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Cereal processing technique inferred from use-wear analysis at the Neolithic site of Jiahu, Central China

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Abstract

Studies investigating different food processing techniques have shed light on the dietary habits and subsistence strategies adopted by prehistoric populations. They have shown that grinding cereals into flour has taken place since the Palaeolithic period, yet the grinding method employed has often not been investigated. The analysis presented here identified different types of use-wear traces associated with the dry-grinding and wet-grinding of cereals, which can be used to infer prehistoric grinding techniques. Applying this reference baseline to Jiahu, an early Neolithic site known for the earliest findings of domesticated rice in the central plain of China, reveals that dry-grinding rather than wet-grinding was employed for cereal (including rice) processing 9000 years ago. This grinding method could have been inherited from the earlier hunter-gatherers, but could also result from a broad-spectrum subsistence strategy adopted at Jiahu. By comparing the properties and ethnographic uses of different plant species, it is also suggested that cereals such as rice were a more sensible choice for the dry-grinding process.

Keywords: cereal processing; grinding; soaking; subsistence strategy; Neolithic Central China; use-wear analysis

3.1 Introduction

The ability to process food using various techniques is, along with mastery of fire and cooking, one of the key improvements that differentiated early humans from their antecedents and other animals (Wrangham, 2009; Wollstonecroft, 2011; Zink and Lieberman, 2016). Food processing facilitates the removal of undesirable substances in the raw material (Stahl et al., 1984; Johns, 1999; Stahl, 2014), helps to enhance the flavours, and extends the preservation period of foods (Caplice and Fitzgerald, 1999).

Grinding is one of the most basic forms of food processing and has been passed down from the earliest humans (Stahl et al., 1984; Wollstonecroft, 2011). In the past two decades, extensive research has been carried out on grinding implements (e.g. Van Gijn and Houkes, 2006; Tsoraki, 2007; Liu et al., 2014; Dubreuil and Nadel, 2015; Yang et al., 2015; Yang et al., 2016b; Fullagar et al., 2017). As revealed by research worldwide, a large proportion of grinding tools were employed for plant food processing (e.g. Piperno et al., 2004; Verbaas and Van Gijn, 2007; Hamon, 2008; Yang et al., 2009; Liu et al., 2016; Fullagar et al., 2017; García-Granero et al., 2017).

Depending on the plants' properties and the dietary habits preferred by different human groups, some plant species may require additional treatment before the grinding process. The study of different techniques involved in food processing practices is important as they often reflect the culinary traditions and subsistence strategies adopted by prehistoric populations (Wright, 2004; Capparelli et al., 2011). For example, enlargement and other damage features recorded on starch grains of maize recovered from ancient human dental calculus in the Caribbean (Mickleburgh and Pagán-Jiménez, 2012), demonstrated that intense grinding of hard endosperm maize kernels in their mature state was carried out as part of selection and processing behaviours associated with the consumption of bread-like foods. In another case, the state of starch grains preserved on a grinding tool discovered at an Upper Palaeolithic site in Southern Italy indicates that thermal treatment of oats was performed before grinding (Mariotti Lippi et al., 2015). This additional stage possibly was applied in order to accelerate drying of the freshly cut cereal grains to make the subsequent processes easier and faster.

The soaking of plant organs such as cereal grains is another common procedure used before grinding (e.g. Stock et al., 2000; Kethireddipalli et al., 2002; Wronkowska, 2016). Pre-soaking of cereals can neutralize compounds (e.g. phytic acid and enzyme inhibitors) that interfere with the absorption of nutrients in plants (Graf et al., 1987; Lopez et al., 2002; Soetan et al., 2010). Soaking can also stimulate the fermentation of sugar compounds in seeds, which is essential when making fermented products such as steamed cakes from rice (Rhee et al., 2011). According to the inscriptions from Bencaogangmu (an ancient Chinese book written in the Ming dynasty), wet-grinding (with a pre-soaking stage) was applied to plant processing at least 2000 years ago in China. However, whether this kind of grinding technique was employed in earlier periods has not been systematically investigated to date.

Use-wear (or "microwear") analysis has been applied to the study of grinding tools in recent decades (e.g. Adams, 1988; Gibaja Bao and Ferreira Bicho, 2015; Li et al., 2018; Liu et al., 2018). It shows great potential in inferring the worked material on tools, including bone, shell, antler, flax seeds, cereals, acorns (*Quercus* spp.) and wood (e.g. Van Gijn and Verbaas, 2009; Fullagar et al., 2012; Hayes, 2015; Hayes et al., 2017). Moreover, additives, such as water, may cause particular types of use-wear on stone tools (Grace, 1996; Van Gijn and Little, 2016), as water acts as a lubricant during the grinding process, while simultaneously softening hard plant organs such as cereal grains. Hence, use-wear analysis has the potential to give new insights into the techniques and behaviours involved in the processing of plant organs such as the grinding of soaked or dry grains.

In this study, different cereals were chosen for dry-grinding (without prior soaking) and wet-grinding processing, experimental grinding tools were selected, prepared and used to grind the cereals, and microwear analysis was conducted to measure the effect each technique had on the tool surfaces. The resulting reference baseline was then applied to the grinding tools obtained from Jiahu, an early Neolithic site in the central plain of China (Zhang, 1999, 2015) to evaluate the potential of use-wear analysis in the study of different grinding techniques and explore ancient grinding methods utilized in early Neolithic central China.

3.2 Archaeological background of Jiahu

The site of Jiahu is located in the upper catchment area of the Huai River valley (Fig.3.1A). It is the earliest archaeological site to date that clearly exhibits the characteristics of rice agriculture (Zhao, 2010). Remains from Jiahu have been radiocarbon-dated and dendro-calibrated to three sub-phases (Zhang, 1999, 2015): Phase I (ca. 7000-6500 BC), Phase II (ca. 6500-6000 BC) and Phase III (ca. 6000-5500 BC).

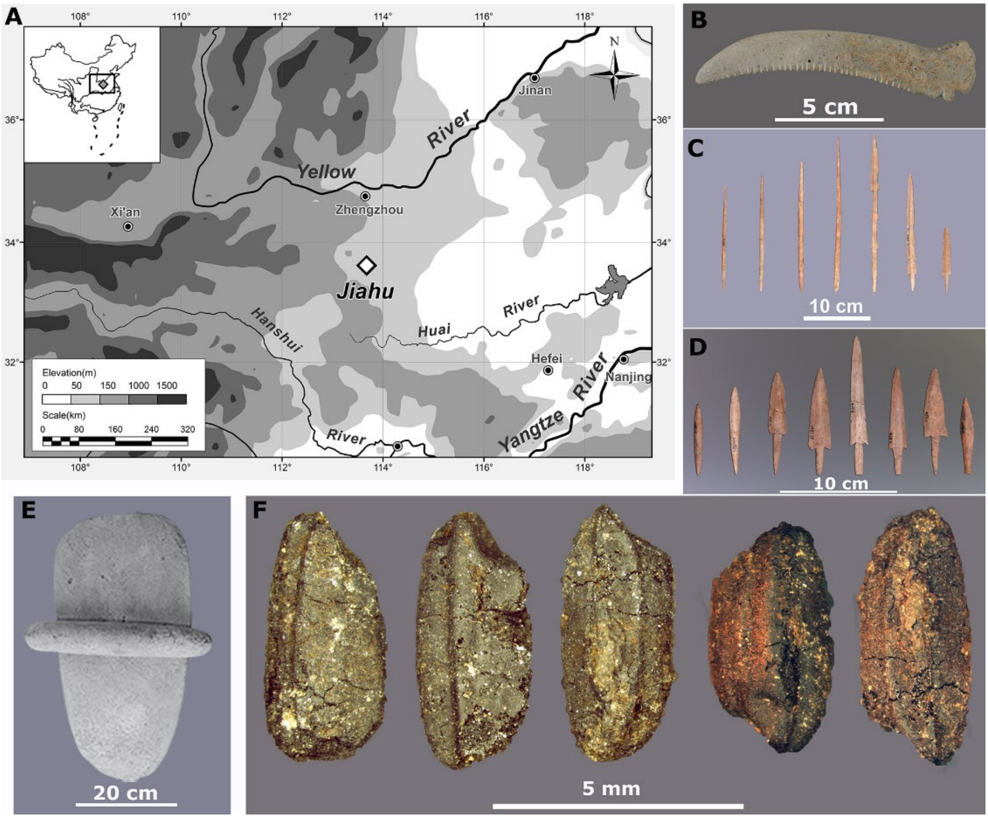

Figure 3.1 The site location of Jiahu and the previous archaeological findings. A: Jiahu in upper catchment of Huai River in the central plain of China; B: an example of the Jiahu stone sickle; C: seven fishing darts from Jiahu; D: eight bone arrowheads associated with hunting from Jiahu; E: a grinding slab without legs and a cylindrical grinding roller selected for use-wear analysis in this study; F: carbonized rice remains from Jiahu.

Rice remains (*Oryza sativa*) (e.g. Fig. 3.1F) have been recovered from all three phases (Zhang, 1999; Yang et al., 2017; Zhang et al., 2018), and were identified as domesticated rice on the basis of their morphological features (Zhang and Wang, 1998; Liu et al., 2007a). Isotope analysis of human skeletons from Jiahu indicates that C_3-based foods, including rice, dominated their diets throughout the site occupation (Hu et al., 2006). Rice was proven to be used as an ingredient for fermented beverage production 9000 years ago at Jiahu (McGovern et al., 2004).

Even though these findings revealed that rice was already part of the diet of the early inhabitants, rice agriculture might have not played a major role in subsistence practices at Jiahu (Zhao, 2010). According to the analysis of 125 soil samples taken from different contexts at Jiahu from all three phases, rice has a lower recurrence rate than other plant species, including wild soybean (*Glycine max subsp. soja*), wild grape (*Vitis* sp.), water caltrops (*Trapa* sp.) and tubers such as lotus root (*Nelumbo* *nucifera*) (Zhao and Zhang, 2009). Quantitative analysis of artefacts associated with farming, hunting and fishing reveals that agricultural tools (e.g. Fig. 3.1B) account for 26% of such activity at Jiahu, slightly above fishing tools (24.8%, e.g. Fig. 3.1C) but less than hunting tools (49.2 %, e.g. Fig. 3.1D) (Lai et al., 2009). Furthermore, fish bones and shells were abundant at the site, which were discovered from almost all trash pits (Zhang, 1999).

It can therefore be argued that although the inhabitants of Jiahu started rice agriculture on a small-scale during phase 1, hunting, fishing, and gathering were still their main subsistence strategies throughout the site occupation (Lai et al., 2009; Zhang and Hung, 2013; Zhou, 2014).

3.3 Material and methods

The site of Jiahu offers a good opportunity to study the grinding techniques in the early Neolithic period, with grinding slabs (lower tools) and rollers (upper tools) predominant in the stone tool assemblage (Zhang, 1999). Previous starch analysis has revealed that grinding tools from Jiahu were used for processing cereals, including rice (Zhang, 2015). Use-wear analysis confirmed this result and indicates that cereals were mainly processed on grinding slabs without feet and cylindrical grinding rollers (Li et al., 2018).

In this study, ten grinding slabs without feet and five cylindrical grinding rollers were chosen (Table 3.1, e.g. Fig. 3.1E). These grinding tools were made from medium to coarse-grained sandstone (Cui et al., 2017). All of these artefacts have clear grinding surfaces, enabling the identification of the used areas for sampling.

Because archaeological grinding tools could not be taken out of the Chinese museums, use-wear samples were collected by using Provil polyvinyl siloxane (PVS) after cleaning the tools. 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 grinding rollers. Each PVS sample is nearly two by two centimetres in size. This sampling technique was described and used in several previous studies (e.g. Liu et al., 2016; Fullagar et al., 2017).

Four grinding experiments were undertaken at the Laboratory for Material Culture Studies at Leiden University, including grinding rice and foxtail millet (*Setaria italica*) into flour in both dry and wet states. Experimental research suggests that use-wear traces associated with plant processing develop after a duration of 15 to 25 minutes during the use of the tools (Fullagar et al., 2012; Hayes et al., 2017). In order to allow for the development of pronounced use-wear traces, each of our grinding experiments was conducted manually for 180 minutes. Medium to coarse grained sandstone materials from the riverbed of the Maas in the Southern Netherlands were used as the experimental grinding tools. Each tool was observed under metallographic microscopes to ensure there was no use or notable damage before the experiments. The rice and foxtail millet used for processing were originally from the Northeast and Shanxi Province of China respectively.

To prepare soaked rice and foxtail millet, the de-husked dry cereal grains were soaked in clean water for ten hours. After the experiments, the grinding tools were cleaned with tap water and detergent. Then the experimental grinding tools were examined under a Leica M80 stereomicroscope to locate any residues and to obtain a general view of the polished zones. Zones with well-developed use-wear traces on the stone surface were located and sampled using PVS for further observations and comparisons with the archaeological use-wear samples.

The experimental and archaeological use-wear PVS samples were observed under a Leica DM6000M metallographic microscope, with magnification up to 630x. The use-wear features observed include micro-striations (including their general distribution on the tools), residues, and micro-polish. Micro-polish was studied in terms of directionality, degree of linkage, texture, morphology, reflectivity, and location on the micro-topography of the stone surface (after Adams et al., 2006). Use-wear features are described using a standardized terminology (Table 3.2).

3.4 Results

The results obtained from the experimental tools indicate that differences between use-wear traces associated with both dry-grinding and wet-grinding are significant, especially of the produced texture and morphology of micro-polish (Table 3.3). The use-wear traces developed from grinding rice and foxtail millet were similar using the identical grinding method. Micro-polish developed on experimental tools used for grinding dry rice and foxtail millet is granular, reticular and moderately reflective (Fig. 3.2A, B, C, and D). It is developed across the tool surface forming distinctive patches but is not well linked. Only a few shallow striations alongside the polish with rough texture are detected in the edges of the tools. The polish with rough texture was formed because of stone-on-stone contact where less processed material accumulated in the edges of the grinding tools.

Micro-polish developed on stone tools used for grinding soaked rice and foxtail millet is characterized by flat-looking polish alongside the granular polish on the higher micro-topography of the stone surface (Fig. 3.2E, F, G, and H). This kind of use-wear trace develops in patches. It is not well linked. The flat-looking polish is rough and moderately reflective. Striations are not observed on the stone surfaces.

Following 180 minutes of each grinding exercise, the density of micro-polish associated with the grinding of wet grains is observed to be lower than the polish associated with dry-grinding.

Considering that the raw material of the experimental tools, the duration of the grinding exercises, and the manner of processing are all consistent in this study, it is very likely that different properties of cereals before and after soaking contributed to the formation of different types of use-wear traces. Soaked grains became softer and enabled much easier grinding. As observed in the experiments, the flour produced after the grinding of dry grains is distributed all over the stone surface, whereas, the flour after the grinding of wet grains is sticky and forms "noodle or roll shapes" (Fig. 3.3). As a result, it seems that the surfaces of the grinding tools were exposed, leading to more contacts between upper and lower tools during the grinding process. This direct stone-on-stone contact when grinding wet grains could have resulted in the formation of rough and flat-looking micro-polish associated with wet-grinding.

The analysis of the archaeological samples shows that use-wear traces associated with cereal processing was detected on 14 grinding tools (Table 3.1). This type of use-wear is characterized by a granular and reticular appearance but without rough and flat-looking polish (e.g. Fig. 3.4A and B). The polish is moderately reflective and mostly appears on the higher micro-topography of the stone surface. The directionality of the polish development is parallel to the long axis in the case of the grinding slabs and perpendicular to the long axis for the rollers. The grinding roller H152:2 only shows polish with rough texture near its handling area. Therefore, the grinding technique employed on this tool was undetermined (Table 3.1).

Overall, the use-wear features of the grinding tools from Jiahu are consistent with experimental tools associated with grinding dry cereals into flour. This suggests that these grinding tools were very likely used for producing dry flour in the early Neolithic period.

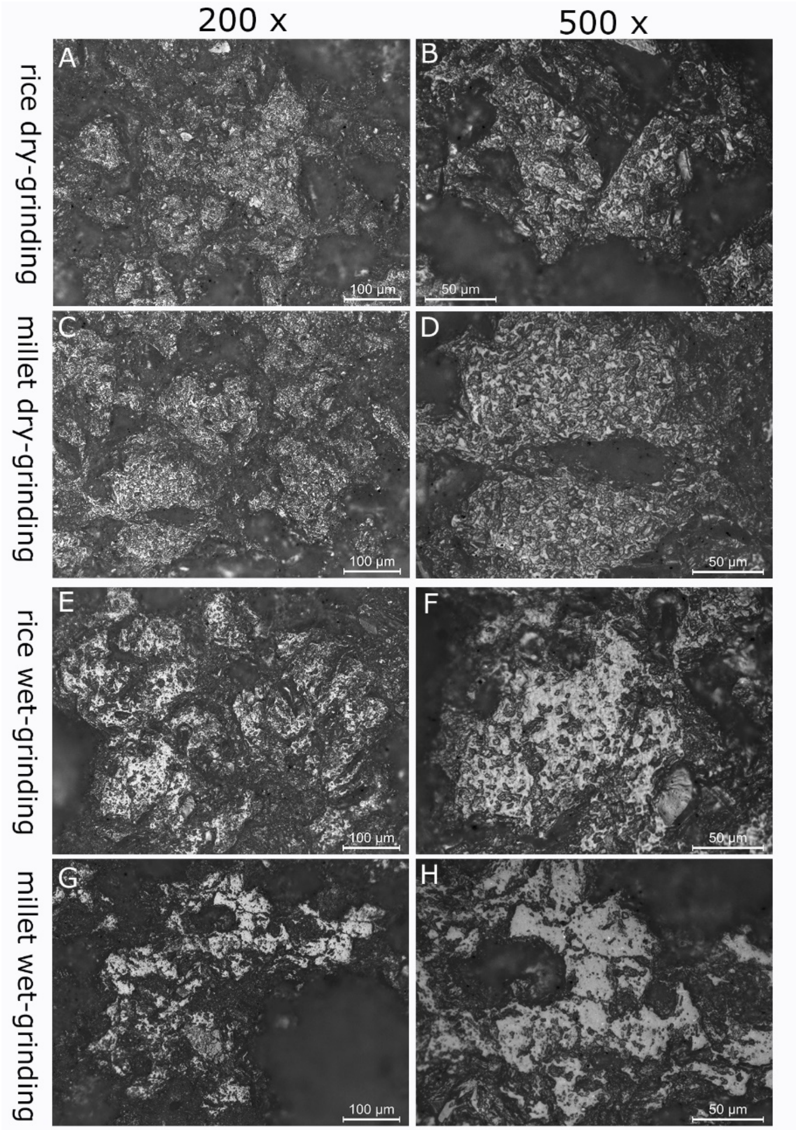

Figure 3.2 Use-wear traces on experimental grinding stone tools under the magnification of 200x and 500x. Use wear associated with processing dry rice (A and B , after 180 min) and foxtail millet (C and D, after 180 min) both characterized by granular, greasy and reticular micro-polish; Use-wear traces associated with processing soaked rice (E and F, after 180 min) and foxtail millet (G and H, after 180 min) consist of rough and flat-looking micro-polish alongside granular micro-polish.

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Figure 3.3 Soaked rice flour forms the "noodle shapes" during wet-grinding (the ellipse illustrates the exposed stone surface).

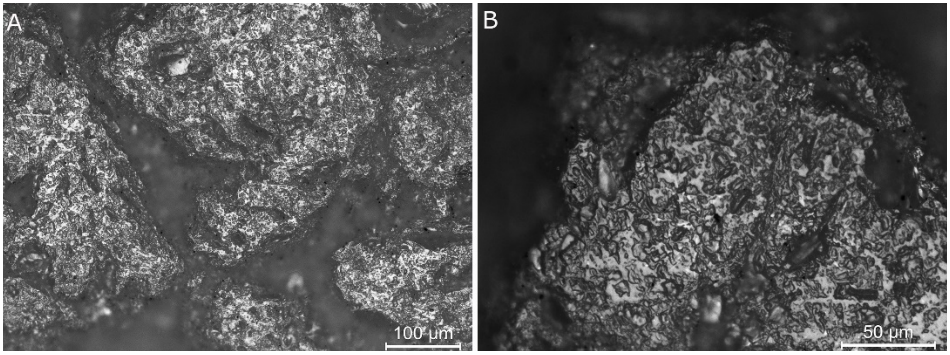

Figure 3.4 Use-wear traces associated with dry-grinding of cereals on Jiahu grinding tools under different magnifications (A: 200x and B: 500x).

3.5 Discussion

Flour has been part of the human diet since the Palaeolithic period in Eurasia (e.g. Aranguren et al., 2007; Revedin et al., 2010; Liu et al., 2013; Mariotti Lippi et al., 2015).

In the Jiahu region, a few fragments of grinding tools were discovered at the site of Lingjing, dating to the period 12000-11000 BC, before the beginning of agriculture (Yang et al., 2016a). Starch grain analysis suggests that these grinding implements were associated with the processing of tubers and grass seeds such as Job's tears (*Coix lacryma-jobi*) and some Triticeae tribe specimens (Yang et al., 2016a). It is clear that grinding as a food plant processing technique has its roots in the culinary preferences of earlier hunter-gatherers in this area. Thus, it seems plausible to suggest that dry-grinding at Jiahu could have been inherited from earlier developments, remaining an important food processing behaviour.

Dry-grinding could have been a practical culinary practice for the Jiahu community rather than just a habitual choice. The early inhabitants of the Jiahu site mainly relied on hunting, fishing and gathering from phase 1 to phase 3 (Lai et al., 2009; Zhao and Zhang, 2009). This mixed subsistence strategy may have caused them to be highly mobile, thus requiring a larger territory to satisfy their needs. This is supported by geological data and field investigations which indicate that the inhabitants of Jiahu acquired the raw material for their stone tool production within a range of 24 - 50 kilometres from the site (Cui et al., 2017). Easily portable food may therefore have been fundamental to the Jiahu community, as this would allow them to have greater mobility and autonomy. Compared to wet flour, which is a product that quickly gets mildew after its production (Adams, 1999), dry flour is suitable for long-term storage and is an easily portable food. Dry flour is also suited to the preparation of a diverse array of foodstuffs and is characterized by its high-energy content (McSweeney and Day, 2016). The inhabitants of Jiahu could have recognized all these qualities of dry flour and hence included dry-grinding as an integral part of their food processing practices.

However, fewer grinding tools have been discovered in the period when agriculture was established in the Jiahu area, around 5000-3000BC (Zhang, 1999). This seems surprising as grinding tools were often associated with agriculture in the Neolithic period (e.g. Chen, 1990), although, in contrast to the Jiahu community with its broad-spectrum subsistence strategy, farming became the major subsistence economy in the later period. It has been argued that food processing required significant energy from the early inhabitants (Keene et al., 1985). However, grinding, a time-consuming and labour-intensive activity, is not necessarily required for preparing and consuming cereals. Hence, it would make sense to find another way of cooking especially when easily portable food such as dry flour possibly became less practical to the settled farmers. Gradually, grinding and related culinary behaviours could have been replaced by other food processing behaviours such as boiling, which remains the most common method for cooking cereals such as rice in present-day China, whereas the grinding of rice is only carried out to make particular Chinese foods. For example, wet-grinding of rice is conducted to make mixian (rice noodles) and niangao (rice cake) (Chiang and Yeh, 2002), while dry-grinding of rice is conducted to make tangyuan (rice dumpling).

The dry-grinding technique employed by the inhabitants at Jiahu also helps to understand why cereals were chosen as the dominant processed material, as shown by use-wear and starch results (Zhang, 2015). Prehistoric plant food resources at Jiahu were diverse, as revealed by the macrobotanical evidence (Zhao and Zhang, 2009), among which, acorns (*Quercus* spp.) and wild soybeans are salient. Acorns contain bitter and astringent tannins that require different processing techniques in order for them to become edible (Egounlety and Aworh, 2003), including soaking, boiling, drying, and grinding (Egounlety and Aworh, 2003; Hosoya, 2011). The seed size and the hardness of soybeans make them very difficult to process by means of direct dry-grinding, so pre-soaking needs to be carried out when making different bean products, such as tofu. In contrast, pre-soaking is not a pre-requisite for those grains which only contain small amounts of phytic acid (Liu et al., 2007b). As the small grain size of cereals is also suitable for the dry-grinding process, when dry flour was needed, cereals such as rice would be a timesaving choice.

3.6 Conclusion

This research has revealed that the micro-polish developed due to dry-grinding and wet-grinding of cereals is different in terms of the resulting texture and morphology of micro-polish. This offers an approach to infer ancient food-processing techniques by analysing the used areas of the prehistoric grinding implements. Although wet- and dry-grinding are both common processing practices in present day, our results from the experimental approach indicate that ancient grinding tools from Jiahu were used to grind dry cereals.

Dry grinding very likely remained as a habitual food processing practice at Jiahu because grinding of food plants had its roots in the previous culinary practices of earlier hunter-gatherers. It is also possible that dry-grinding products (dry flour) were more practical and appropriate for a particular way of living of the Jiahu community than wet flour, and thus the dry-grinding technique may have been more valued at the site. This specific grinding process employed at Jiahu also helps to understand why cereals were chosen over other potential food plants. Compared to other plant species unearthed at Jiahu, cereals such as rice have a lower quantity of anti-nutrients and have more suitable grain size, making them better suited for the dry-grinding process. Overall, this study demonstrates the appropriateness of use-wear analysis of grinding tools at providing new insights into the subsistence strategies and culinary behaviours of one of the most fascinating development stages of Neolithic China.

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