jiahu archaeologists recovered evidence of some of the earliest cultivated rice (*Oryza sativa*) (Liu et al., 2007a, b), domesticated animals (Yan, 1992), and stone tools that have been linked to agricultural practices (Zhang, 1999). The other well-known discoveries include the oldest tonal flutes (Zhang et al., 1999; Zhang et al., 2004), fermented beverages (McGovern et al., 2004), and the earliest examples of Chinese inscriptions (Li et al., 2003). Excavations also brought to light numerous identified houses, storage pits, and pottery kilns. It has been claimed that Jiahu represents a complex and highly structured Neolithic society, which was occupied by the earliest farmers outside of the Yangtze River catchment in China (Zhang and Hung, 2013).

Preliminary starch grain analysis on a subset of the Jiahu grinding tools led to their interpretation as plant processing equipment (Zhang, 2015). However, the interpretation of tool function dependent on one analytical technique has certain limitations. So far, it is difficult to directly date starch grains (Barton and Torrence, 2015). Although modern starch contamination can be ruled out by using control samples, non-use related ancient starch grains could be trapped through nearby activities and be preserved on the tool surfaces (Langejans, 2011). That is to say, even if the discovered starch grains on artefacts are ancient, they are not necessarily related to the tool's use. In order to get a more reliable result, increasingly more studies have combined the data from both starch and use-wear analyses for interpretations of tool functions (e.g. Liu et al., 2010b; Revedin et al., 2010b; Liu et al., 2014a; Fullagar et al., 2017).

The method of use-wear analysis is a complementary approach to starch grain analysis. This analytical technique involves the identification of microscopic traces on the surface of objects produced during tool production, use, reuse, and post-deposition (Adams, 2014). It mainly relies on experimental analogy to make inferences about the function of tools (Van Gijn, 2014). Use-wear analysis has proven its potential for inferring the processed material, especially when using high magnifications (e.g. Liu et al., 2010b; Dubreuil and Nadel, 2015; Hayes et al., 2017). This paper applies use-wear analysis to the Jiahu grinding slabs (lower tools) and grinding rollers (upper tools). The results from the previous starch grain analysis (Zhang, 2015) are compared with those from this use-wear study to consider how the earliest farmers from Jiahu used these grinding tools.

2.2 Materials and methods

Grinding slabs and rollers represent the main types of grinding tools recovered from Jiahu, followed by mortars and pestles (Zhang, 1999; Lai et al., 2009; Zhang, 2015). It appears that specific raw materials were selected for the production of different types of stone tools, and that grinding slabs and rollers were generally made of medium to coarse-grained sandstone (Cui et al., 2017). Most of the unearthed Jiahu grinding slabs are without feet (Fig. 2.2a), and only a few grinding slabs are with four short feet (Fig. 2.2b). Most of the grinding rollers are with a cylindrical shape in cross-section, but oval-shaped, hemispherical or faceted-shaped rollers are also encountered albeit less frequently.

The Jiahu grinding tools were especially suited for use-wear analysis, because complete tools were unearthed, which enabled an easy identification of the used areas for sampling. Moreover, several paired grinding slabs and rollers were discovered in the same archaeological contexts, mostly in ash pits and burials (Zhang, 1999). Studying these paired tools allowed for a comparison of use-wear traces from the upper and lower tools, which was important to improve our understanding of tool function and the processes they were involved in. Furthermore, the presence of different grinding tool morphologies made it possible to test the relationship between tool type and function.

Figure 2.2 Grinding tools from the site of Jiahu with different morphologies. a. a grinding slab without feet was paired with a cylindrical roller from the same context H482; b. a grinding slab with feet (M371:1).

Seventeen objects were sampled for use-wear analysis in this study (Table 2.1). Five of these objects were complete, including two grinding slabs without feet and their associated upper tools (cylindrical grinding rollers) and one grinding slab with feet that was originally paired with a grinding roller with an oval-shaped cross-section (this roller was unfortunately inaccessible for study). The rest of the objects were fragments but of sufficient size to determine their original shape. Nine of the fragments belonged to the type of grinding slabs without feet and one was part of a grinding slab with feet. Three of the fragments derived from cylindrical grinding rollers. Out of the 17 objects subjected to use-wear analysis, nine were sampled for starch grain analysis in a previous study (Zhang, 2015) (Table 2.1).

Table 2.1 Overview of the artefacts and the processed material suggested by use-wear traces

tool no.	phase	tool type	tool completeness	processed material suggested by use-wear traces
H482:4	1	grinding slab without feet	complete	cereal
H482:3	1	cylindrical grinding roller	complete	cereal
H198	2	cylindrical grinding roller	fragment	cereal
H152:2	1	cylindrical grinding roller	fragment	unknown plant
T41(2):13	2	grinding slab without feet	fragment	cereal
T44(1):2	1	cylindrical grinding roller	fragment	cereal
M88:3	2	cylindrical grinding roller	complete	cereal
M88:2	2	grinding slab without feet	complete	cereal
M119:2*	2	grinding slab without feet	fragment	cereal
M371:1*	2	grinding slab with feet	complete	wood-like material
T17(3C):11*	1	grinding slab without feet	fragment	cereal
T12(3B):4*	2	grinding slab without feet	fragment	cereal
H69:4*	3	grinding slab without feet	fragment	cereal
T4(3):12*	2	grinding slab without feet	fragment	cereal
T8(3):3*	2	grinding slab without feet	fragment	cereal
T101(3B):17*	2	grinding slab without feet	fragment	cereal
T109(3B)*	2	grinding slab with feet	fragment	wood-like material

Note: tool no. with * were previously studied by starch grain analysis

Polyvinyl siloxane (PVS) impressions were used to sample the archaeological artefacts because they could not be transported out of the Chinese museums. Prior to use-wear sampling, the grinding tools were cleaned using tap water, detergent, and a soft brush to remove adhering sediments. The used surfaces of Jiahu grinding tools show intense levelling of grains that are visible by initial naked eye observation. Forty PVS samples were taken from the central grinding areas of the grinding slabs and rollers, the edges of the grinding slabs, and the handling areas of the rollers. All of the samples were observed under a Leica DM 6000m metallographic microscope (with magnification from 100x to 500x). In order to obtain micrographs with a depth of field, a compilation of micrographs were taken when needed using a Leica DFC450 camera attached to the microscope. The microscope, fitted with mechanized z-drives, automatically stacked these micrographs. The use-wear features observed include micro-striations (including their general distribution on the tools), residues, and micro-polish. Polish attributes include directionality, degree of linkage, texture, reflectivity (dull, moderately or highly reflective), and location of polish on the micro-topography (cf. Adams et al., 2009; Hayes et al., 2017).

The analysis of use-wear on stone tools depends heavily on experiments (Adams, 2014; Dubreuil and Savage, 2014). The Laboratory for Material Culture Studies at Leiden University has an experimental reference collection of stone tools used for the processing of various materials, including cereals, wood, flint, bone, antler, clay, metal, and pigments. For the study of the grinding tools from Jiahu, similar sandstone cobbles were collected from the valley of the Maas River in the southern Netherlands for grinding rice (*Oryza saliva*), millet (*Setaria italica*), and acorns (*Quercus robur*), to add to the experimental reference collection. Each grinding experiment was conducted manually for 180 minutes.

2.3 Results

The use-wear traces associated with cereal grinding have been described in previous publications (e.g. Van Gijn and Houkes, 2006; Fullagar et al., 2012b). They are characterized by a granular micro-polish with a greasy texture. The use-wear traces have a reticular distribution (also described as net-like e.g. Fullagar et al., 2016). The results of cereal grinding experiments conducted within the remits of this study are consistent with the previous research. The results of the experiments also suggest that use-wear traces from grinding different types of cereals are very similar, in terms of the polish distribution, polish texture, and polish location on micro-topography (Fig. 2.3a, b and c). It is therefore not possible to infer the type of grain on the basis of the use-wear features alone. Nevertheless, it is possible to differentiate between the wear traces from processing cereals and those from acorn processing. Contact with acorns results in an uneven and more rough-textured micro-polish texture as mentioned in previous research (Liu et al., 2010a). Fullagar and colleagues (2012a) also found that the use-wear traces associated with the

processing of acorns were different from grinding seeds, in terms of the features of micro-polish on the lower part of the micro-topography, striations and pitting on the implements. Our experiments additionally show that spots of linked and smooth micro-polish are less often discovered on stones used for processing acorns (Fig. 2.3d).

Table 2.2 Ancient starch grains extracted from 9 of the studied Jiahu grinding tools (after Zhang, 2015)

Tool type and tool no.		*Oryza sativa*	*Coix lacryma-jobi*	Triticeae	*Nelumbo nucifera*	*Dioscorea opposita*	*Trapa* spp.	*Vigna* spp.	Total
slabs without feet	M119:2	0	10	10	4	0	3	0	27
	T17(3C):11	1	18	28	12	3	15	0	77
	T12(3B)	4	128	64	44	17	22	3	282
	H69:4	5	46	163	31	3	114	8	370
	T4(3)12	0	60	83	25	18	41	1	228
	T8(3):3	1	20	108	38	0	31	4	202
	T101(3B):17	4	56	92	46	8	140	5	351
	Total	15	338	548	200	49	366	21	1537
slabs with feet	T109 (3B)	3	43	44	20	0	0	1	111
	M371:1	1	5	5	3	1	2	3	20
	Total	4	48	49	23	1	2	4	131

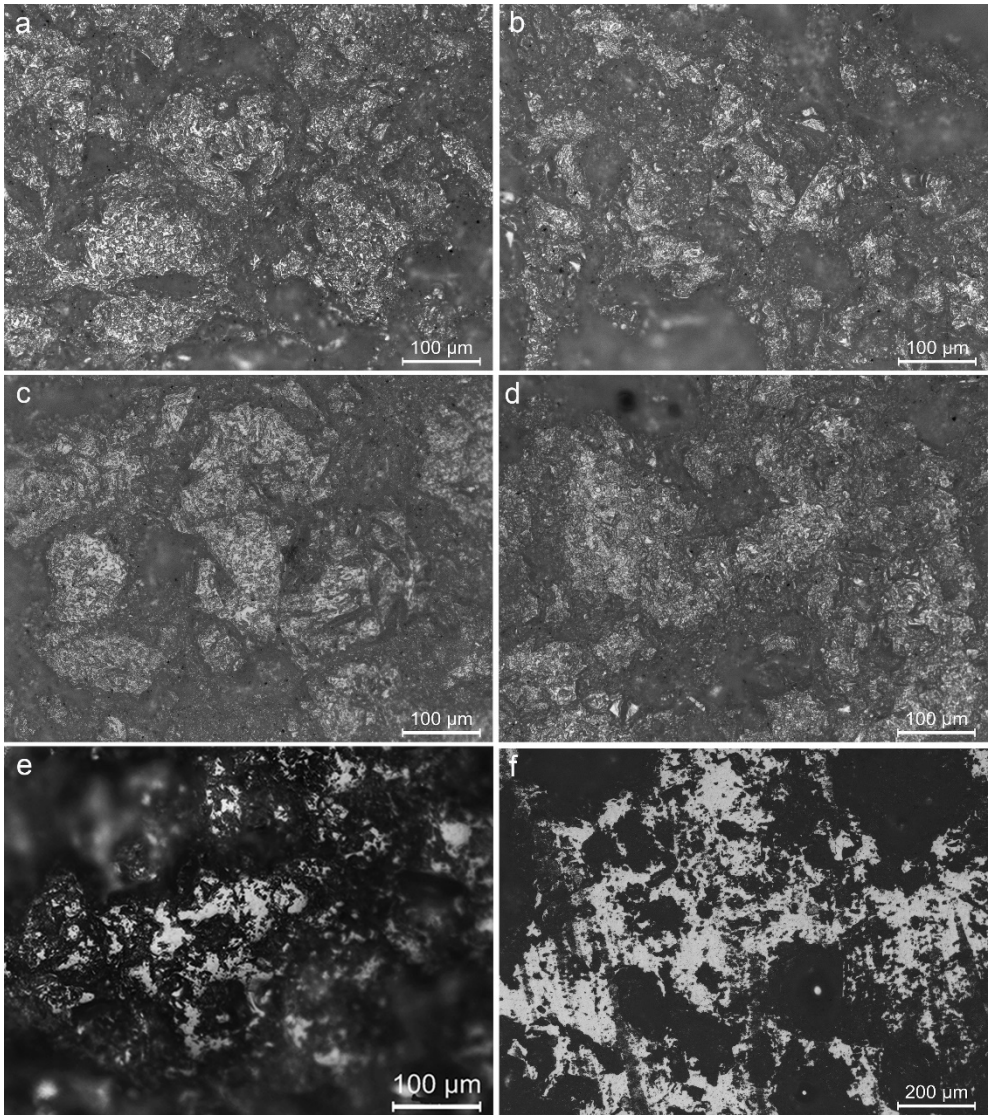

Figure 2.3 Reference collection of use-wear associated with processing different kinds of materials. a: stone surface involved in millet grinding for 180 min 200X; b: stone surface involved in rice grinding for 180 min 200X; c: stone surface involved in wheat (*Triticum monococcum*) grinding for 600 min 200X; d: stone surface involved in acorn (*Quercus robur* L.) grinding for 180 min 200X; e: stone surface involved in abrading wood after 3200 strokes for about 60 min 200X; f: stone surface involved in flint grinding after 5117 stokes for about 90 min 200X.

Two different types of use-related use-wear traces were discovered in the Jiahu grinding tool assemblage. The first type of use-wear was associated with cereal processing (Fig. 2.4a and b), which was found on 14 Jiahu grinding tools (Table 2.1). The polish had a distinct directionality, which was oriented parallel to the long axis

in the case of the grinding slabs and perpendicular to the long axis for the rollers. The polish mostly appeared on the higher micro-topography of the sampled stone surfaces, characterized by the formed patches and smooth micro-polish (localised spots with linked micro-polish, e.g. Fig. 2.4b). Micro-striations were rarely observed on the main grinding areas of the slabs and rollers, but rather on their edges, along with a polish with a rough texture (e.g. Fig. 2.4e and f). The latter polish is very similar to experimental polish resulting from stone-on-stone contact (Fig. 2.3f). It was discovered mostly in the areas where less processed material would have accumulated. We believe this polish was formed because of the contact with stone as well as the intermediate processed plant material.

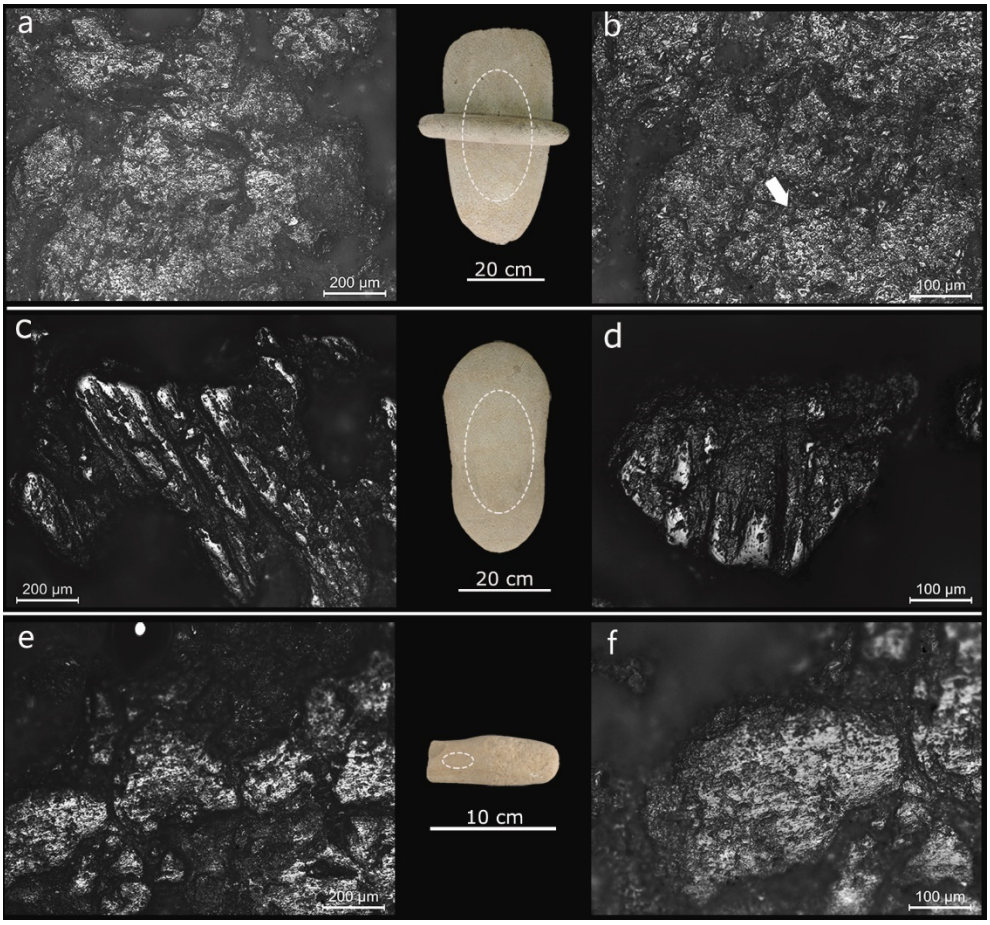

Figure 2.4 Different types of use-wear distributed on the grinding tools from the site of Jiahu. a and b: cereal use-wear on the central area of the grinding slab and the grinding roller from the same context H482, 100x and 200x, localized spots with smooth linked polish are pointed out by the arrow; c and d: wood-like material use-wear on the central area of the grinding slab (M371:1), 100x and 200x; e and f: polish with rough texture on the surface of the grinding roller fragment (H152:2), 100x and 200x.

The second type of use-wear was associated with processing wood-like material, which was found on two Jiahu grinding tools (Table 2.1). The use-wear is characterized by a very smooth, domed and moderately reflective polish (Fig. 2.4c and d). The polish has a localized distribution and forms on individual mineral grains but can also extend on aggregations of grains forming elongated patches across the main grinding area. The polish displays no micro-striations and mainly appears on the higher micro-topography. The directionality of the polish is parallel to the long axis of the grinding slabs. These features are consistent with the experimental stone tools associated with processing wood (Fig. 2.3e). Nevertheless, furrows were found between the elongated patches on Jiahu grinding slabs (Fig. 2.4c and d), which were probably formed by other harder materials before wood processing. Although use-wear analysis has been conducted on grinding tools from several sites, use-wear traces associated with the processing of wood-like material have so far not been reported in previous publications (e.g. Liu et al., 2014a; Liu et al., 2014b).

If we look at the two types of wear traces, those from grinding cereals and those from wood-like material, it turns out that the first was only identified on the samples belonging to grinding slabs without feet and with cylindrical rollers (Table 2.1; e.g. Fig. 2.4a and b). In contrast, use-wear traces associated with processing wood-like material were only found on samples from grinding slabs with feet (Table 2.1; Fig. 2.4c and d). Thus, there is a clear morphological distinction of the grinding slabs related to specific usage.

2.4 Discussion

A previous study showed that starch grains from cereals were found in abundance in the Jiahu grinding tool assemblage, including rice, Job's tears (*Coix lacryma-jobi*) and plants from the tribe Triticeae (Zhang, 2015). Further analysis of the starch data shows that the quantity of cereal starch grains accounted for nearly half of the total starch grains recovered (Fig. 2.5b). The ubiquity index of the starch grains from cereals (including rice, Job's tears and plants from the tribe Triticeae) is also higher than that of other plants (Fig. 2.5a). This is corroborated by the results of the use-wear analysis which shows that use-wear traces associated with cereal processing were consistently found on the Jiahu grinding tools. The identified traces suggest that cereals might have been locally ground into flour for consumption at Jiahu. Several studies have revealed that flour production has taken place since the Palaeolithic period in Eurasia (e.g. Aranguren et al., 2007; Revedin et al., 2010a). In China, according to the findings from the site of Shizitan (c. 28 000-8500 cal. BP), the production of flour from grass seeds begun long before the Neolithic period in the Middle Yellow River Valley China (Liu et al., 2011; Liu et al., 2018). The use-wear study of the Jiahu grinding tools confirms that cereal flour production took place in the upper catchment of Huai River during the early Neolithic period. The cereals

used to produce flour most likely include rice as suggested by the analysis of the macrobotanical remains; domesticated rice remains including dehusked rice grains were unearthed from all three chronological phases at Jiahu (Zhang and Wang, 1998; Zhang, 1999; Liu et al., 2007b). The produced flour could have been used for different types of food products, such as bread and noodles (Lu et al., 2005; Arranz-Otaegui et al., 2018). Dietary choices usually have a strong continuity once they are established (Ma, 2015), a proposition that is also substantiated at Jiahu as use-wear traces associated with cereal processing were found on tools from all three occupation phases (Table 2.1), suggesting that cereal grinding was likely adopted as a habitual food processing practice by the Neolithic communities at Jiahu.

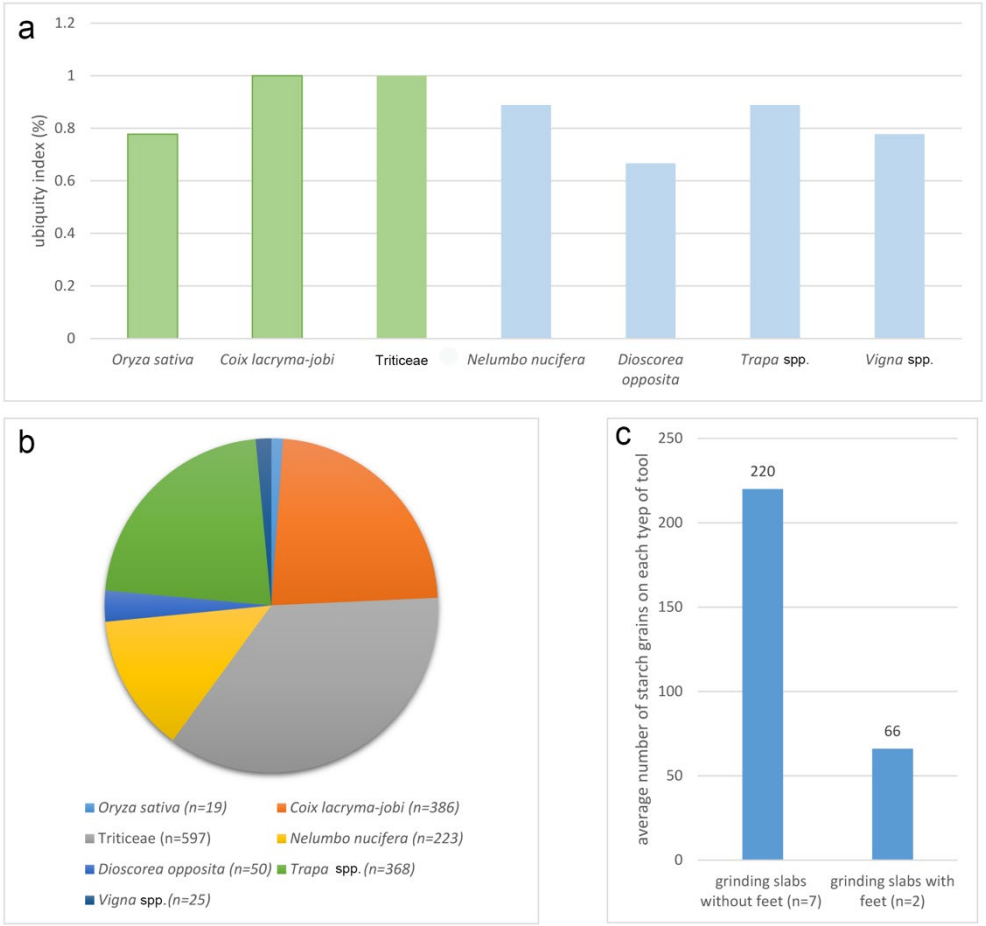

Figure 2.5 Quantitative analysis of starch grains at the site of Jiahu. a: ubiquity index of each plant on the nine grinding tools applied for starch grain analysis b: number of starch grains from different plant species discovered on the Jiahu grinding tool assemblage c: the average number of starch grains from grinding slabs without feet (n=220) is notably higher than the average number from grinding slabs with feet (n=66) (after Zhang, 2015).

Apart from use-wear interpreted as resulting from processing cereals, another type of use-wear related to processing wood-like materials was discovered on two grinding slabs (Table 2.1). It has been suggested that a wooden grinder in conjunction with a stone grinding slab could have been used for cereal processing (Delgado-Raack and Risch, 2008). However, the stone rollers were always placed on top of the slabs on the site of Jiahu (Zhang, 1999). For example, in this study, the grinding slab M371:1 associated with wood-like material was recovered with a stone oval-shape roller on top of it in the same grave (Zhang, 1999). Moreover, polish with a rough texture was detected on the edges of this slab (Fig. 2.6). It resembles the polish related to stone-on-stone contact (Fig. 2.3f), suggesting the slab was indeed used with an upper stone roller. Therefore, the use-wear related to the processing of wood-like material that was discovered on this tool is more likely from contact with the processed substance, rather than from its upper tool. This study therefore strongly suggests that the Jiahu grinding tools were not only used for processing cereals, but also for processing wood-like material. This result highlights the diversity of functions represented in the grinding tool assemblage. In that sense, this result is consistent with previous studies of grinding tools in the same area (e.g. Liu et al., 2010a; Yang et al., 2015), indicating Neolithic grinding tools were not exclusively associated with processing agricultural products, such as rice.

Ethnographic accounts reveal that the type of processed material is often correlated with the shape and type of the implement employed (Schroth, 1996). At Jiahu, use-wear associated with processing cereal was only found on grinding slabs without feet and cylindrical rollers, while use-wear associated with processing wood-like material only appears on grinding slabs with feet. This use-wear distribution indicates a relationship between tool type and function. Although both types of slabs seem to have been used for processing different kinds of starchy foods based on the data from starch grain analysis (Fig. 2.7 and Table 2.2), stone tools primarily associated with processing material with limited starch grains such as wood would have preserved fewer starch grains. This is affirmed by further quantitative analysis of the previous starch data. There is indeed a difference in starch quantity among different types of grinding tools. Seven grinding slabs without feet yielded 1537 starch grains in total, while two slabs with feet only produced 131 starch grains together (Table 2.2). The average number of starch grains from grinding slabs without feet (n=220) is notably higher than the average number from grinding slabs with feet (n=66) (Fig. 2.5c). The correlation between tool type and function as indicated by both methods of study could thus suggest that people at Neolithic Jiahu choose specific types of grinding implements primarily but not exclusively for the processing of certain types of substances.

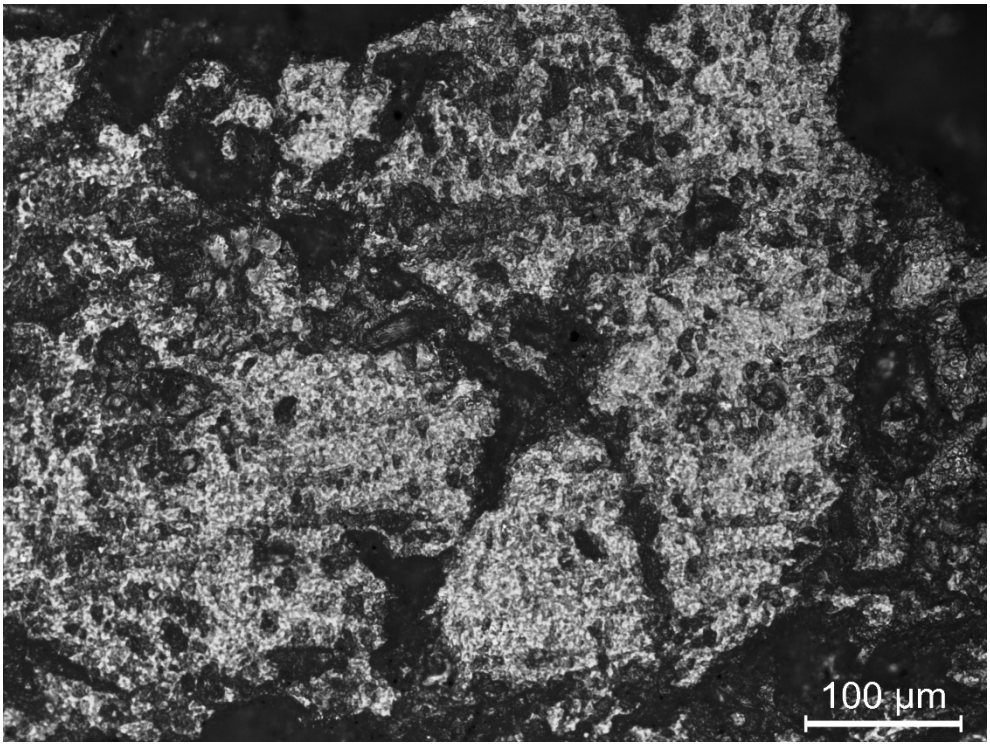

Figure 2.6 Polish with a rough texture found on the edges of the grinding slab with feet (artefact no. M371:1, 200x).

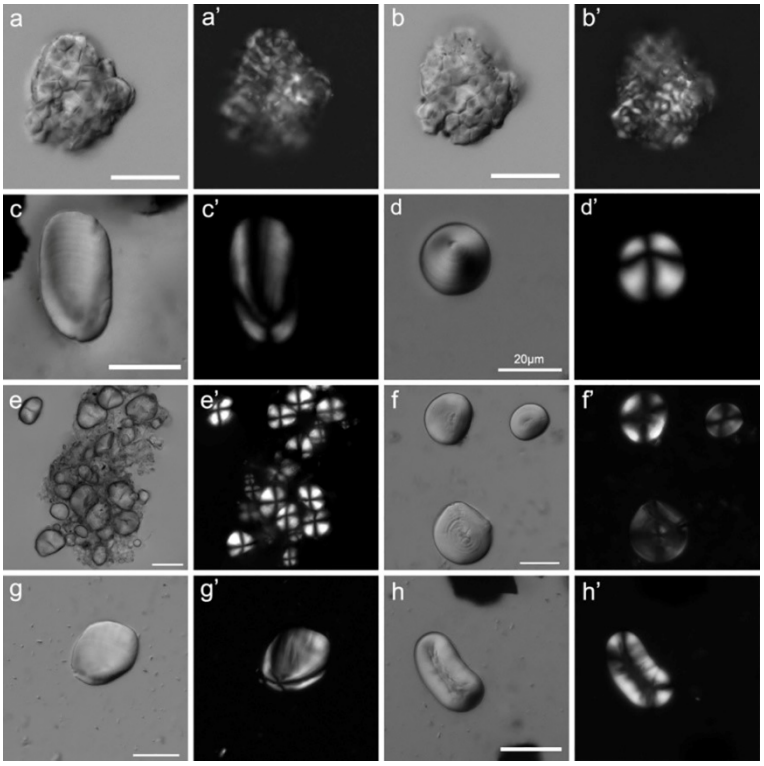

Figure 2.7 Starch grains discovered in the Jiahu grinding tool assemblage. *Oryza sativa* (a, a', b, b). *Nelumbo nucifera* (c, c'). *Trapa* spp. (d, d'). *Coix lacryma-jobi* (e, e'). Triticeae (f, f'). *Dioscorea opposita* (g, g'). *Vigna* spp. (h, h') (after Zhang, 2015).

2.5 Conclusion

The processing of cereals has been confirmed through the study of grinding implements at the site of Jiahu. The use-wear traces associated with cereal processing were very similar to those on our experimental tools used for grinding cereal to flour. This provides evidence of cereal flour production, most likely rice flour, in the upper catchment of Huai River during the early Neolithic period. In addition, use-wear traces associated with cereal processing were identified on grinding stones from all three occupation phases at Jiahu, suggesting a continuity in culinary behaviour for these early farming communities.

Apart from use-wear associated with cereal processing, wear traces resulting from the processing of wood-like material were also documented. Although the attributes of the use-wear traces do not allow for a more precise characterisation of the wood-like material that was processed, these results indicate that the grinding tools from Jiahu were not solely associated with cereal processing and demonstrate the diversity of functions of this grinding tool assemblage.

Overall, the distribution and character of the use-wear traces as well as the quantitative analysis of starch grains of the grinding tools from Jiahu indicate a correlation between tool type and function. While at present the reasoning behind certain technological choices made by the Jiahu communities such as the manufacture of grinding tools with feet eludes us, the combined results of the use wear and residue analysis indicate that specific types of grinding tools were designed to process specific kinds of substances. A series of further experiments focusing on the processing of different types of wood-like materials and their associated traces is planned and this is expected to improve our understanding of the types of materials processed and the nature of activities taking place at Neolithic Jiahu. Yet, the holistic approach used here, making use of the strengths of two different analytical methods, use wear and starch grain analysis, shows how a more detailed understanding of the technological choices of these early farmers can be achieved.

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