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

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Front cover: a pair of Neolithic grinding tools unearthed at the site of Jiahu, China

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Chapter 1 Introduction

Around 12,000 years ago, humans started a gradual transition from foraging to agriculture, which coincided with the end of the last Ice Age and the beginning of the recent geological epoch, the Holocene (Balter 2007; Purugganan and Fuller 2009). This agricultural revolution forever changed how humans live, eat, and interact. Since then, the human population was able to grow exponentially because crops and animals could be farmed to meet demand. This revolution also stimulated significant developments in social organization and technology, paving the way for 'modern civilization'. Even though the exact reasons for the transition are still under debate (e.g. Weisdorf 2005; Barker 2009), evidence of foragers transitioning to farmers has been documented worldwide (e.g. Zhang and Hung 2012; Asouti and Fuller 2012; Hung and Carson 2014; Rowley-Conwy 2014).

China was one of the world's primary centres of independent agricultural development. The most thoroughly studied early agricultural societies in China are located along the Yangtze and Yellow River Valleys, which provide some of the oldest firm evidence for formalized rice (*Oryza sativa* L. [1]) and millet (*Setaria italica* L. and *Panicum miliaceum* L.) farming. So far, the earliest remains of millet have been recovered from pottery sherds as well as from lithic grinding tools from the sites of Nanzhuangtou (c. 9500-9000 BC) and Donghulin (c. 9000-7500 BC) in the upper Yellow River valley, as attested by starch grain analysis (Yang et al. 2012). In the lower Yangtze River valley, charred rice remains embedded in potsherds at the site of Shangshan (c. 9000-7000 BC) form the earliest record of the use of this plant (Jiang and Liu 2006). These rice remains were identified as a more primitive variety with some properties of modern japonica or tropical rice (Zhen and Jiang 2007).

Notably, the upper catchment of Huai River (UCHR), which is a transitional climatic zone between northern and southern China, also has some of the first significant occurrences of domesticated rice, dated to 7000 BC (Zhang and Wang 1998; Liu et al. 2007). In this area, further studies at the site of Tanghu, suggested that mixed farming of broomcorn millet (*Panicum miliaceum* L.) and rice was practised as early as 5800 BC (Zhang et al. 2012). These novel findings revealed that the UCHR region was also one of the centres for early agriculture development. Because of the geographic location of the UCHR, more studies in this region hold great potential to offer more data to understand the natural and cultural reasons underlying choices

[1] Scientific names are noted when plants are firstly mentioned in each chapter. For the rest, common names are used.

made by different early farming groups. This dissertation aims to contribute to this goal by studying Neolithic foodways in the UCHR region (Fig. 1.1).

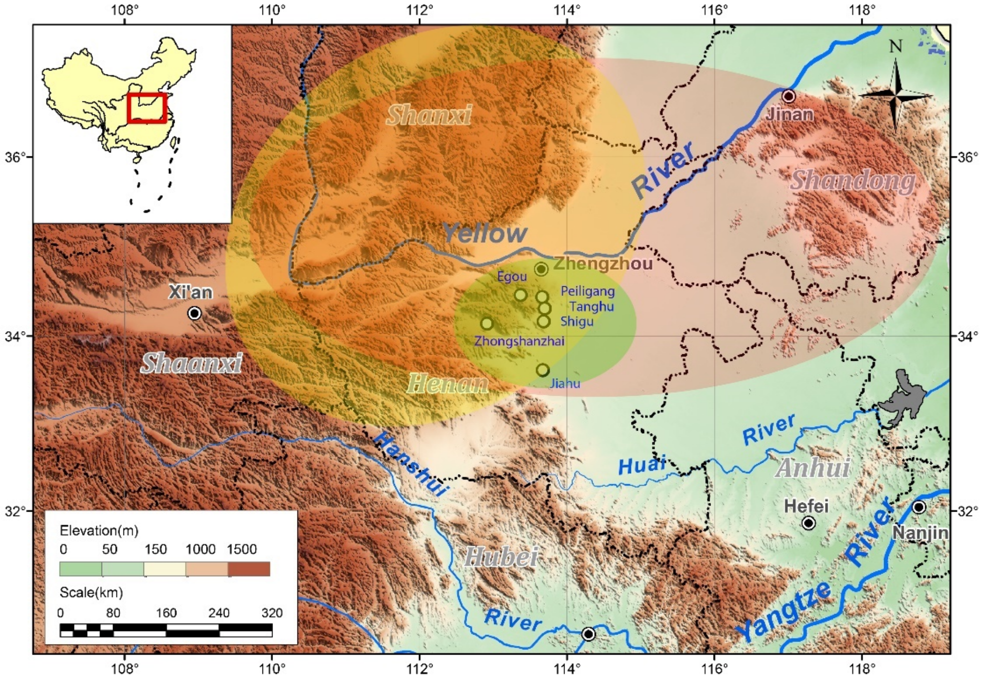

Figure 1.1 The location of the sites attributed to the Jiahu and Peiligang Culture sites. The general distributions of the Peiligang-Jiahu Culture, Yangshao Culture, and Longshan Culture are highlighted in green, yellow, and red colour accordingly (© Weiya Li).

Food is a broad topic in archaeology because it provides insights into past human diet, subsistence, as has the potential to offer insights into social phenomena such as status, ethnicity, gender, and religion (Samuel 1996; Gumerman 1997; Twiss 2012; Ma 2015; Hastorf 2017). As has been proposed by Brillat-Savarin (1862) and later repeated or rephrased by many others (e.g. Doolittle 1998; Liang and Silverman 2000; Pietrykowski 2004; Vartanian et al. 2007): you are what you eat. It should be noted that food-related activities may also have a powerful impact on the human body. For instance, when using a sickle to harvest rice, people must bend their bodies and repeat tedious cutting movements all day long. Hunting also requires people to run, throw spears or shoot arrows repeatedly. When processing food, ethnographic research, and iconographic sources (Fig. 1.2) show many grinding tasks were conducted by people who have to kneel on the ground and engage in a back and forth movement again and again (Arthur 2014; Robitaille 2016; Shoemaker et al. 2017). After a prolonged period, these activities would inevitably sour the knees and arms, and eventually leave marks on human bones, which can be investigated archaeologically (e.g. Sadvari et al. 2015; Larsen 2015). In addition to these physical effects on human bodies, interactions involved in these activities between humans, tools, and nature also played important roles in shaping cultural practices in different regions (Reynoso Ramos 2004; Cheung 2007; Yasmeen et al. 2008; Staller and Carrasco 2010; Simms 2013). It thus seems more sensible to argue that: "We are not only what we eat", but also "how we carry out different food-related activities". In other words, our lives can be reflected in our 'foodways', a term that refers to all kinds of activities, rules, and meanings that surround the procurement, processing, storing, cooking, serving, and consumption of food (Peres 2017).

Because the concept of foodways is wide-ranging, a collaboration between specialists from different disciplines becomes the absolute key to understanding the breadth and diversity of past foodways. This dissertation focuses on a set of archaeological grinding tools in order to make them 'speak' more about a crucial aspect of foodways: food processing. The data obtained are combined with previous studies on food and food-related activities to deliver a more comprehensive study of Neolithic foodways of the earliest farmers in UCHR. The foremost reason for choosing grinding tools is because these artefacts are often involved in food processing in the past and the present worldwide (Aranguren et al. 2007; Liu et al. 2010a; Portillo et al. 2013; Portillo Ramírez et al. 2014; Fullagar et al. 2015; Shoemaker et al. 2017; Dietrich et al. 2019). These implements were also closely associated with the early agricultural societies in the region of UCHR, especially at the sites attributed to the Jiahu Culture (c. 7000-5500 BC) and Peiligang Culture (c. 7000-5000 BC) (Kaifeng Cultural Relics Management Committee of Xinzhen 1978; Li 1979; Zhang 1999; Xin et al. 2010; Yang et al. 2017), where evidence of exploitation of rice and millet were discovered (Table 1.1). Compared to grinding tools unearthed from contexts dated to the Upper Palaeolithic in China (e.g. Liu et al. 2011; Liu et al. 2013), Neolithic grinding tools were well-designed with symmetrical shapes (Fig. 1.3). Some of the grinding slabs (lower tools) were even manufactured with four short 'feet'. Wang (2008) has tried to make a replica of a grinding slab with feet using hammerstones. After three days of pounding, only a rough shape of the slab was formed, and one of the feet was even broken because of a small mistake. Thus, we can envision that early Neolithic people invested a considerable amount of time and energy into the design and manufacture of grinding tools. Interestingly, the number of similar types of grinding tools dramatically dropped when agriculture became the primary subsistence strategy during the later Yangshao Culture (c. 5000-3000 BC) in the UCHR region (Sun 2001). More studies on these Neolithic grinding tools have the potential to understand why these objects seem more important to the early farming societies.

Overall, studies of grinding tools can contribute to the understanding of different aspects of past human practices. Dubreuil and colleagues (2015) among others have suggested that the life history of a lithic tool is often associated with several stages including raw material procurement, manufacture, primary and secondary use, recycling, discard, and lastly, post-depositional processes. The investigation and reconstruction of these different stages allow us to address broader questions such as resource exploitation, ancient technological practices and ancient belief systems (e.g. Adams 1999; Ebeling and Rowan 2004; Van Gijn and Houkes 2006; Tsoraki 2007; Van Gijn and Verbaas 2009; Delgado-Raack et al. 2009; Rosenberg and Gopher 2010; Shoemaker et al. 2017; Tsoraki 2018; Lucarini and Radini 2019), which provide important information when evaluating changes accompanying the agricultural revolution in different societies.

Figure 1.2 A grinding scene depictured in the chapel of a tomb during the Old Kingdom (2592-2120 BC) in Egypt. Note: the two people on the left kneeling on the ground conducting grinding tasks, and the produced flour is depicted between the two grinding tools (photo taken by Weiya Li at the National Museum of Antiquities at Leiden, Netherlands. According to the official website of the museum https://www.rmo.nl/en/research/photo-service/ "The images (content) are made available under a CC BY licence, which means that you are permitted to copy, adapt, distribute, or perform this material without permission from the National Museum of Antiquities").

1.1 The research region

This dissertation gives central stage to the UCHR located in the present-day Henan province in China. The province covers an area of 167,000 km^2, approximately four times the size of the Netherlands. Currently, Henan province has the third-largest population in China, with nearly 100 million inhabitants. In Chinese, 'he' and 'nan' literally means 'river' and 'South' respectively, so Henan refers to the place to the South of the Yellow River. It should be noted that a small part of Henan is located to the North of the Yellow River. Meanwhile, the Huai River originates from the Tongbai Mountains of Henan province and flows 360 km inside the province and flows to the Yellow Sea. Thus, Henan is often described as the region in the middle and lower catchment of Yellow river or the UCHR. Because of its central location, Henan is also called zhongyuan in Chinese, which means the central plain of China.

It is worth mentioning that geographically in the narrow sense, the Central Plain also covers the southern part of Hubei, the southern part of Shanxi, and the western part of Shandong province. A broader interpretation would add the Guanzhong plain of Shaanxi, the north-western part of Jiangsu, and parts of Anhui and northern Hubei as well (Fig. 1.1).

Henan is a hotspot for Chinese archaeology. The recent finding of the Late Pleistocene archaic human crania from the Xuchang city proves that humans appeared in this region at least 100, 000 years ago (Li et al. 2017). Neolithic archaeological cultures discovered here include the Peiligang Culture, Jiahu Culture, Yangshao Culture, and Longshan Culture (Table 1.1, Fig. 1.1). Additionally, Henan has been important for Chinese civilization since the beginning of recorded history. Before the Qin dynasty (221-207 BC), present-day Luoyang and its nearby areas in Henan Province were considered the "Centre of the World" "because it was the political seat of the Xia dynasty (c. 2070 - 1600 BC) was probably located there. The city of Anyang in Henan later was also served as the capital for the Shang dynasty (c. 1600 - c. 1046 BC) for 264 years.

Nowadays, the Henan Province has a subtropical climate that is humid, with an average temperature of 14 °C annually (Chang et al. 2011). The weather roughly corresponds to Central European atmospheric conditions. Summer in Henan is hot and humid due to the East Asian monsoon. Also, most of the annual rainfall occurs during the summer. Winter is generally cool to cold, windy, and dry, with the influence of the vast Siberian anticyclone. Studies have indicated that the climate in Henan was warm and humid around 3000 to 1000 BC (Dong et al. 2007; Li et al. 2015). The temperature was even about two degrees warmer than present day average temperature and multiple climate fluctuations were detected in this region, including a sudden decrease in temperature between 3400 BC and 2000 BC (Dong et al. 2007; Li et al. 2015). West of the Henan Province, results from palynological analysis suggest that vegetation in this area changed from a broad-leaved deciduous forest (7230-6850 BC) to a steppe-meadow ecoregion (6850-5550 BC), and then the vegetation transitioned to steppe ecoregion with sparse trees (5550-2920 BC) (Zhang et al. 2018).

1.2 A brief introduction to Chinese archaeology and the Neolithic archaeological cultures in the research region

Thanks to the fastest growing economy since the 1980s, the Chinese government has been able to finance numerous archaeological excavations and projects in and outside of the country. However, for many decades before the 21st century, comprehensive English books on Chinese archaeology were limited. The most popular one has been "The Archaeology of Ancient China" written by Kwang-Chih Chang (1963). Although more books and publications have come out in recent years (e.g. Liu and Chen 2012; Underhill 2013), Chinese archaeology is still not well-known outside of China. Thus, a brief introduction to Chinese archaeology and Neolithic cultures in the research region are necessary.

1.2.1 Development of Chinese archaeology

China has a long history of studying its archaeological remains. Since the 11th century, scholars from the Northern Song dynasty (960-1126 CE) have studied ancient bronze and jade artefacts. The western-style archaeological fieldwork methods, however, were not practised in China until the collapse of the last imperial Qing dynasty (1644-1911 CE). In 1914, the first excavation was conducted by the Swedish geologist J. G. Andersson in Anyang of Henan Province. This excavation found the 'Yangshao Culture', which is characterized by painted pottery (Andersson 1923). Back then, Yangshao Culture was considered the earliest Neolithic Culture in China. Soon after that, Chinese archaeologists carried out excavations elsewhere by themselves. One of these early Chinese archaeologists was Ji Li, who organized the excavation at Yinxu near Anyang from 1928–1937 until the outbreak of the Second Sino-Japanese War (1937–1945). The archaeological evidence at Yinxu confirmed the existence of the Shang dynasty (c. 1600 BC to 1046 BC) for the first time. This fruitful excavation was later acknowledged as the beginning of modern Chinese archaeology (Liu and Chen 2012).

After the establishment of the People's Republic of China in 1949, more archaeological research was able to be carried out. Large quantities of archaeological data have been accumulated across China from all periods. For example, the excavations of Palaeolithic sites at Zhoukoudian, Lantian, and Yuanmou offered valuable data for the study of early human evolution (Rightmire 1996). Additional investigations of the earliest remains of the Xia and Shang dynasties carried on (Liu and Xu 2007). For present-day Chinese archaeologists, three major topics have become the focal points: the origins of early humans, the origins of agriculture, and the origins of civilization (Liu and Chen, 2012).

1.2.2 Neolithic Cultures in the Central Plain of China

In different regions in China evidence of Neolithic cultures has been recovered, which have been primarily classified based on their unique ceramic traditions. According to Liu and Chen (2012), Neolithic cultures in China can be generally divided into three phases: Early Neolithic (7000-5000 BC), Middle Neolithic (5000-3000 BC), and Late Neolithic (3000-2000 BC). The following sections briefly summarize the Neolithic Cultures in the research region (Table 1.1).

Peiligang Culture (c. 7000-5000 BC)

The Peiligang Culture is named after the site discovered in 1977 at Peiligang (Li 1979), a village in Xinzheng, Henan Province. The site of Peiligang dates to c. 6200–5600 BC. After the discovery of the site of Peiligang, more than 120 locations attributed to the Peiligang Culture have been identified so far. The Peiligang Culture sites can be classified into two types based on their location in the landscape: a) sites on alluvial plains are generally large, with thick cultural deposits; b) sites on hilly lands are small, with thin deposits and fewer remains. Liu and Chen (2012, p. 144) have argued that "the former types are larger in size, with thicker deposits and more elaborate material assemblages, which may suggest higher levels of sedentism and more complex social organization, while some of those in hilly areas are likely to have been seasonal campsites or small villages". Other sites assigned to the Peiligang Culture include Tanghu (Kaifeng Cultural Relics Management Committee of Xinzhen 1978; Zhang et al. 2008; Xin et al. 2010), Egou (Yang 1979), and Shigu (Guo and Chen 1987) among others.

Ground stone tools unearthed from the Peiligang Culture sites include grinding tools, axes, chisels, awls, and sickles. Pottery was made by coiling and was mostly unpainted and sometimes decorated by stamping and impressing. Macrobotanical remains or phytoliths from millet (broomcorn millet or foxtail millet) have been found at many of the sites attributed to the Peiligang Culture (Table, 1.1, Lee et al. 2007; Wang et al. 2017). Only two of the Peiligang Culture sites (i.e. Tanghu and Zhuzhai) cultivated both rice and millet (also, see below in section 1.4, Zhang et al. 2012; Bestel et al. 2018). It is also believed that the Peiligang Culture was non- hierarchical, with little political organization (Liu 2004, pp. 74–78).

Jiahu Culture (c. 7000-5500 BC)

The Jiahu Culture is named after the discovery of Jiahu in Wuyang, Henan Province. Many archaeologists consider Jiahu as one of the Peiligang Culture sites because these sites were all located in the region of UCHR with many similar material culture remains, such as grinding tools and denticulate sickles (e.g. Liu and Chen, 2012). In contrast to the main Peiligang Culture settlements that were located on alluvial plains in central Henan, albeit at slightly higher altitude (Fig. 1.1), Jiahu is situated to the south of Henan, near two rivers and a lake. The different ecologies of Jiahu and the main Peiligang Culture settlements (wetland versus relatively dry) likely resulted in their different choice in agriculture (Wang et al. 2017). For example, the Jiahu inhabitants cultivated rice while a majority of the Peiligang Culture sites practised millet farming (Zhang and Wang 1998; Zhang and Hung 2013). The only exceptions are the Peiligang Culture sites of Tanghu and Zhuzhai, where both rice and millet were cultivated (Zhang et al. 2012; Bestel et al. 2018). Jiahu also possesses some unique findings that have not been encountered in any of the other Peiligang Culture sites, including playable musical instruments (Zhang et al. 1999; Zhang et al. 2004), evidence for fermented beverages (McGovern et al. 2004), and the earliest examples of Chinese inscriptions (Li et al. 2003). Because of these findings as well as some other differences reflected in burial traditions, pottery, and percentage of different types of tools used in agriculture, hunting, and fishing, some archaeologists have proposed that Jiahu represents a different Culture (Zhang 1989; Chen 2014). So far, many of the detected Jiahu Culture sites have not been excavated except for the sites of Jiahu and Zhongshanzhai (Fang 1978; Yang 1986; Zhang 1999; Zhang 2015; Yang et al. 2017).

Yangshao Culture (c. 5000-3000 BC)

The first discovery of the Yangshao Culture was made by A. J. G. Andersson in Mianchi County, Henan Province in 1921 (Andersson 1923). The settlement patterns and social organization associated with the Yangshao Culture show great variability in time and space, reflecting the broad temporal and spatial expanse of this culture. The Yangshao Culture is conventionally divided into three phases: the early period (or Banpo phase, c. 5000–4000 BC), the middle period (or Miaodigou phase, c. 4000–3500 BC), and the late period (c. 3500–3000 BC). The Yangshao is characterized by fine white, red, and black painted pottery with human facial, animal, and geometric designs. Sedentary farming societies were well established, indicated by frequent discoveries of remains from domesticated plants and animals (Zhao 2011). Social inequality was believed to have emerged during the Yangshao Culture period (Xu 2001). Unlike the previous Peiligang and Jiahu Cultures, only a few grinding tools have been found in Henan in the Yangshao period, suggesting that rice was processed in a different way, which may explain the reason for a lack of grinding stones from all Yangshao Culture sites (see also Chapter 3).

Longshan Culture (c. 3000-2000 BC)

The Longshan Culture was first identified at the village of Chengziya in the Province of Shandong in 1928. The site is named after the nearby town called Longshan, which literally means dragon mountain. The culture is also distributed in other Provinces along the middle and lower catchment of the Yellow River, including Henan, Shanxi, and Shaanxi. The Longshan Culture was noted for its highly polished black pottery that often been called egg-shell pottery (Underhill 1991; Underhill 1996). Crops found in Longshan settlements include foxtail millet, broomcorn millet, rice, and wheat, and yet only a few grinding tools were encountered (Ceng 2012). The most common source of meat was pig, while remains from sheep and goat were also found in western Henan by 2800 BC (Li 2001). During the Longshan period, population density dramatically increased. Many of the Longshan settlements were less than 0.5 km^2 and distributed in equidistant patterns over the landscape (Liu and Chen 2012). Studies also show that violence and warfare increased and human sacrifice intensified during the later Longshan period (Shao 2002; Zhao 2013). Around 2000 BC, the Longshan Culture was gradually replaced by the Erlitou Culture (c. 1900-1600 BC) that was probably associated with the Xia dynasty (Xu 2009; Liu 2009).

Table 1.1 Chronology, dating, and some key findings in the Neolithic cultures mentioned in this chapter. Note: each culture has been divided into several phases and this table only displays the general features of the cultures (see more detailed information by Liu and Chen, 2012)

	Dating	Key agroeconomic crops	Key findings
Peiligang Culture	c. 7000 to 5000 BC	millet	grinding tools, denticulate sickles, unpainted pottery
Jiahu Culture	c. 7000 to 5500 BC	rice	grinding tools, denticulate sickles, unpainted pottery, flute, turtle shell with pebbles
Yangshao Culture	c. 5000 to 3000 BC	millet, rice	painted pottery
Longshan Culture	c. 3000-2000 BC	millet, rice, and wheat	thin-walled and polished black pottery

1.3 Overview of previous studies and research questions

In China, the earliest grinding tools can be dated to the late Palaeolithic period, represented by the sites of Shizitan in Shanxi and the site of Longwangchan in Shananxi Province in Northern China (Liu et al. 2013; Zhang et al. 2011). According to previous research conducted by Liu and colleagues (2013), the majority of these Palaeolithic grinding tools were used for processing wild plants by hunter-gatherers. In the early Neolithic, more grinding tools were found in the region of UCHR, where grinding slab artefacts (lower tools) can be generally divided into two types on the basis of typological classification: a) slabs with feet, and b) slabs without feet (Zhang 1999; Zhang et al. 2008). The rollers (upper tools) can be divided into different types based on the shape of their cross-sections, which usually include round, triangular, or ovate. The predominant raw material used to produce grinding tools was coarse-grained sandstone. For instance, at Jiahu, all of the analysed grinding slabs (n=52) and 94.7% of the grinding rollers (n=72) were made from sandstone (Cui et al. 2017), whereas other implements such as stone axes, adzes, and chisels were mainly made from diabase or diorite, and shovels from schist stone. The preferences of using specific stone raw materials for lithic tool production reflect that the inhabitants in this region possessed a good level of knowledge of physical properties of rocks. Field surveys conducted around the Neolithic sites indicate that raw materials used for stone tool production were procured from the nearby mountains or the riverbed (Cui et al. 2017).

Figure 1.3 Well-manufactured grinding slab and roller from the Neolithic site of Jiahu in the upper catchment of the Huai River (© Weiya Li).

Distribution patterns of grinding tools across different Neolithic sites suggests that most complete grinding tools were deposited in graves and only a few in pits that may be related to ritual depositions (Kaifeng Cultural Relics Management Committee of Xinzhen 1978; Zhang 1999; Zhang et al. 2008; Xin et al. 2010; Yang et al. 2017). In contrast, grinding tools unearned from residential areas were all broken (see Chapter 5 and 6). Several studies were conducted to understand the role these grinding tools played in these Neolithic societies. For instance, in the 1990s, based on simplistic analogical reasoning, these tools were considered to have been used for processing domesticated rice and millet (Chen 1990; Song 1997). Because of this assumption, the appearance of these artefacts was often used as a proxy for the arrival of agriculture (Bellwood 2005; Higham 2005). In the first decade of the 21st century, when microwear and residue analyses were first used in Chinese archaeology, it became apparent that the early Neolithic grinding tools were used for processing domesticated cereals as well as wild plants, such as acorns and underground storage organs (Liu et al. 2010c; Zhang 2011; Dong et al. 2014). Thus, it has been proposed that these grinding tools supported a broad-spectrum subsistence economy.

While previous research has provided some data regarding the morphology, raw material, and use of these Neolithic grinding tools, nevertheless, some issues remain unclear. First, the grinding tools unearthed from Neolithic sites in the UCHR are characterized by different shapes, suggesting that different technological choices were made by the past populations during tool production. However, the reason underlying these choices has not been investigated further.

Second, nowadays, dry-grinding (without pre-soaking cereals in water) and wet-grinding (with pre-soaking cereals) are both commonly used for processing cereals, especially in many Asian countries (Chiang and Yeh 2002; Kethireddipalli et al. 2002; Suksomboon and Naivikul 2006). However, previous studies focused on the type of plants processed on the grinding tools, whilst the grinding techniques employed during food processing were often overlooked. The study of different techniques adopted in food processing activities is important as they often reflect ancient culinary practices and subsistence strategies (Capparelli et al. 2011). For example, at an Upper Palaeolithic site in Southern Italy, the state of starch grains preserved on a grinding tool 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 processing stages easier and faster.

Third, exploitation of rice has been demonstrated by phytolith analysis or macrobotanical remains at the early Neolithic sites of Jiahu and Tanghu in the region of UCHR, but only a small amount of starch grains from rice have been recovered and identified from grinding tools (Zhang 2015; Yang et al. 2015b). The ubiquity value (a statistical concept used to describe the proportion of samples with at least one recovered and identified taxa from all examined samples, Hubbard 1980) of rice is also lower than other plant species, such as plants from the Triticeae tribe, Job's tears (*Coix lacryma-jobi* L.) and various underground storage organs (Zhang 2015; Yang et al. 2015b). Similarly, in the catchment of Yangtze River, starch grains from rice were also absent or rarely found from the sampled archaeological grinding tools (Liu et al. 2010b; Yang et al. 2015a; Yao et al. 2016). The scarcity of starch grains from rice recovered from grinding tools was often taken to suggest that rice was not the primary processed material. However, another possible interpretation is that starch grains from rice could be underrepresented on the grinding tools because of starch damage during grinding or degradation during post-depositional processes. An experimental study to test this idea is imperative because the results may significantly change the previous view in terms of the early use of rice in the early farming communities, not only in UCHR, but also in the Yangtze River basin, and related ancient Asian foodways.

Last, but not least, grinding tools were utilized by different early farming communities in the UCHR. Studies on the grinding tools unearthed from the Jiahu and other Peiligang Culture sites have indicated that many of these tools were involved in plant food processing (e.g. Liu et al. 2010c; Zhang 2015). However, whether these past communities shared the same culinary practices has not been further investigated. A comparative study on the grinding tools from the same region thus is important to facilitate the discussion of cultural boundaries and interactions among Neolithic communities.

The aforementioned issues led to the following research questions:

1. What is the correlation between tool type and function of Neolithic grinding tools?
2. What kind of grinding technique was practised by early farmers in the research region?
3. Why has there been a scarcity of recovered starch grains from rice from grinding tools unearthed from early farming societies where rice was certainly cultivated?
4. What were the similarities and differences among Neolithic communities in terms of their food processing practices?

By answering these questions, this dissertation intends to offer new insights into the use of different types of grinding tools, ancient grinding practices, early exploitation of rice, and other culinary practices from different farming societies in the Central Plain of China. These strands of information are put together to obtain a more detailed knowledge of ancient foodways in the research region.

1.4 Case studies

Grinding tools from the sites of Jiahu and Tanghu from the region of UCHR form the backbone of this research. Jiahu went through eight excavation seasons since 1983, with 2900 m^2 excavated so far (Zhang 1999, 2015; Yang et al. 2017). The excavations have brought to light houses, storage pits, pottery kilns, burials, and ditches interpreted as moats (Zhang 1999; Zhang 2015; Yang et al. 2017). Different categories of materials have been recovered, including, pottery, lithic tools, plant remains, animal and human remains. The site has been radiocarbon-dated and dendro-calibrated to three sub-phases: phase I (c. 6000-6500 BC), phase II (c. 6500-6000 BC), and phase III (c. 6000-5500 BC) (Zhang 1999). Among Jiahu Culture sites Jiahu is the only one that has been excavated to date (see also Chapter 2 and 3). Evidence of early agriculture documented at Jiahu includes some of the earliest macrobotanical remains of cultivated rice (Liu et al. 2007) and lithic tools that have been linked to agricultural practices (Zhang 1999). Flotation at Jiahu also revealed fruit remains (e.g. grapes (*Vitis* sp.) and sour jujube (*Ziziphus* sp.)), underground storage organs (USOs, e.g. lotus roots (*Nelumbo nucifera*)), nuts (e.g. acorns (*Quercus* spp.), water plants (e.g. water caltrop (*Trapa* sp.), and wild soybeans (*Glycine max subsp. soja*) (Zhao and Zhang 2009; Zhang et al. 2018, see also

Chapter 6). In addition, remains of domesticated animals including dogs and pigs have been recovered from Jiahu (Yan 1992; Zhang and Wang 1998). A majority of the houses found at Jiahu are semisubterranean, and a few were stilt houses (Zhang 1999; Zhang 2015; Yang et al. 2017).

During the first seven excavation seasons, 52 grinding slabs and 100 rollers were recovered (Lai 2009; Zhang 2015). The author took part in the eighth excavation season at Jiahu and noticed more grinding tools were recovered, but the exact number was not mentioned in the site report from that year (Yang et al. 2017). The Jiahu grinding tool assemblage was suitable for a more detailed study due to the good degree of preservation of the tools; the presence of complete tools allowed for the secure identification of the used areas and this permitted the sampling of tools for residue or microwear analysis. In addition, several paired grinding slabs and rollers were discovered in the same archaeological contexts (Zhang, 1999). Studying these paired tools allowed for a comparison of information collected from the upper and lower tools, which was important to improve our understanding of tool function and some of their potential uses. The presence of different grinding tool morphologies at Jiahu also made it possible to test the relationship between tool type and function. For this case study, seventeen objects, including eight from residential floor contexts, five from pits, and four from grave caches, were selected (see Chapter 2). 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 this study). The rest (n=12) of the objects were lithic fragments 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.

The site of Tanghu is assigned to the Peiligang Culture and was included for the purpose of a comparative study. It is the largest settlement site attributed to the Peiligang Culture that has been excavated. Like Jiahu, Tanghu is also situated on an alluvial plain (Fig.1.1). Excavations at the residential area revealed 63 semisubterranean houses, 201 pits, and one drainage system (Kaifeng Cultural Relics Management Committee of Xinzhen 1978; Zhang et al. 2008; Xin et al. 2010). Tanghu can also be divided into three phases according to the radiocarbon dating data: phase I (c. 6500-6000 BC), phase II (c. 6000-5500 BC), and phase III (c. 5500-5000 BC). At the site of Tanghu, although flotation for archaeobotanical recovery yielded few macrobotanical remains, phytoliths from rice and millet have been identified in soil samples taken from the houses and pits (Zhang et al. 2012). The current research selected all seventeen of the grinding tools that were excavated during the last two archaeological seasons. Fourteen of these tools derived from grinding slabs and three from grinding rollers. It should be noted that only two graves have been found during the excavation seasons, and no grinding tools were found in the burials. Thus, all the sampled grinding tools came from the residential area and were fragments.

1.5 Methodological framework

The data from two analytical methods, namely microwear (or use-wear) and starch grain analysis, are used to study the selected grinding tools from the sites of Jiahu and Tanghu. Microwear analysis is applied to both archaeological and experimental grinding tools, while starch grain analysis is mainly used to investigate the taphonomy of starch grains by studying the experimental grinding tools. Both starch grain analysis and microwear analysis have been applied in archaeology for decades and many books and papers have been published on these methods (e.g. Torrence and Barton 2006; Van Gijn, 2014, Dubreuil et al. 2015; Marreiros et al., 2015). The following sections introduce these two methods briefly and explain why and how an integrated approach is adopted. In addition, a separate section is included in the Appendix I, which explains the variables that have been used to describe microwear traces.

1.5.1 A brief introduction to the analytical methods

Microwear analysis departs from the observation that the production, use, and other treatments (e.g. rejuvenation, redesign, reuse, and handling) of things leave distinctive wear traces on the surface of the objects that can be observed and analysed microscopically. Different activities and contact materials leave different kinds of traces, enabling us to infer the activities ancient tools were used for. These inferences are based on a comparison of the archaeological use-wear traces with those on experimentally used tools. In the 20th century, use-wear analysis was largely used for studying flint artefacts (e.g. Semenov, 1964; Newcomer and Keeley 1977; Odell 1977; Van Gijn 1990). Gradually, this method has been applied to more categories of material, such as ground stone, bone, and antler tools, as well as shell and coral implements, pottery sherds, and bodily adornments (Van Gijn and Hofman 2008; Gao and Chen 2008; Van Gijn and Verbaas 2009; Dubreuil and Savage 2014; Dubreuil et al. 2015; Hayes et al. 2017; Marreiros et al. 2018; Hayes et al. 2018; Breukel 2019; Guzzo Falci et al. 2020). Microwear analysis requires the use of optical microscopes such as a stereoscope for observations at low magnifications (under 100x) or an incident light metallographic microscope with high magnification (100x-630x). Scanning Electron Microscopy (SEM) and Confocal Laser Scanning Microscopy can also be used for both high and low magnification analyses. When applied to grinding tools, the low power approach was often used to infer hard or soft processed materials and efficiently determine the used area of an artefact (but see Hamon 2009b). The high-power approach, on the other hand, is more time-consuming, but it enables a more nuanced inference of the worked material, including bone, shell, antler, cereals, acorns, wood, and many others (e.g. Van Gijn and Verbaas 2009; Fullagar et al. 2012; Fullagar, Stephenson, and Hayes 2017; Hayes et al. 2017). In addition, the high-power approach shows the potential to reveal the grinding techniques involved in the processing of plant organs, for instance, the grinding of soaked or dry cereal grains. This is because additives, such as water, may cause particular types of use-wear on stone tools, because water acts as a lubricant during the grinding process, while simultaneously softening cereal grains (Grace 1996; Van Gijn and Little 2016). The low- and high-power approaches complement each other and thus ideally should be combined (Van Gjin 2014).

Starch grain analysis has been widely applied to objects that may have been in contact with starch-rich plants, such as lithic grinding tools, teeth (dental calculus), and pottery (Piperno et al. 2004; Lu et al. 2005; Barton 2007; Zarrillo et al. 2008; Yang et al. 2012; Nadel et al. 2012; Allen and Ussher 2013; Buckley et al. 2014; Yang et al. 2014; Pagán-Jiménez et al. 2016; Yao et al. 2016). Starch is the main form in which plants store carbohydrates. It occurs as semi-crystalline grains, which are called starch granules or starch grains. The morphology of starch grains depends on the biochemistry of the chloroplast or amyloplast, as well as the physiology of plants (Badenhuizen 1969). Different plants produce starch grains with specific morphological properties (e.g. Fig. 1.4 a and b), so accordingly, the grains coming from different species and sometimes subspecies can be distinguished. Starch grains can preserve in a variety of archaeological contexts and depositional environments, despite their susceptibility to degradation by a number of physical, biological, chemical, and thermal processes (Haslam 2004; Langejans 2012). This is because starch grains can easily become trapped or embedded in areas of an artefact where they are protected from degradation, such as pores, micro fractures, cracks, holes, and micro-striations on the surface of an artefact (Fig. 1.5a and b), soil aggregates, or charred or calcified matrices (Barton and Torrence 2015). By recovering the preserved starch grains from ancient artefacts, this method can often identify the preserved starch remains to a genus taxonomic level and sometimes even species or subspecies level (Yang and Perry 2013; Liu et al. 2014b). In addition, pressure, moisture, and heat involved in different culinary practices could result in different physical and morphological changes to starch grains (Babot 2003; Henry et al. 2009; Crowther 2012). Thus, a detailed observation of the damage features of starch grains often enables a further interpretation of ancient food processing techniques.

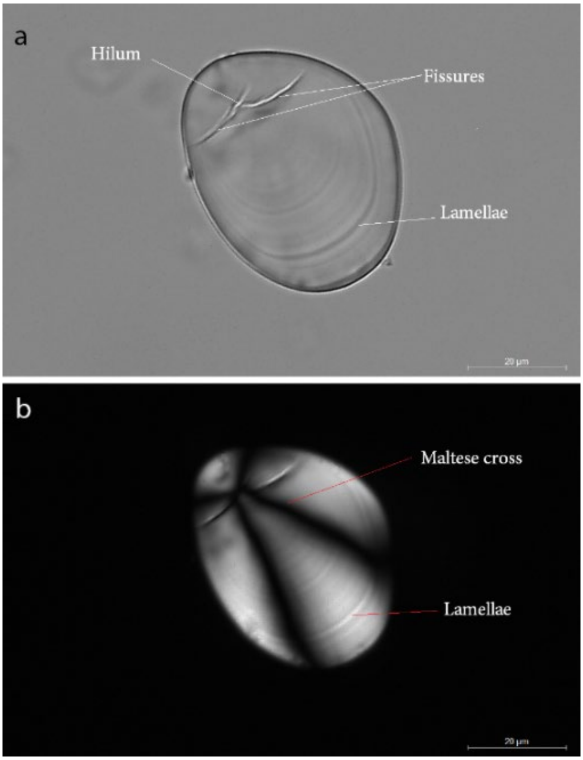

Figure 1.4 Morphological features on the starch grains from potato (*Solanum tuberosum* L.). a: A starch grain with an eccentric hilum, lineal fissures, and concentric lamellae, under normal light and bright field view; b: X-shaped Maltese cross and concentric lamellae under cross-polarized light and darkfield view (© Weiya Li).

Although both microwear and starch grain analysis are useful methods in the study of ancient artefacts, each of the methods has certain limitations. In terms of microwear analysis, it relies heavily on the traces formed on experimental grinding tools, which are mostly used on one contact material and in a very simple mechanical motion (Van Gijn 2014). However, prehistoric grinding tools could have been used in different ways. For instance, multiple types of plants were probably processed using the same grinding implements (Phillipson 2012; Robitaille 2016). It is also possible that certain kind of processed material may have been processed on the ancient grinding tools but were not included in the processed materials of existing experimental reference tools (Van Gijn 2014). Thus, a microwear specialist cannot always interpret the exact processed material (e.g. the wood-like material in Chapter 2). Moreover, a grinding tool would have experienced a complex life history, which means that apart from traces developed during initial use, other processes including manufacture, re-use, re-pecking, storage, transportation, and destruction may have left traces as well. Although these traces offer the potential to reveal different stages of a tool's life history, later formed traces may sometimes obliterate previously developed traces and make their interpretation more complicated. Furthermore, short usage of tools (i.e. expedient tools) may leave no interpretable traces.

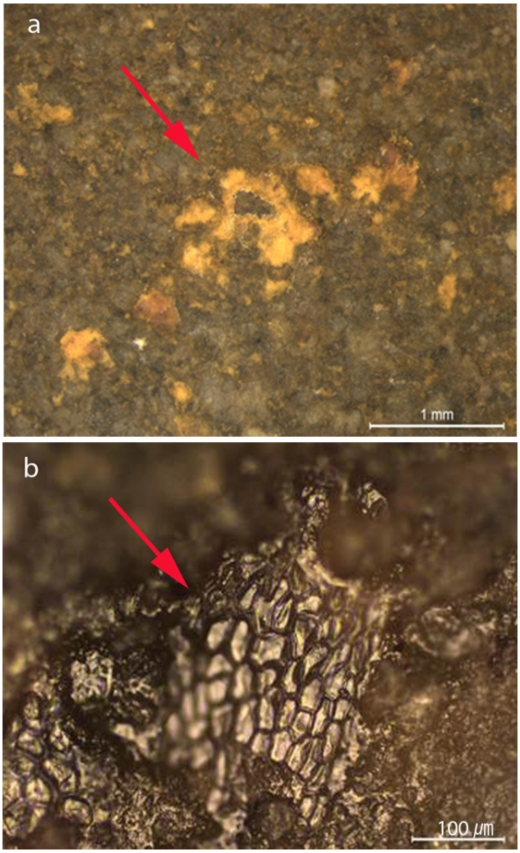

Figure 1.5 Residues on an experimental grinding tool that was used to process cereals (© Weiya Li).

Contamination is a vital issue in starch grain analysis because starch grains cannot be directly dated to date. 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). Even if the discovered starch grains on artefacts are ancient, they are not necessarily related to the tool's use. In addition, starch grain analysis has the best potential to identify remains from starch-rich plants. Yet, archaeological implements such as grinding tools were not exclusively used for processing starch-rich plants, but were also involved in processing leather, minerals, and other kinds of materials (see a detailed summary by Hayes et al. 2018). Apart from the widely reported contamination issue, other limitations of starch grain analysis have been recently discussed by a group of researchers (Hutschenreuther et al. 2017; Mercader et al. 2018). For example, studies have shown that different environments affect the preservation of starch grains on artefacts (e.g. Haslam 2004; Langejans et al. 2012) with certain starch grains being more resistant than others to amylolysis during their deposition into soils (Hutschenreuther et al. 2017). This variation could have led to a bias in the preservation of the starch grains.

Bearing these limitations in mind, this dissertation integrates the data from both microwear and starch grain analysis for the study of the grinding tools. In addition, ethnographic, experimental, and textual information are considered in order to provide a better understanding of the use of the ancient grinding implements.

1.5.2 Microwear analysis for the study of experimental and archaeological grinding tools

The high-power approach (with magnifications ranging from 100x to 630x) is adopted for the case study (see Chapter 2, 3, and 5) of the grinding tools from the Neolithic sites in the UCHR. It should be mentioned that this approach is still relatively new in China, especially for the study of grinding implements so the reference collections are limited. The current research thus makes use of the resources available at the Laboratory for Material Culture Studies at Leiden University, which has an experimental reference collection of sandstone tools used for the processing of various materials, including cereals, wood, flint, bone, antler, clay, metal, and pigments (see figures presented in Appendix I). Prior to this research project, experiments for the study of Chinese grinding tools were primarily carried out by Liu and colleagues (Liu et al. 2010a, 2010b, 2010c, 2011, 2013, 2014, 2018). Their work has documented microwear patterns associated with various materials using a microscope with high magnifications, including stone, wood, cereals (e.g. oats (*Avena sativa* L.)), acorns (*Quercus* spp.), beans (e.g. mung bean (*Vigna radiata* L.)), USOs (e.g. roots of *Trichosanthes kirilowii Maxi*m.). Microwear traces have also been documented by scholars from other countries (e.g. Van Gijn and Verbaas 2009; Hayes et al. 2015, 2017). Most of the previous grinding experiments were designed for specific research purposes and conducted manually with different durations (but see Marreiros et al. 2020). In order to add more data to effectively study the grinding tools from the sites of Jiahu and Tanghu, as well as to gain a better understanding of the grinding processes, further experiments were carried out within the remits of this doctoral research, which included the grinding of rice, foxtail millet and acorns (*Quercus robur* L.) using sandstone cobbles that were collected from the valley of the Maas River in the southern Netherlands.

Furthermore, this research carried out grinding experiments of different cereals in dry and wet conditions. The purpose is to explore what kind of ancient grinding technique was employed by the past inhabitants in UCHR. Microwear traces developed on these experimental grinding tools were observed, documented, and compared with those on the archaeological ones in the research region.

Because the archaeological artefacts could not be transported out of the Chinese museums, Polyvinyl siloxane (PVS) impressions were used. This PVS material can get accurate impressions of the stone surfaces and has been proven to be efficient and effective in previous studies (Liu et al. 2014a; Fullagar et al. 2017). Yet, a major disadvantage of using PVS is that this material cannot hardly take samples covering an entire grinding tool, which is usually large. Thus, this method may lose some information depending on how the sampling was done (see more discussion in section 7.1). The brand of the PVS product used in this project is Kulzer Provil Novo Light Regular. Prior to use-wear sampling, the grinding tools were cleaned using tap water, detergent, and a soft brush to remove adhering sediments. The 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 the samples were observed under a Leica DM 6000m metallographic microscope, attached with a Leica DFC450 camera. The microscope is also fitted with mechanized z-drives that can stack several micrographs automatically, which helps to create a photo with a depth of field (see some of the examples in Chapter 2, 3, and 5). 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. Van Gijn and Houkes 2006; Adams et al. 2009; Hayes et al. 2017, see a more detailed decription of these vriations in the Appendix I).

1.5.3 Starch grain analysis in this research

Previous research has revealed that grinding could result in considerable morphological changes to starch grains (Babot 2003; Ge et al. 2011; Mickleburgh and Pagán-Jiménez 2012), but whether starch damage patterns would lead to a biased representation of these remains was unclear. In this research, a set of systematic experiments were carried out to explore this issue further. Four types of cereals, including rice, foxtail millet, Job's tears, and barley (*Hordeum vulgare* L.), were subjected to dry- and wet-grinding on experimental grinding tools. Each of the grinding experiments was carried out with the following steps:

1. Each type of cereal was soaked in clean water for ten hours before conducting wet-grinding experiments.
2. Then, seeds were ground into flour with a back-and-forth motion for 60 min.
3. Document of the efficiency: an assessment of the efficiency of each grinding process was documented using four categories: 0= not effective, very difficult to grind the cereals into flour; 1= moderately effective, cereal can be ground into flour but with a lot of effort; 2= effective; cereal can be ground into flour with some effort; 3= highly effective, very easy to grind the cereals into flour.

After grinding each type of seed, sampling of the experimental tools was carried out following the procedures outlined by previous publications but with slight modifications (Torrence and Barton 2006; Ge et al. 2011, Cnuts and Rots 2018):

1. Distilled water was placed on the surface of the stone tools for 2 mins, then starch grain samples were obtained from the stone surfaces using a pipette.
2. These samples were placed in 2 ml micro-centrifuge tubes. The tubes were centrifuged and the supernatant was decanted using a pipette.
3. Each of the remaining samples was then mixed with a solution of 50% (vol/vol) glycerol and distilled water. The use of is 50% glycerol is a common and suitable protocol step in starch research because it aids in birefringence and starch rotation (e.g. Coster and Field, 2015; Hart, 2011; Liu et al., 2018; Mariotti Lippi et al., 2015).
4. A volume of 40 μL of each sample containing the processed starch grains was placed onto a new, clean, glass slide.
5. These slides were covered and then sealed with neutral balsam to prevent dehydration of the starch grains.
6. Further observations were conducted in the same period (within one month) to keep the results as consistent as possible.

Starch grains from unprocessed cereals were studied for comparative purposes; the reference collection was prepared following the procedures mentioned in previously published modern starch research (Wei et al. 2010).

Different variables are often used for starch grain analysis (e.g. Torrence and Barton 2006 García-Granero et al. 2017). In this dissertation, the attributes selected for studying damaged starch grains included (a) starch type (singular or compound), (b) shape (2D shape of starch grains have been adopted for description), (c) size (maximum length), (d) hilum (centre of a starch grain, see Fig. 1.4a and b, hilum can be centric or eccentric; closed or open), fissures (internal crack that naturally formed during growth, usually originating at the hilum, see Fig. 1.4a and b, fissures can be lineal, V-, X-, or Y-shaped), and lamellae (concentric growth rings on a starch grain, see Fig. 1.4a and b), (e) compression facets (flat faces that naturally form on a starch grain during growth from pressure due to adjacent granules), and (f) extinction cross (i.e. maltese cross, which means dark cross pattern seen when rotating polarized light, Fig. 1.4b).

Following Gong and colleagues (Gong et al. 2011), starch grains are divided into three categories based on the characteristics of the extinction crosses. Type I refers to starch grains with clear extinction crosses, this category includes the undamaged starch grains and slightly damaged starch grains; type II are starch grains with faint extinction crosses, which are still visible under polarized light and darkfield microscopic view; type III starch grains are represented by those with non-visible extinction cross features. All starch samples were observed using a Leica DM2700P polarizing light microscope (100X to 400 X) with an attached Leica MC170HD camera. Starch grains were measured and counted using the Leica application suite version 4.8.

In addition, because the grinding tools from the sites of Jiahu and Tanghu have been subjected to starch grain analysis in previous studies (Zhang 2015; Yang et al. 2015c), the current research decided to summarize the existing starch data and further analyse them using a quantitative approach. The quantity of starch and ubiquity value of each type of identified plant are calculated and compared. Ubiquity refers to the occurrence of identified plant taxa amongst the entire artefact sample spectra. The measurement of ubiquity has increasingly been applied in recent starch research (Yao et al. 2016; Ciofalo et al. 2019). Results obtained by combining the ubiquity value with the absolute number of different types of starch grain shed light on which kind of plant was mainly processed with the grinding tools and has the potential to interpret "cultural staple" plants (i.e. preferred plants, targeted, or those used ubiquitously) regardless of their presumed subsistence contributions.

1.6 Dissertation outline

This dissertation has been organized into seven chapters. The current chapter (Chapter 1) introduces the objectives of the study and provides a brief review of Chinese archaeology and Neolithic cultures in the research region. It also gives details of the case studies and methodological framework in this dissertation.

The subsequent four chapters (from Chapter 2 to 5) take the form of published academic articles, consisting of research carried out on experimental and archaeological grinding tools. All these articles have been published in the following peer-reviewed scientific journals: Quaternary International, Journal of Archaeological Science-Reports, Archaeometry, and Lithic technology.

In the first research paper (Chapter 2), data from microwear analysis and starch grain analysis are integrated to investigate the function of different types of grinding tools at Jiahu. The goal of the study is to evaluate whether all the grinding tools were used for culinary practices despite their various morphologies, and if not, how these different types of grinding tools were used. This study contributes to our understanding of the use of grinding tools and ancient technological choices in tool use.

The second paper (Chapter 3) departs from the interpretation results reached in the first paper that grinding tools without feet at Jiahu was primarily associated with cereal processing. Cereal processing, however, may entail the use of different grinding techniques, a practice also encountered in present-day China, and thus the second paper explores which grinding technique was employed for cereal processing at Jiahu 7000 BC. Four grinding experiments were carried out, mainly grinding rice and foxtail millet into flour in dry and wet states. Subsequent microscopic observations were carried out on these experimental grinding tools, which create a reference baseline for inferring ancient grinding techniques. Based on the results from the grinding experiments in the second paper, it has been successfully inferred that dry-grinding (without prior soaking) was employed for processing cereals at Jiahu.

The third paper (Chapter 4) investigates how the adopted dry-grinding technique might have affected the preservation of ancient starch grains, especially starch grains from rice. Starch grain analysis was employed to achieve this goal by studying the experimental grinding tools that have been used for cereal processing in both dry and wet conditions. The study compares the preservation of starch grains from different plant species after grinding, which provides an important explanation regarding the relative scarcity of starch grains from rice on the Neolithic grinding tools.

The fourth paper (Chapter 5) presents the grinding tool assemblage at the site of Tanghu (c. 7000-5000 BC), the largest Peiligang Culture settlement site in the north of Jiahu. This paper adopts microwear analysis to reveal the ancient grinding technique and how the grinding processes were carried out. It also makes use of the data from the previous starch grain analysis to reveal the ancient preferences towards the plants used for producing flour. The results from these two methods allow a comparison of culinary practices at the sites of Jiahu and Tanghu in the central plain of China.

Because the four aims outlined in section 1.3 have been achieved in four separate papers (Chapter 2 to 5) and the results of each paper have been discussed in each paper, Chapter 6 thus adopts the concept of 'foodways' to integrate the data from these four research papers and previous studies on different material categories in the research region, such as the fishing darts, bone arrows, denticulate sickles, and shovels that were associated with food procurement activities; grinding tools that were used for food processing; pottery that was used for cooking, containing, and serving food. The chapter starts from addressing foodways at the site level of Jiahu, which is exceptionally well-researched. The changes of foodways over different periods at Jiahu are also discussed.

The last chapter (7), summarizes the main results and implications of each research paper and compares the foodways at Jiahu with some of the Peiligang Culture sites. At last, it proposes suggestions for future research on ancient grinding tools as well as ways to improve the methodologies.

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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).

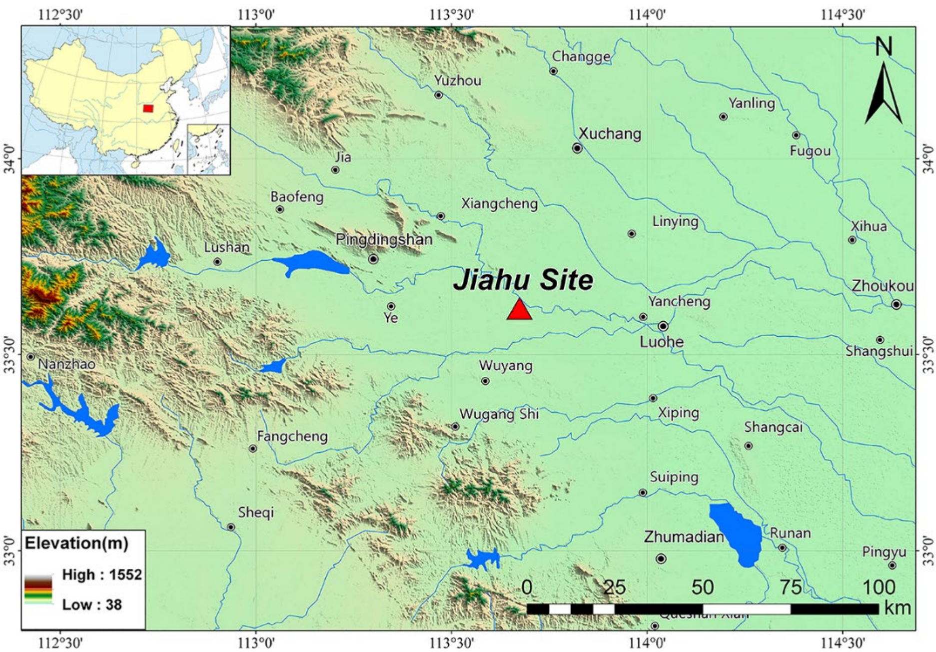

Figure 2.1 The site of Jiahu in the central plain of China

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

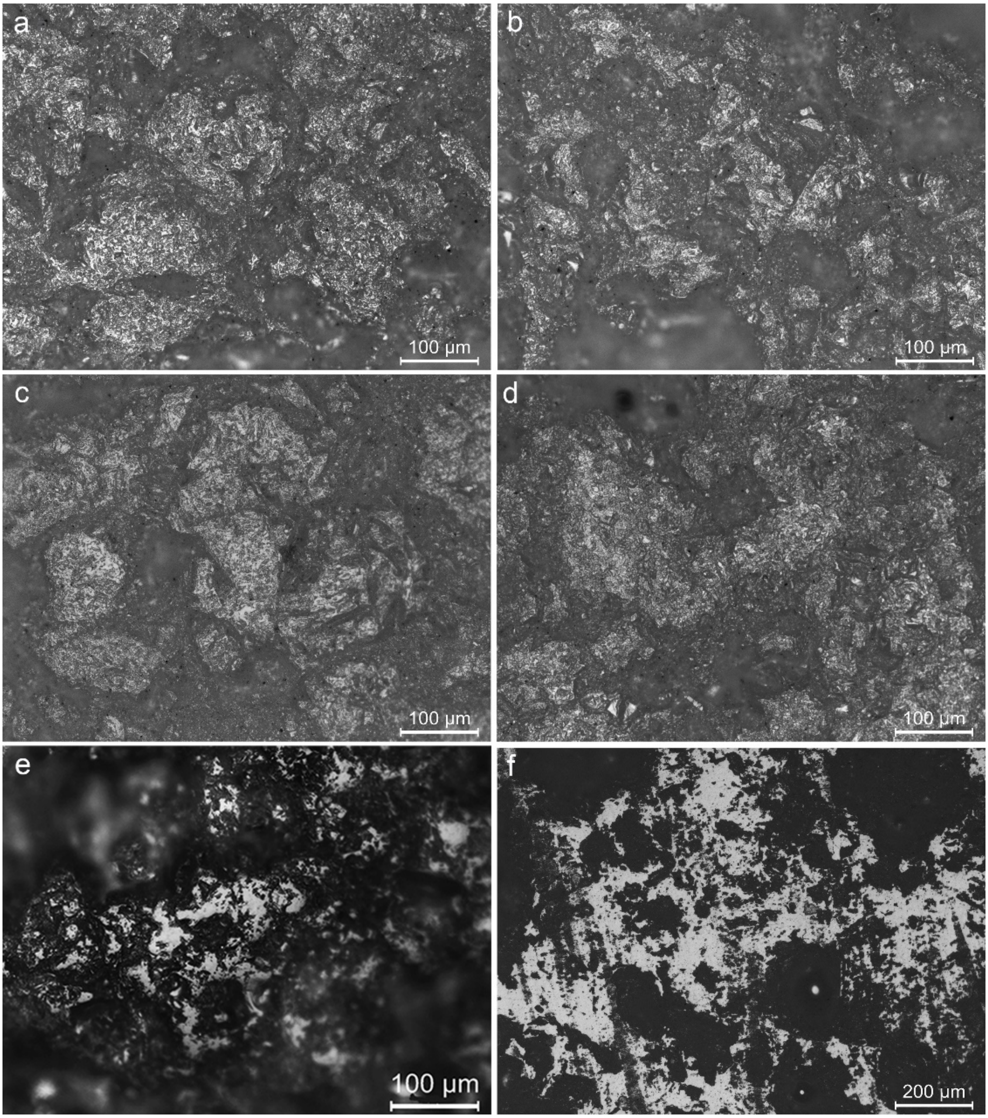

Figure 2.3 Reference collection of use-wear associated with processing different kinds of materials. a: stone surface involved in millet grinding for 180 min 200X; b: stone surface involved in rice grinding for 180 min 200X; c: stone surface involved in wheat (*Triticum monococcum*) grinding for 600 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.

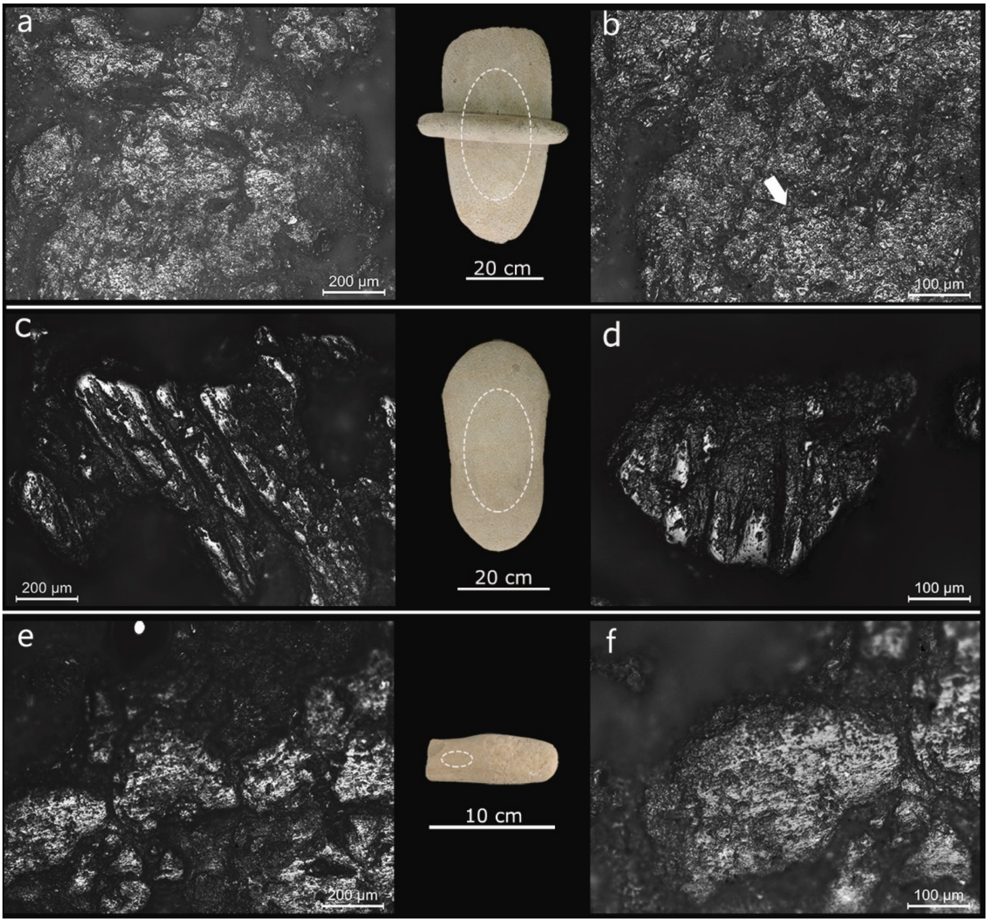

Figure 2.4 Different types of use-wear distributed on the grinding tools from the site of Jiahu. a and b: cereal use-wear on the central area of the grinding slab and the grinding roller from the same context H482, 100x and 200x, localized spots with smooth linked polish are pointed out by the arrow; 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.

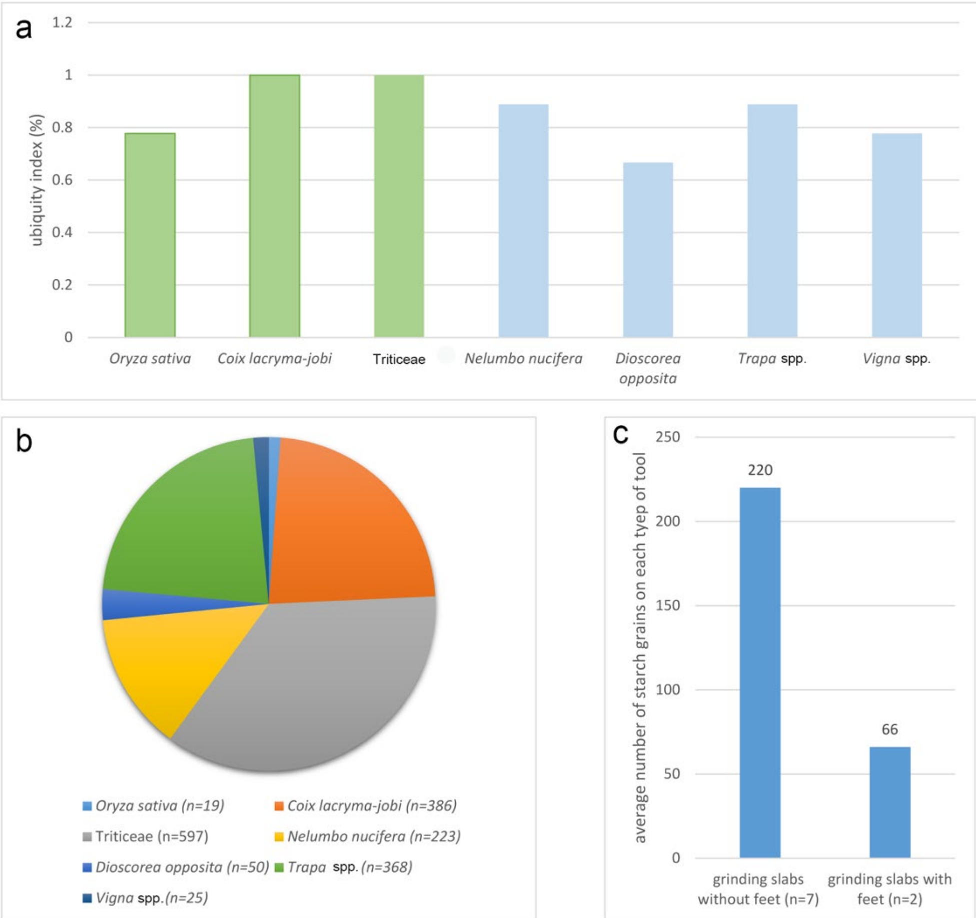

Figure 2.5 Quantitative analysis of starch grains at the site of Jiahu. a: ubiquity index of each plant on the nine grinding tools applied for starch grain analysis b: number of starch grains from different plant species discovered on the Jiahu grinding tool assemblage c: the average number of starch 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.

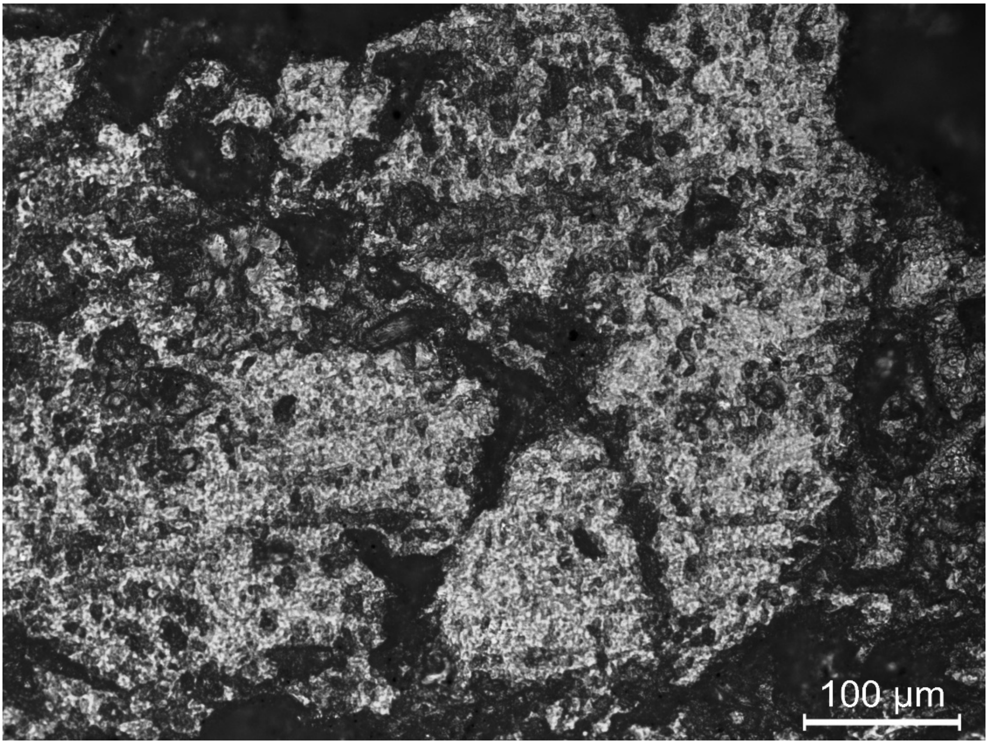

Figure 2.6 Polish with a rough texture found on the edges of the grinding slab with feet (artefact no. M371:1, 200x).

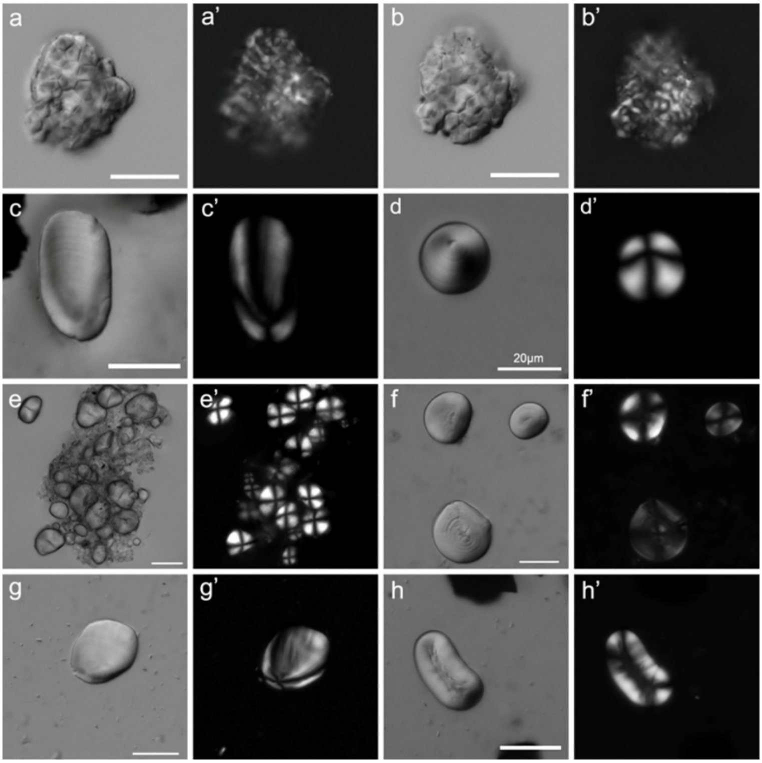

Figure 2.7 Starch grains discovered in the Jiahu grinding tool assemblage. *Oryza sativa* (a, a', b, b). *Nelumbo nucifera* (c, c'). *Trapa* spp. (d, d'). *Coix lacryma-jobi* (e, e'). Triticeae (f, f'). *Dioscorea opposita* (g, g'). *Vigna* spp. (h, h') (after Zhang, 2015).

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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Chapter 3 Cereal processing technique inferred from use-wear analysis at the Neolithic site of Jiahu, Central China

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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).

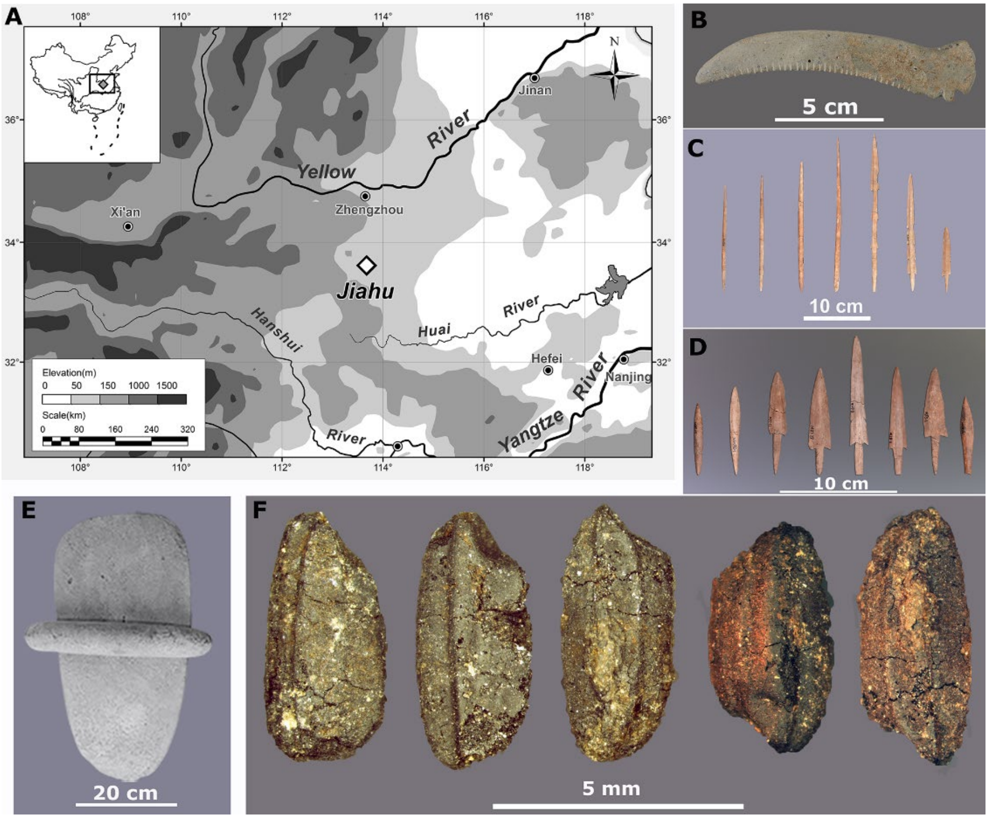

Figure 3.1 The site location of Jiahu and the previous archaeological findings. A: Jiahu in upper catchment of Huai River in the central plain of China; B: an example of the Jiahu stone sickle; C: seven fishing darts from Jiahu; D: eight bone arrowheads associated with hunting from Jiahu; E: a grinding 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.

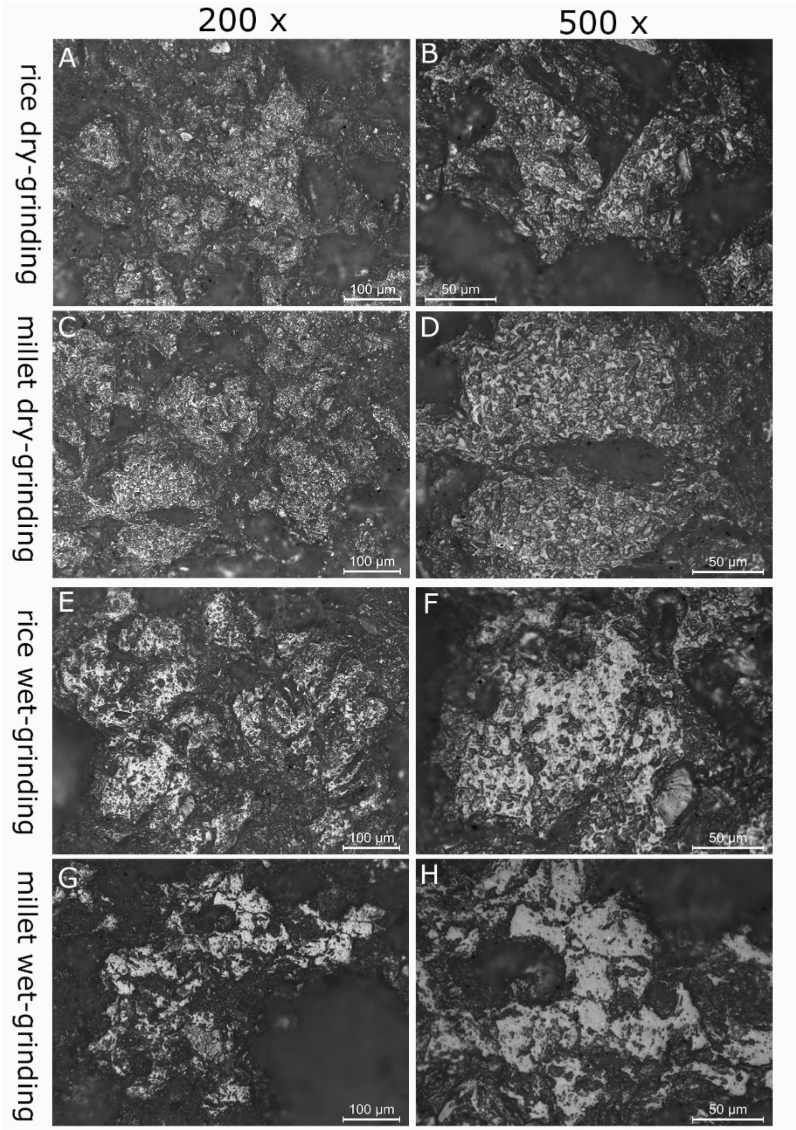

Figure 3.2 Use-wear traces on experimental grinding stone tools under the magnification of 200x and 500x. Use wear associated with processing dry rice (A and B , after 180 min) and foxtail millet (C and D, after 180 min) both characterized by granular, greasy and reticular micro-polish; Use-wear traces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

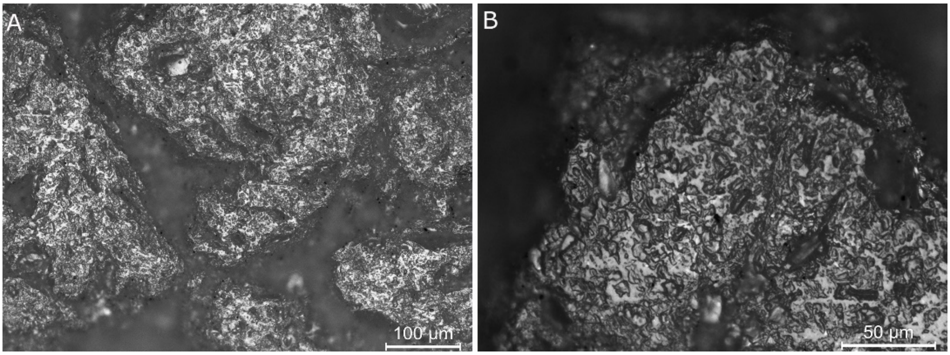

Figure 3.4 Use-wear traces associated with dry-grinding of cereals on Jiahu grinding tools under different magnifications (A: 200x and B: 500x).

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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Chapter 4 The influence of grinding on the preservation of starch grains from rice

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The influence of grinding on the preservation of starch grains from rice

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Abstract

China is a major centre for rice domestication, where starch grain analysis has been widely applied to archaeological grinding tools to gain information about plant use by ancient Chinese societies. However, few starch grains from rice have been identified to date. To understand this apparent scarcity of starch grains from rice, we carried out dry- and wet-grinding experiments with stone tools on four types of cereals: rice (*Oryza sativa* L.), foxtail millet (*Setaria italica*), Job's tears (*Coix lacryma-jobi* L.), and barley (*Hordeum vulgare* L.). The results reveal that dry-grinding produces significant damage to starches to the point where they may be undetected in archaeological samples, while wet-grinding causes only slight morphological changes to the starch grains. Moreover, rice starch grains have the most substantial alterations from dry-grinding, possibly impeding their identification. These findings provide a possible means to explain the relative scarcity of rice starch grains recovered from archaeological grinding tools, which we now suggest was caused by the use of the dry-grinding technique. We therefore suggest that rice starch grains have been likely underrepresented in the archaeological record, and previous interpretations of starch analyses need to be reconsidered.

Keywords: rice, grinding technique, starch grains, experimental archaeology, Neolithic China

4.1 Introduction

Rice (*Oryza* spp.) is an important crop in Asia, where cooking techniques, eating habits, and feasting rituals have been historically associated with this plant (Cheung and Tan 2007). China has three major regions that are currently considered the earliest centres for rice domestication, which include the lower catchment of the Yangtze River (Jiang and Liu 2006; Liu et al. 2007b; Liu et al. 2007a; Trivers et al. 2009), the middle catchment of the Yangtze River (e.g. Zhao, 1998), and the upper catchment of the Huai River (Wang and Zhang, 1998: Fig. 4.1a). On the basis of the previous research, these regions all possess well-documented evidence for rice domestication during the early Neolithic period (e.g. Liu et al., 2007b, 2007a; Lu et al., 2002; Wu et al., 2014; Yang et al., 2016; Zhao, 2010). For instance, in the upper catchment of the Huai River, at the site of Tanghu (c. 9000-7000 cal. BP) phytolith analysis yielded evidence of rice cultivation as early as 7800 to 4500 BP (Zhang et al. 2012). At the nearby site of Jiahu (9000-7500 cal. BP), domesticated rice macrobotanical remains have been recovered from all three sub-phases (Zhang 1999; Yang et al. 2017; Zhang et al. 2018). Isotope analysis of human skeletons from Jiahu indicates that C3-based foods, potentially including rice, dominated human diets throughout the occupation of Jiahu (Hu et al., 2006). Rice has also been proven to have been used as an ingredient for fermented beverage production 9000 years ago at Jiahu (McGovern et al. 2004).

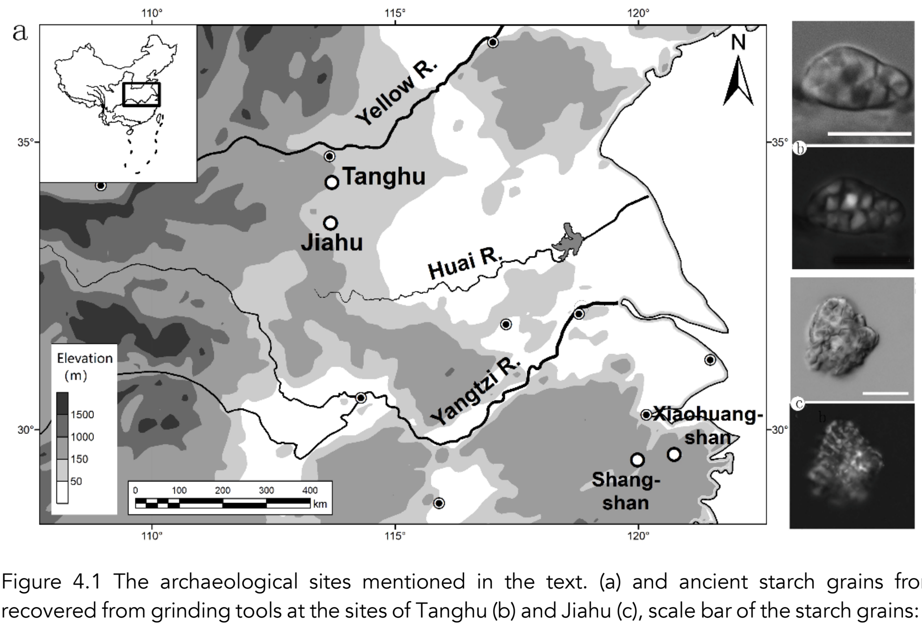

Figure 4.1 The archaeological sites mentioned in the text. (a) and ancient starch grains from rice recovered from grinding tools at the sites of Tanghu (b) and Jiahu (c), scale bar of the starch grains: 20μm. Note the majority of ancient starch grains from rice from these two sites are compound (after Yang et al., 2015b; Zhang, 2015).

Even though the exploitation of rice has been demonstrated by different analytical methods, rice starch grains have seldom been recovered from archaeological grinding tools from these regions (Liu et al., 2010; Yang et al., 2015). In the few cases where rice starch grains have been identified (Yang et al. 2015b; Zhang 2015; Yao et al. 2016), they only account for a very small amount of the total identified starch grains. The ubiquity value (a term used to describe the proportion of samples including a certain type of starch grains against all examined samples; see Li et al., 2018; Yao et al., 2016) of rice is also relatively lower than other plant species, such as plants from the Triticeae tribe, Job's tears (*Coix lacryma-jobi*), and various underground storage organs (e.g. Liu et al., 2014a; Y. Yang et al., 2015; Zhang et al., 2011).

The scarcity of rice starch grains recovered from grinding tools was often used to suggest that rice was not the primary processed material on these tools (Liu et al. 2010b; Yang et al. 2015a; Yang et al. 2015b; Yao et al. 2016). This seems a reasonable hypothesis considering that rice could also have been processed by other ways such as boiling (Yang et al. 2015a; Yao et al. 2016). However, nowadays in China, grinding rice into flour and boiling rice directly are both common culinary practices that could have been passed down through generations from the distant past. If so, rice might have been processed with grinding tools to a larger extent than previously suggested, implying rice starch grains might be underrepresented in samples from archaeological grinding stones. This is possible because studies have suggested that different depositional environments affect the preservation of starch grains (Haslam 2004; Langejans et al. 2012). Indeed, certain starch grains are less resistant than others to amylolysis (Hutschenreuther et al. 2017). Thus, this variation could have led to representation biases on ancient starch grain studies. Similarly, pressure, moisture, and heat involved in different food processing practices could also result in considerable morphological changes (due to starch gelatinization), and even complete destruction of starch grains (Tester and Morrison 1994; Henry et al. 2009; Pagán-Jiménez et al. 2017). Those damage features, especially the loss of extinction crosses, will inevitably have affected starch detection and identification (Lamb and Loy, 2005).

Starch damage features associated with grinding have been investigated in experiments using several types of cereals, such as wheat (*Triticum aestivum* L.), broomcorn millet (*Panicum miliaceum* L.), and maize (*Zea mays* L.) (Babot 2003; Ge et al. 2011; Mickleburgh and Pagán-Jiménez 2012). However, it has been difficult to compare different damage patterns on starch grains from different plant species associated with grinding because the parameters amongst those studies were not always consistent. For instance, the duration of grinding experiments, the tool types, and the grinding technique all varied. Therefore, in this paper, we propose a set of systematic experiments to explore whether starch grains from rice share the same damage features with those from other types of cereals.

Four types of cereals are selected in this experimental study: rice (*Oryza sativa* L.), foxtail millet (*Setaria italica*), Job's tears (*Coix lacryma-jobi* L.), and barley (*Hordeum vulgare* L.) (Table 4.1). These plants were chosen due to their long history of use in China. Rice and foxtail millet are both known to have been cultivated in China at least 10,000 years ago (Zhao 2010; Yang et al. 2012; Wu et al. 2014). Starch grains from Job's tears have been widely recovered from grinding tools at sites dating to at least 8000 years BP in both southern and northern China (Liu 2015; Yao et al. 2016; Liu et al. 2018b). Early evidence for the use of barley has been found on the margins of the Tibetan Plateau 3400 BP (Guedes et al. 2015) and in the Hexi Corridor c. 4000 BP (Flad et al. 2010). Barley belongs to the tribe Triticeae and starch grains from wild Triticeae specimens have been identified on grinding tools dated to the Upper Paleolithic period in northern China (Liu et al. 2018a).

De-hulled cereals were chosen as the processed material because previous studies reveal that Neolithic grinding tools were more likely used to grind cereals into flour rather than for separation of hulls (Liu et al. 2010c; Li et al. 2018). De-hulling was likely carried out using wooden pestles, as such a process was documented in ancient Chinese literature, such as YiJing (from the Western Zhou period, 3000-2750 BP). Wooden pestles were also recovered from the archaeological sites of Bashidang (7540-7100 BP) and Hemudu (c. 7000-5000 BP) in the Yangtze River basin (Peregrine and Ember 2012; Xu 2017).

Table 4.1 Information on the grinding experiments

Exp. No.	Grinding technique	Material	Origin of the cereals	Duration (minutes)	Efficiency
1	dry-grinding	rice	Northeast China	60	1
2	wet-grinding	rice	Northeast China	60	2
3	dry-grinding	foxtail millet	Taiwan	60	1
4	wet-grinding	foxtail millet	Taiwan	60	2
5	dry-grinding	Job's tears	Taiwan	60	2
6	wet-grinding	Job's tears	Taiwan	60	3
7	dry-grinding	barley	Netherlands	60	0
8	wet-grinding	barley	Netherlands	60	0

Note: "Efficiency'' refers to the interpretation of the efficiency to grind the cereals into flour from lower to higher levels 0-3.

4.2 Materials and Methods

In the present study, all the cereals were purchased from Chinese supermarkets in The Hague, Netherlands (Table 4.1). The grinding tools were made from sandstones obtained from the riverbed of the Maas in the southern Netherlands. These stones exhibit great similarity to archaeological grinding tools from Neolithic Chinese sites in terms of their coarseness and texture (Liu et al. 2010c; Cui et al. 2017). The grinding tools all possess at least one flat grinding surface. An example of the experimental grinding tools used in this study is depicted in the supplementary data (Fig. S4.1).

Selected cereals were subjected to dry-grinding (without pre-soaking of the cereals in water) and wet-grinding (by pre-soaking of the cereals in water). These two grinding techniques are both common in present-day societies in Asia (Chiang and Yeh 2002; Kethireddipalli et al. 2002; Suksomboon and Naivikul 2006). The selections of specific grinding techniques are generally based on cultural preferences regarding food texture (e.g. Nout, 2009) or the desire to remove bitterness resulting from pre-soaking (e.g. Hosoya, 2011). For the wet-grinding experiment, each type of cereal was separately soaked in tap water for ten hours. Then, each cereal was ground into flour with a back-and-forth motion (see also Li et al., 2019). An assessment of the efficiency of each grinding experiment was documented using four categories: 0= not effective, very difficult to grind the cereals into flour; 1= moderately effective, cereal can be ground into flour but with a lot of effort; 2= effective; cereal can be ground into flour with some effort; 3= highly effective, very easy to grind cereals into flour (Table 4.1).

After 60 minutes of grinding each type of cereal, the stone tools were sampled following the procedures outlined by previous publications (Torrence and Barton 2006; Cnuts and Rots 2018, with slight modifications). Ultra-purified water was placed on the surface of the stone tools for two minutes. Then the starch grain samples were obtained from the stone surfaces using a pipette. These samples were placed in 2ml micro-centrifuge tubes. The tubes were centrifuged and then mixed with a solution of 50% glycerol in distilled water, a common and suitable method in starch research (Pagán-Jiménez 2007; Hart 2011; Coster and Field 2015; Mariotti Lippi et al. 2015; Liu et al. 2018b). A volume of 40 µL of each sample containing the processed starch grains was placed onto a clean glass slide. Then, cover slides were placed on each slide and were sealed with neutral balsam to prevent the dehydration of starch grains. Microscopic observations were carried out within one month of the slide preparation. Starch grains from unprocessed cereals were studied for comparative purposes. The cereal samples were prepared following the method mentioned in the previously published literature on modern starch research (Wei et al. 2010). First, each specimen was put in a separate 2ml micro-centrifuge tube filled with ultra-purified water. After 8 hours, a disposable pipette was used to press the grain inside the tube in order to release the starch grains. Then the liquid sample containing the released starch grains were transferred to a clean tube for centrifuging. The next steps of the procedure are identical to the one described above for the ground starch samples.

The attributes selected for studying damaged starch grains included (a) starch type (single or compound), (b) shape, (c) size, (d) presence and absence of features on the starch surface (hilum, fissures, and lamellae), and (e) extinction cross morphology (see the description of these starch features e.g. García-Granero et al., 2017; Torrence and Barton, 2006). Following Gong and colleagues (2011), starch grains were divided into three categories based on the characteristics of the extinction crosses. Type I refers to starch grains with clear extinction crosses. This category includes the undamaged starch grains and slightly damaged starch grains. Type II are starch grains with faint extinction crosses, which are still visible under polarized light and dark field view. Type III starch grains are represented by those with non-visible extinction crosses (Fig. 4.3b). All starch samples were observed under a Leica DM2700P microscope with polarizing light and an attached Leica MC170HD camera. When possible, at least 50 single starch grains from each sample were measured and counted (see also Fig. 4.3) using the Leica application suite version 4.8.

4.3 Results

From our experience, dry-grinding of cereals requires more effort than wet-grinding (Table 4.1). Only Job's tears were very easy to dry-grind into flour, which is consistent with the grinding experiment conducted by Liu and colleagues (2018a). In contrast, dry-grinding barley was difficult, an observation that is consistent with previous experiments (Lull et al. 2010). Rice and foxtail millet can both be dry-ground into fine flour with some effort. After soaking, rice, foxtail millet, and Job's tears become much softer and easy to grind, whereas the grinding of soaked barley remains as difficult as in the dry conditions. Detailed morphological changes of starch grains from each type of cereals after dry- and wet-grinding are described below.

4.3.1 Rice

Unprocessed starch grains exhibit various morphologies depending on the plant species, and their morphological types are classified as either compound or single (Tateoka 1962). Both morphological types of starch grains are found in the unprocessed rice samples (Fig. 4.2a and b). The shape of single starch grains is polygonal. The average maximum length of the single rice starch grains is 5.64 ± 1.89μm (Table 4.2). The hilum is centric and closed. No fissures or lamellae are visible. Their extinction crosses are radially symmetrical and cross-shaped. Compound rice starch grains consist of an aggregate of single starch grains. In these cases, the compound structure is oval in shape (Fig. 4.2b) and has diagnostic reflected star-shaped extinction crosses (Fig. 4.2b').

The dry-grinding technique results in severe damage to the starch grains. The most noticeable change is that few single rice starch grains remained, and more starch aggregates are formed (Fig. 4 2c and d). These starch aggregates have irregular shapes (Fig. 4.2c and d) and their extinction crosses are invisible or become faint and blurry (Fig. 4.2c' and d'). Only a few compound starch grains survived with observable birefringence (Fig. 4.2c'). A low number of single starch grains that remained completely lost their extinction crosses (Fig. 4.3b). The average maximum length of the single dry-ground starch grains from rice is 8.95 ± 2.58μm (Table 4.2, Fig. 4.3a).

In sharp contrast to dry-grinding, wet-grinding produced no damage signs to rice starch grains. These starch grains are very similar to the unprocessed samples in terms of size (Fig. 4.3a), shape, extinction cross, and characteristics of the starch surface (Fig. 4.2e, e', f, and f'). The average maximum length of rice single starch grains submitted to wet-grinding is 6.24 ± 1.40μm (Table 4.2, Fig. 4.3a).

4.3.2 Foxtail millet

Starch grains from unprocessed foxtail millet samples consist of both single structures and compound grains (Fig. S4.2a and a'). Single starch grains are polygonal, round, or oval. The mean length of single foxtail starch grains is 10.21± 2.15μm (Table 4.2). The hilum of the starch grains is centric and closed. The extinction cross is clear and cross-shaped. Neither lamellae nor fissures are visible. The compound starch grains from foxtail millet are circular but with some angled flat sides (Fig. S4.3b and b').

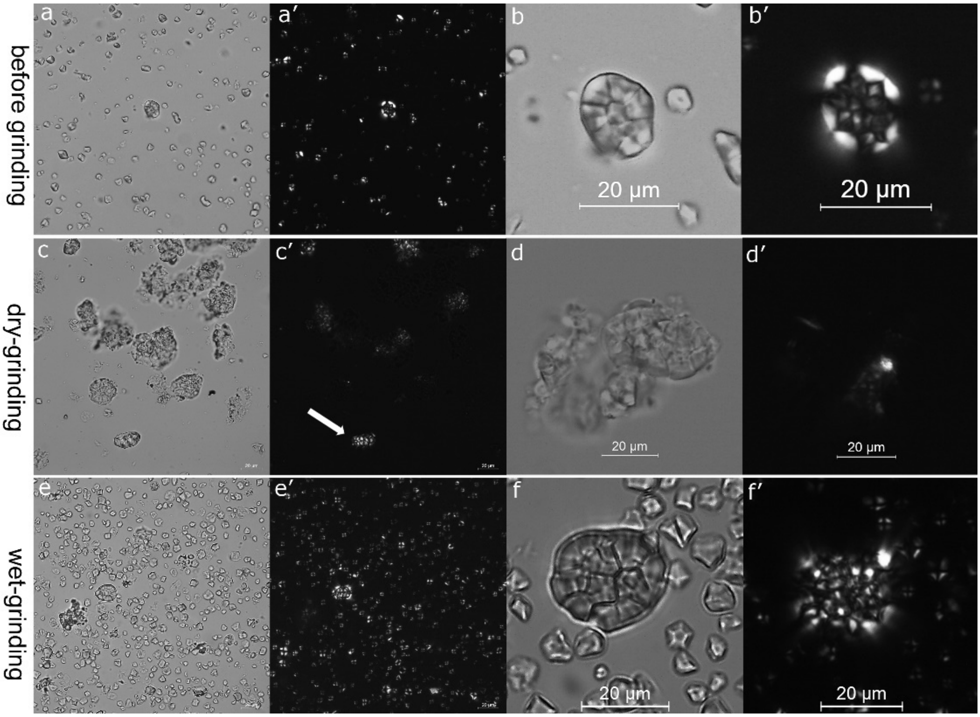

Figure 4.2 Morphological changes of starch grains from rice after dry- and wet-grinding. a, a′: single and compound starch grains coexist in the unprocessed rice samples; b: the oval-shaped compound starch grains under normal light, b′: star-shaped extinction cross of the compound starch grains under polarized light; c, c′: single starch grains nearly invisible after dry-grinding, the only visible compact compound starch grains are marked with the arrow; d, d′: irregular shape aggregates under the normal and polarized light; e, e′, f′ and f′: starch grains perform similar features as the unprocessed samples.

After dry-grinding foxtail millet, more starch aggregates tend to be formed. However, the single starch grains from foxtail millet still remained. Extinction crosses in aggregate starch grain became blurry. Single starch grains had fissures generated on their surfaces and their size enlarged (Fig.4.3a). After dry-grinding, the average maximum length is 13.79 ± 4.42μm (Table 4.2). Most starch grains (43%) display nearly intact extinction crosses; 35% have faint extinction crosses; the rest (22 %) become invisible under polarized light (Fig. 4.3b).

After wet-grinding, the starch grains still have a compact shape and showed clear extinction crosses. The average maximum length of single starch grains is similar to the unprocessed samples (Fig. 4.3a): 10.79 ± 2.47μm (Table 4.2). The most noticeable damage patterns are shallow fissures and radiating striations on the surfaces of the starch grains (Fig. S4.2f and f′).

4.3.3 Job's tears

Starch grains from unprocessed Job's tears consist of polygonal, spherical and oval-shaped single grains. The average maximum length of these starch grains is 10.31 ± 3.77μm (Table 4.2), which is smaller than that reported in previous studies (e.g. 12.4 ± 3.0 μm in Yang and Perry, 2013). This disparity is reasonable, based on studies showing that starch grain size is partially affected by the geographic origins of the source plants (e.g. Perry 2002; Liu et al. 2014b). The starch grain surfaces are smooth, lamellae are not visible, and the hilum is centric. Linear-, V-, Y-shaped, or stellate fissures are present on starch grain surfaces and the extinction cross is mainly cross-shaped.

After dry-grinding, most of the starch grains remain as single structures (Fig. S4.3c and c'). Their size is relatively stable (Table 4.2, Fig. 4.3a) with few dry-ground starch grains found to be enlarged considerably (e.g. Fig. S4.3d and d'). The average maximum length of these single starch grains is 10.74 ± 4.60μm (Table 4.2). Deeper and stellate fissures are observed on the surface of the single starch grains. The majority of the starch grains (68%) remain nearly unchanged in terms of their extinction crosses, though 23% totally lost their birefringence features (Fig. 4.3b); the rest (9%) still possess visible birefringence features under polarized light (Fig. 4.3b).

Wet-grinding resulted in no significant changes to the starch grains (Fig. S4.3e, e', f and f'). The shape, extinction cross, and other surface features of the processed starch grains all resemble the unprocessed samples. The average maximum size of these starch grains increased to 11.29 ± 3.27μm (Table 4.2), which is slightly larger than the unprocessed samples.

4.3.4 Barley

Starch grains from the Triticeae tribe are divided into two types according to their size. Type A refers to starches that were larger than 10μm, while Type B refers to starches less than 10μm in diameter (Lindeboom et al. 2004; Howard et al. 2011). Starch grains from Type B are small with very few diagnostic characteristics, so archaeological identifications of starch grains from the Triticeae tribe are largely based on Type A starch grains (e.g. Y. Yang et al., 2015; Yang et al., 2016b). Unprocessed Type A barley starch grains are oval-shaped. The average maximum length of the barley starch grains measured 21.85 ± 4.43μm (Table 4.2), which is larger than previously suggested (e.g. 18.0 ± 4.1μm in Yang and Perry, 2013). The hilum of these starch grains is centric and closed. Shallow lamellae are visible on some starch grains, usually the bigger ones, and the extinction crosses are thick and "X-shaped" (Fig. S4.4a, a', c and c').

After dry-grinding, lamellae on the starch surfaces of barley became deeper and shallow striations were formed on the surface (Fig. S4.4d). These starch grains also became flatter (Fig. S4.4c). Some of them (43 %) totally lost their birefringence features (Fig. 4.3b), whereas others (36%) still exhibited extinction crosses resembling the ones registered in unprocessed samples (e.g. Fig. S4.4c'). In other cases (21 %), the extinction crosses became faint but still visible under polarized light (Fig. 4 3b). The average maximum length of the dry-ground starch grains is 25.97 ± 8.06μm (Table 4.2).

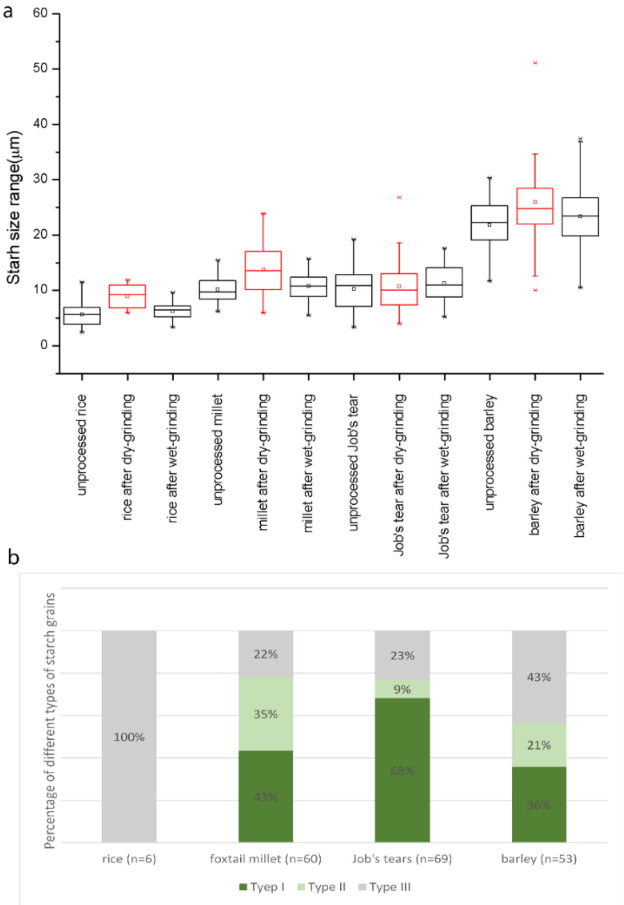

Figure 4.3 The size of starch grains from the unprocessed, dry-grinding (in red colour) and wet-grinding samples. (a) and the proportion of three different categories of damaged starch grains from the dry-grinding samples (b). a: The size of starch grains from the unprocessed, dry-grinding (in red colour) and wet-grinding samples, note the size of the starch grains from the dry-grinding samples is bigger than their unprocessed and wet-grinding samples, except Job's tears. b: Type I, Type II, and Type III refer to three different categories of damaged starch grains. At least 50 single starch grains were measured from each sample except the dry-grinding samples from rice, in which the single grains mostly disappeared, supporting data for Figure 3b can be found in the supplementary data (Appendix II), including Table S4.1 and Figure S4.5- Figure S4.23.

The morphological changes on barley starch grains after wet-grinding are minor in terms of their shape and extinction crosses (Fig. S4.4e, e' and f'). Only some shallow lamellae are observed on starch surfaces under normal light (bright field view, e.g. Fig. S4.4f). The average maximum length of the single wet-ground starch grains is 23.38 ± 5.21μm (Table 4.2).

4.4 Discussion

No damage features are observed on the samples from rice or Job's tears after wet-grinding. Wet-grinding only produced noticeable damage patterns to foxtail millet and barley starch grains. In contrast, dry-grinding results in more extensive starch grain modifications. A formula developed in food chemistry research (see the detailed description in Asmeda et al., 2016) also revealed that starch damage during dry-grinding is the most intense. The present study thus adds an additional line of evidence indicating that the type of observed damage patterns is directly related to the employed grinding techniques, in which the use of water for soaking cereals might result in less damage to starch grains.

Our experimental results also indicate that dry-grinding produced different types of damage patterns depending on the types of cereal. First, the size of Job's tears starch grains remains stable after processing, which is possibly because grinding Job's tears requires only minimal pressure to make flour (Table 4.1). In other words, the seed coat (endosperm) of this species seems to be softer than in the other plants used in the present study. Previous dry- and wet-grinding experiments comparing damage patterns also revealed a similar relationship between starch enlargement and seed coat hardness (Mickleburgh and Pagán-Jiménez 2012). The collated data suggests that the harder the seed coat, the greater the enlargement of the starch grains due to grinding (Table 4.2).

Polarized light and dark field view are often used to recognize, detect, and identify starch grains (e.g. Liu et al., 2011; Lu et al., 2005; Perry and Michael Quigg, 2011; Y. Yang et al., 2015). Our experiments demonstrated that birefringence and extinction crosses of starch grains became invisible after dry-grinding. Moreover, other minerals and organic particles (e.g. fungi and cellulose) also show birefringence and produce optical features similar to extinction crosses (Haslam 2004; Ge et al. 2011). It is thus likely that damaged irregular starch aggregates from rice could have easily been overlooked in the archaeological samples. This phenomenon leads us to reconsider the data from previous research carried out on grinding tools from Chinese Neolithic sites.

Based on the experimental results from the present study, rice starch grains tend to form aggregates after dry-grinding, while inversely many of the single rice starch grains do not remain. The most likely opportunity to detect rice starches after dry-grinding is to locate the few surviving compound grains with intact extinction crosses (Fig. 4.2c'). This is the case at the site of Tanghu, where only one intact compound starch grain has been recovered (Fig. 4.1b) (Yang et al. 2015b). Similarly, the starch grains from rice recovered from Jiahu are mostly compound as well (83%, 69 out of the 83, e.g. Fig. 4.1c) (Zhang 2015). This phenomenon is consistent with the results from our rice dry-grinding experiment. In addition, previous microwear analysis of grinding tools from Jiahu demonstrated that dry-grinding was used for cereal processing (Li et al. 2019).

Starch grain analysis has been carried out at the Neolithic sites of Xiaohuangshan and Shanshan (Liu et al. 2010b; Yao et al. 2016; Yang et al. 2015a) in the Yangtze River basin in Eastern China. This area is presumed to be the one of the earliest areas for rice cultivation and domestication in the world, though only four rice starch grains have been recovered from the grinding tools at the site of Xiaohuangshan (Liu et al. 2010b; Yao et al. 2016), and no starch grains have been identified from grinding tools at the site of Shanshan (Yang et al. 2015a). If dry-grinding was employed at these sites, it might have adversely affected the preservation and potentially the recovery of ancient rice starch grains.

Because no starch grains from rice have been found on the grinding tools from the site of Shangshan, Yang et al. (2015) suggested that there might be an under-representation of rice starch grains. The authors argued that rice single starch grains are normally less than 10μm, which is too small to be easily detected under a microscope. However, a magnification up to 630x has been used for starch research and small size starch grains (less than 5μm) have been revealed in archaeological samples (e.g. Liu et al., 2014c, 2010b; Yang et al., 2016b). Thus, the results of this experimental study provide another possible explanation regarding the scarcity of starch grains of rice on grinding tools, caused by the dry-grinding technique.

Based on observations derived from our experimental research, we need to point out a problematic issue for detecting starch grains in samples obtained from grinding tools by only using polarized light. After dry-grinding, most of the starch grains became more difficult to recognize with polarized light because of the loss of birefringence and their extinction crosses. Therefore, it is imperative to combine normal, white field microscopy to detect such starch grains during the scanning of sample slides. This practice will maximise the chance of detecting both native and damaged starch grains (Pearsall 2016).

Table 4. 2 Characteristics of starch grains before and after grinding

Plant species	Size of starch grains		Main features of starch grains after grinding
	Size range (μm)	Average size (μm)	
Unprocessed rice	1.89-11.45	5.64± 1.89 (n=55)	Dry-grinding results in greater enlargement of the size of starch grains than wet-grinding; Most of the single starch grains disappear after dry-grinding.
Dry-ground rice	5.92-11.88	8.95 ± 2.58 (n=5)	
Wet-ground rice	3.32-9.63	6.24 ± 1.40 (n=66)	
Unprocessed foxtail millet	6.21-15.45	10.21± 2.15 (n=52)	Dry-grinding result in greater enlargement of the size of starch grains than wet-grinding; 22% single starch grains totally lost their extinction crosses after dry-grinding.
Dry-ground foxtail millet	5.87-13.79	13.79 ± 4.42 (n=79)	
Wet-ground foxtail millet	5.50-15.72	10.79 ± 2.47 (n=61)	
Unprocessed Job's tears	3.33-19.16	10.31±3.77 (n=61)	Dry-and wet-grinding both result in slight enlargement of the size of starch grains; 23% single starch grains totally lost their extinction crosses after dry-grinding.
Dry-ground Job's tears	3.92-26.81	10.74 ± 4.60 (n=54)	
Wet-ground Job's tears	5.20-17.54	11.29 ± 3.27 (n=52)	
Unprocessed barley	11.63-30.32	21.85 ± 4.43 (n=75)	Dry-grinding result in greater enlargement of the size of starch grains than wet-grinding; 43% single starch grains totally lost their extinction crosses after dry-grinding.
Dry-ground barley	10.01-51.08	25.97 ± 8.06 (n=68)	
Wet-ground barley	10.46-23.38	23.38 ± 5.21 (n=97)	
Zea mays (mature and hard kernels, control sample)	2-28	13± 3.9 (n=116)	Samples with harder kernels result in the greater the enlargement of the size of starch grains (Mickleburgh and Pagán-Jiménez, 2012)
Zea mays (green and soft)	5-25	12.1±4.7 (n=60)	
Zea mays (mature and hard kernels) *	10-38	23.2± 6.6 (n=60)	
Zea mays (semi-mature and partially hard kernels) *	7-34	20.8±5.7 (n=60)	

Note: Samples marked with * were soaked for one hour and then intensively ground for five minutes. *Zea mays* (maize) control samples were soaked for 24 hours and then ground 15 seconds to avoid overly damaging of starch grains. All the *Zea mays* samples were ground with a marble mortar and pestle (Mickleburgh and Pagán-Jiménez 2012).

4.5 Conclusion

The application of starch grain analysis has grown quickly in China, with increasingly more papers on ancient starch research being been published each year (Yang 2017). Some limitations and issues of this method have been noticed and discussed elsewhere (Haslam 2004; Hutschenreuther et al. 2017; Mercader et al. 2018). These are known taphonomy issues such as soil bacteria, enzymes, fungal degradation, and chemical digestion that may bias representation of starch grains in the archaeobotanical record. In addition, our results indicate different grinding techniques also result in different levels of damage to starch grains and hence different degrees of preservation. Among the different grinding techniques, dry-grinding causes significant morphological changes to starch grains and consequently affects starch grain detection, especially in the case of rice. This result suggests that the scarcity of rice starch grains recovered from grinding tools in Neolithic Chinese sites could be caused by the employment of the dry-grinding technique by ancient communities. Thus, previous interpretations inferring that rice was not the primary cereal processed with Neolithic grinding tools needs to be reconsidered. We have also noticed that the current methodological approach widely applied in starch grain research needs to be adjusted and improved in order to avoid overlooking of damaged starch grains. Overall, by exploring the morphological changes in starch grains caused by different grinding techniques, this research contributes towards a more nuanced interpretation of how rice was processed by past societies.

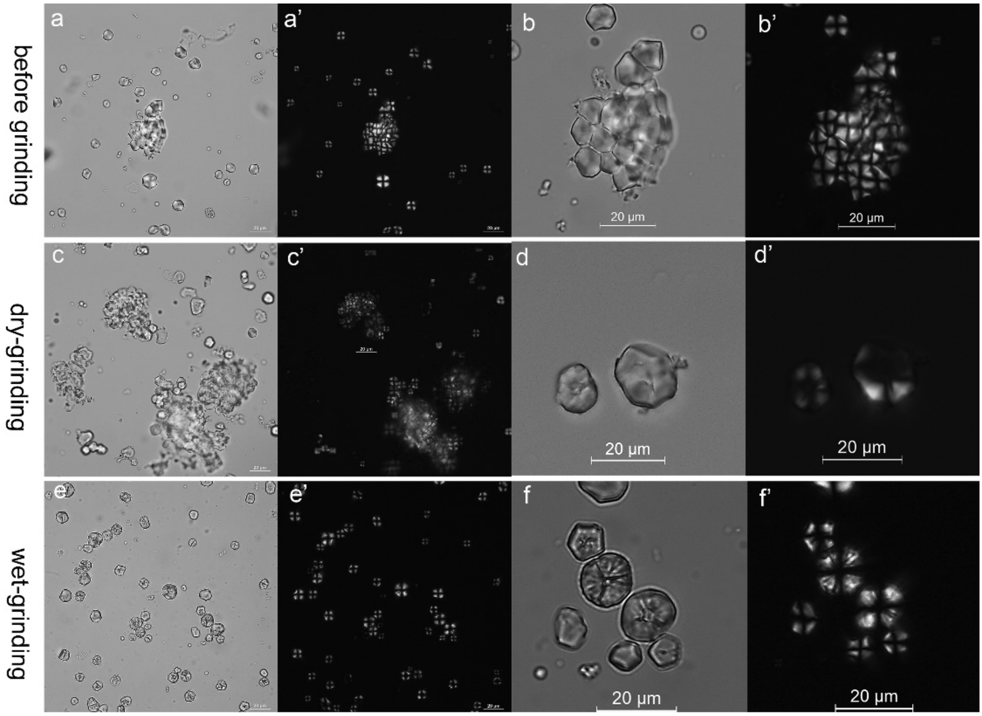

Figure S4.1 Morphological changes of starch grains from foxtail millet after dry- and wet-grinding. a, a': single and compound starch grains coexist in the unprocessed millet samples; b: single and the irregular shape compound starch grains under normal light, b': "+"- shaped extinction cross of the millet starch grains under polarized light; c: single starch grains still exist and more irregular starch aggregates generated in the millet samples, c': the extinction crosses of starch aggregates became blurry; d: irregular fissures on the starch grain surfaces; d': incomplete extinction crosses of the single starch grains; e: single starch grains under the normal and polarized light; f: radical fissures on the starch surfaces; f': arms of the extinction crosses became thicker.

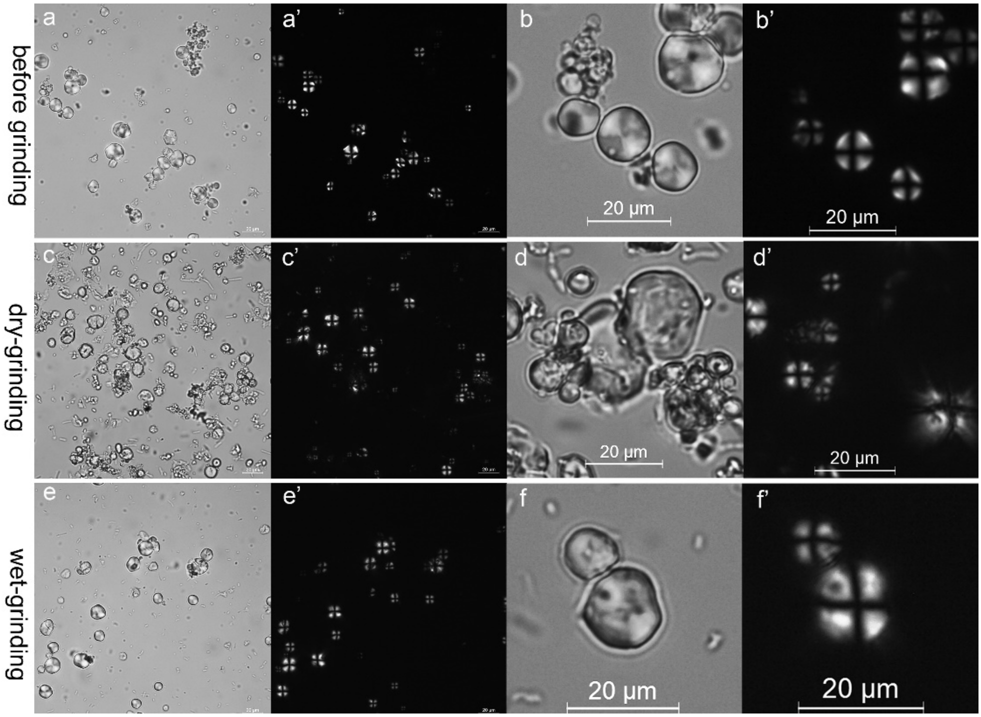

Figure S4.2 Morphological changes of starch grains from Job's tears after dry- and wet-grinding. a, a', b and b': single starch grains in the unprocessed samples from Job's tears; c, c': overview of the single starch grains after dry-grinding, see a majority of these grains still visible under polarized light; d, d': two extremely enlarged single starch grains without extinction crosses; e, e', f and f': starch grains show features resemble the unprocessed samples.

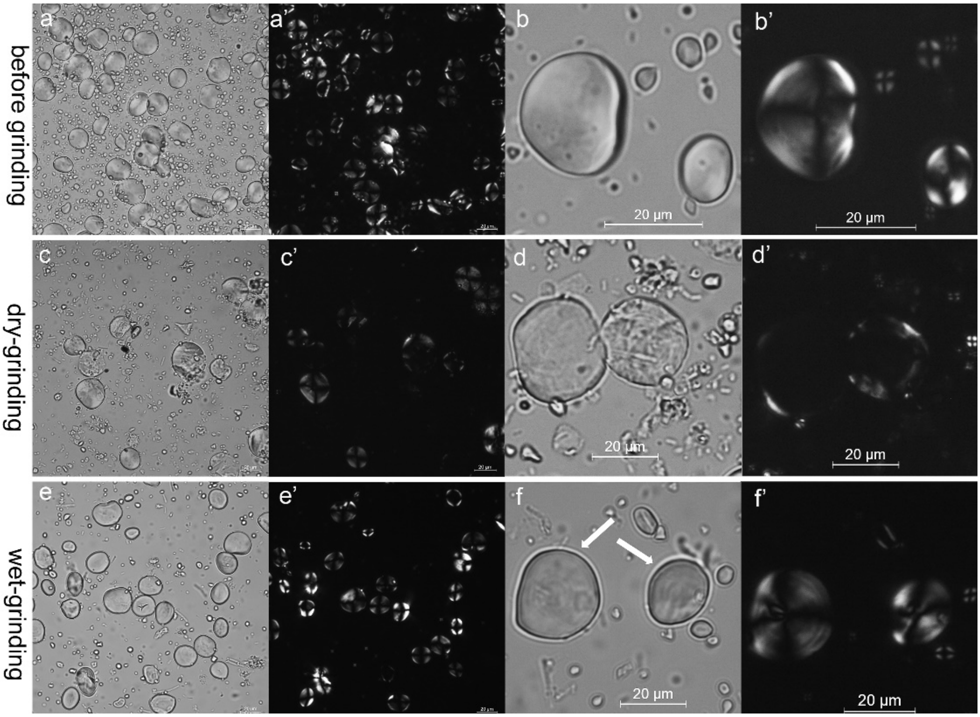

Figure S4. 3 Morphological changes of starch grains from barley after dry- and wet-grinding. a, a': type a and type b starch grains coexist in the unprocessed millet samples; b: barley starch grains with smooth surface; b': "X" -shaped extinction cross of the barley starch grains under polarized light; c, c': overview of the ground barley starch grains, see only very few of them became totally invisible; d: lamellae and shallow striations formed on the starch surface; d': barley starch grains with faint extinction crosses; e, e': overview of starch grains after wet-grinding under normal and polarized light; f: shallow lamellae represent on starch surfaces; f': the extinction crosses resembles the unprocessed samples.

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Chapter 5 Plant foods and different uses of grinding tools at the Neolithic site of Tanghu in Central China

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Plant foods and different uses of grinding tools at the Neolithic site of Tanghu in Central China

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Abstract

In the central plain of China, grinding tools are a common category of artefacts at sites attributed to the Peiligang Culture (9000-7000 BP). This paper focuses on the grinding tool assemblage from the site of Tanghu, the largest Peiligang Culture settlement yet discovered. The results from the microwear and residue analyses both suggest that cereals were the primary plant material processed with the grinding tools. Other plants, including acorns and underground storage organs (USOs), were also processed, but probably to a smaller extent. Furthermore, microwear analysis suggests that the dry-grinding technique was adopted for cereal processing, and a piece of hide or animal skin was placed underneath the grinding slabs to gather the processed plant material. Apart from plant food processing, one of the grinding tools was also involved in processing bone. These data put more insights into the Neolithic culinary practices and different uses of grinding tools in this region.

Keywords: plant foods, use-wear, starch grain, Peiligang Culture, grinding tools, Neolithic China

5.1 Introduction

Plant foods are significant resources of energy, protein, vitamins, and minerals in human diets in the present and past (Herry, 2011; Liu et al., 2013; Nestle, 1999; Wickler et al., 1992; Wollstonecroft et al., 2008). Investigating prehistoric exploitation of plant foods and plant food processing techniques enriches our understanding of their impact on human health and culinary cultures (e.g. Capparelli et al., 2011; Sadvari et al., 2015; Searcy, 2011; Yang and Jiang, 2010). Archaeological excavations to date have provided some fascinating evidence for the consumption of plant foods by past societies worldwide (e.g. Arranz-Otaegui et al. 2018; Fuller and Gonzalez Carretero 2018). A striking example in China is Neolithic noodles unearthed at the site of Lajia (ca. 4000 BP), where the shape of the noodles could still be clearly recognized in a sealed earthenware bowl (Lu et al. 2005). However, such archaeological findings are not always encountered, probably due to complex post-depositional processes (Evershed, 2008). Thus, archaeologists often study ancient grinding tools to retrieve information on prehistoric plant foods and food processing techniques in different regions worldwide.

In the upper catchment of the Huai River (UCHR) in central China, grinding tools (e.g. Fig. 1c and d) were frequently unearthed from sites associated with the Neolithic Peiligang Culture (c. 7000-5000BC), coinciding with the emergence of agriculture (Li, 1979; Liu et al., 2010; Ren et al., 1984; Yang et al., 2017; Zhang, 2015, 1999; Zhang et al., 2012; Zhang and Wang, 1998). Although intensive studies have been carried to understand 'what did these grinding tools process?' the yielded results are not always consistent. For example, at the sites that are all attributed to the Peiligang Culture: Egou, Shigu, and Peiligang, the grinding tools have been subjected to starch grain and microwear analysis (Liu et al., 2010; Zhang et al., 2011). The results suggest that these tools were primarily used for processing acorns. On the other hand, our recent study conducted at Jiahu in the same region reveals that cereals were mainly processed with the grinding tools, while some of the Jiahu grinding tools were associated with processing wood-like material (Li et al., 2018).

In order to add more data to facilitate the discussion of the use of grinding tools and their roles among the early farming communities, this paper analyzes the grinding tools unearthed from the Peiligang Culture site of Tanghu in the UCHR region (Fig. 5.1a). The site is located in the city of Xinzheng in Henan Province. It covers nearly 1.4 square kilometres and represents the largest Peiligang Culture settlement yet discovered in this region. A total of 63 semi-subterranean roundhouses (Fig. 5.1b) and 201 pits have been excavated (Kaifeng , 1978; Xin et al., 2010; Zhang et al., 2008). Material remains including ground stone tools, pottery sherds, and animal bones were commonly found, while macrobotanical remains are poorly preserved at the site. Phytolith analysis of the soil samples has provided important evidence for the exploitation of cereals, suggesting that mixed farming of rice (*Oryza sativa*) and millet (*Panicum miliaceum*) had started there by at least 5800 BC (Zhang et al., 2012).

5.2 The grinding tool assemblage from the site of Tanghu

The grinding tools from the site of Tanghu were made of sandstone characterized by medium grain size. This raw material can be found at the riverbeds seven kilometres to the north of the site (Dr. Jianxing Cui, personal communication). A similar type of material was also used for making grinding tools at neighbouring sites, such as the site of Jiahu, Peiligang, Egou, and Shigu (Cui et al., 2017; Liu et al., 2010).

The morphology of the grinding tools was variable. The grinding slabs were divided into three types: a) slabs with feet, with oval-shaped distal end; b) slabs without feet, with an oval-shaped distal end, and c) slabs without feet, with a triangular-shaped distal end (Zhang et al., 2008). The rollers were also divided into three different types based on the shape of the cross-section: round, triangular, and ovate. The grinding slabs range in size from 50 to 74 centimetres in length and 22 to 37 centimetres in width. The rollers range from 19.2 to 57.5 centimetres in length and 4.4 to 5 centimetres in diameter (Li, 1979). These typo-morphological features occur consistently in the grinding tool assemblages from the other nearby sites associated with the Peiligang Culture (Li, 1979; Zhang, 1999). Traces of manufacture were often encountered on the surfaces of the grinding tools, indicating that percussive and grinding techniques were used to form these artefacts. Pecking races were often encountered in the grinding area of the tools, probably resulted from maintenances that were carried out to make grinding surfaces rougher and more efficient after a certain time of use

At the site of Tanghu and other Peiligang Culture sites, complete grinding tools mostly came from graves and a few from pits that may be related to ritual human sacrifice (Kaifeng, 1978; Xin et al., 2010; Yang et al., 2017; Zhang, 1999; Zhang et al., 2008). The distribution pattern suggests that these objects were deposited intentionally in funerary contexts before they were worn out or broken through regular use. In contrast, grinding tools unearthed from the residential areas were all broken. Each fragment at Tanghu possesses over three fractured surfaces on average (Table 5.1), suggesting they were more likely to be intentionally broken. These fragments were distributed randomly in the residential area, pending a further discussion of their context of use, such as where the grinding activities were conducted (e.g. Wright, 2014)

Table 5.1 Processed materials on the grinding tools inferred by microwear analysis

tool no.	tool type	context	completeness	fractured surface	processed material
H80*	grinding slab	pit	fragment	2	cereals and bone
F52*	grinding slab	house	fragment	6	cereals
T0314(3):1*	grinding roller	cultural layer	fragment	3	cereals
T0314(3):2*	grinding slab	cultural layer	fragment	6	cereals
H74*	grinding roller	house	fragment	2	cereals
T0113(3):1*	grinding slab	cultural layer	fragment	2	cereals
T0113(4):1*	grinding slab	cultural layer	fragment	6	cereals
T0313(3)*	grinding slab	cultural layer	fragment	3	cereals
H8	grinding slab	pit	fragment	8	nouse-related traces
H10	grinding slab	pit	fragment	4	cereals
F65	grinding slab	house	fragment	3	cereals
F41:3	grinding slab	house	fragment	3	cereals
T0103(3):8	grinding slab	cultural layer	fragment	3	cereals
T0203:3	grinding roller	house	fragment	1	cereals
T0401(4)	grinding slab	cultural layer	fragment	3	cereals
T0203	grinding slab	cultural layer	fragment	3	cereals
F3	grinding slab	cultural layer	fragment	4	cereals

Note: Eight of the artefacts with * were subjected to starch grain analysis

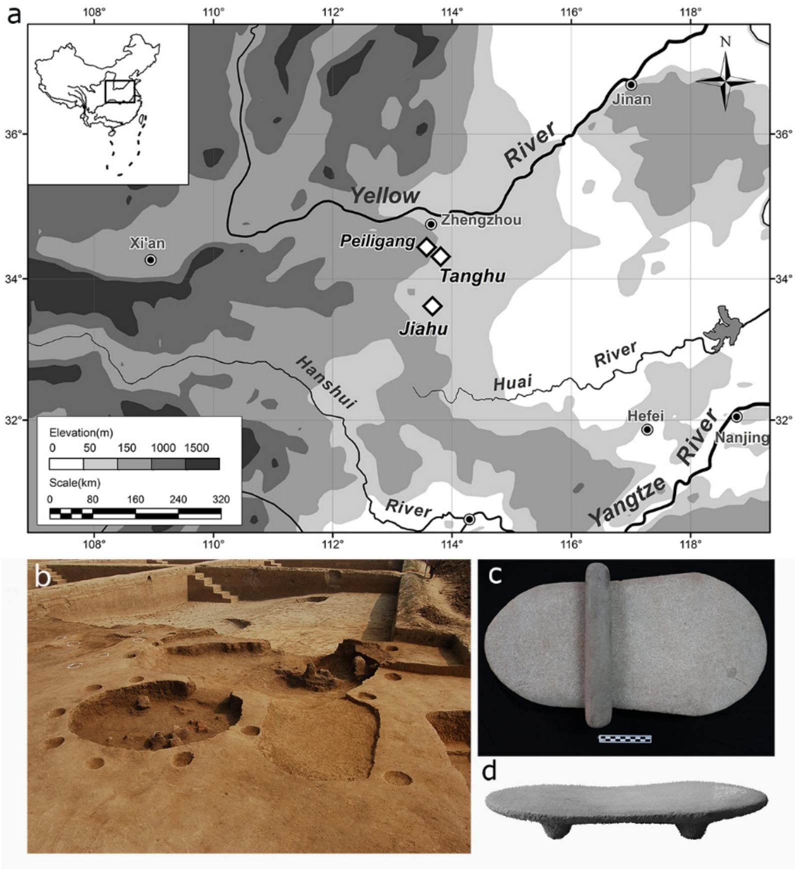

Figure 5.1 The location (a) and archaeological findings at the site of Tanghu and the nearby sites (b and c). a) the location of the sites of Tanghu, Jiahu, and Peiligang in the upper catchment of the Huai River, China; b) the house remains unearthed at the site of Tanghu; c and d) the front and side views of a pair of grinding tools from the site of Jiahu in the research region, showing the symmetric shape and standing feet at the bottom of the slab.

For the current study, we selected all of the 17 grinding tools excavated from the residential area during the last two excavation seasons (Table 5.1 and Fig. 5.2). Only two graves have been found, and no grinding tools were found in the burials. Fourteen of these tools derived from grinding slabs and three from grinding rollers. The morphology of the grinding slabs (e.g. with or without feet) was undetermined because of their high degree of fragmentation (Table 5.1).

5.3 Methods

Starch grain and microwear analysis can provide evidence for the function of grinding tools. For instance, by extracting the preserved plant residues on grinding tools, starch grain analysis has been used to identify the types of plant foods processed (e.g. Babot and Apella, 2003; Fullagar et al., 2008; Li Liu et al., 2014;

Piperno et al., 2000). Microwear analysis provides further insight in the type of materials processed on these tools, and can also be used to infer how the grinding processes were conducted (Dubreuil and Savage, 2014; Van Gijn, 2014). More recently, a microwear reference baseline has been built and applied to indicate the adopted ancient grinding techniques (Li et al., 2019). These two analytical methods, i.e., starch grain and microwear analyses, complement each other and are often integrated in artefact studies (e.g. Fullagar et al. 2006; Liu et al. 2013a; Gibaja Bao and Ferreira Bicho 2015).

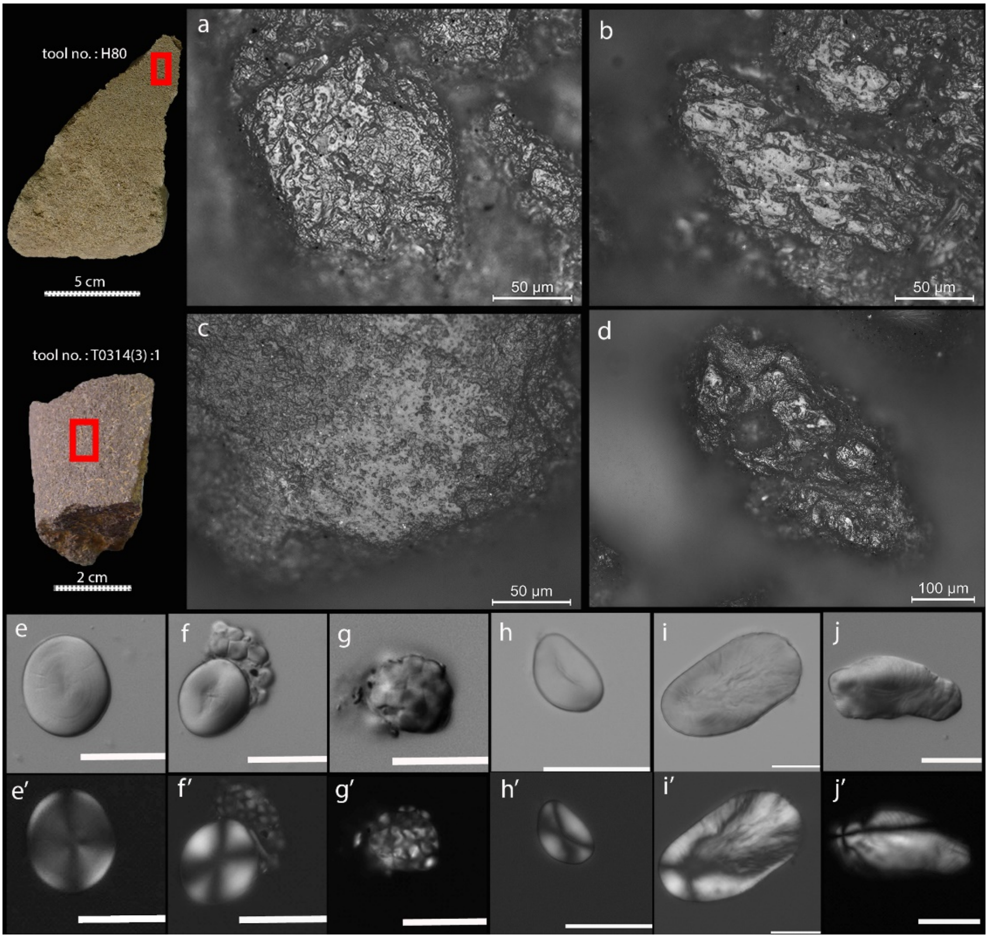

Figure 5.2 Microwear traces and starch grains on the grinding tools from Tanghu. a) microwear traces associated with the dry-grinding of cereals, taken on the tool T0314(3):1(area with the red square); b and c) microwear traces associated with processing bone, taken from used surface (area with the red square) of the tool H80 ; d) microwear traces associated with the contact with hide, taken from the opposing surface of tool H80; e and e') starch grain from Triticeae tribe; f and f') starch grains from millet; g and g') starch grains from acorns; h and h') starch grains from rice; i and i') starch grains from unidentified USOs (scale bar of the starches: 20 ㎛, see the identification of the starch grains by Li, 2015; Yang et al., 2015).

Eight of the selected grinding tools from the site of Tanghu were subjected to starch grain analysis and the data have been published in Chinese (Li, 2015; Yang et al., 2015). In the previous starch research, the residue samples were taken from the grinding tools using an ultrasonic toothbrush. Each brush head was used only once. The contamination was tested by comparing the number of yielded starch grains from the used and unused surfaces of the grinding tools. In total, 242 starch grains were yielded from the used surfaces and no starch grains were found in the control samples. The identifications of the starch grains were conducted based on the modern starch grain reference collection at the University and Science and Technology of China (over 50 species) as well as the published starch data (Torrence and Barton, 2006; Wan et al., 2012, 2011; Wei et al., 2010; Yang et al., 2009; Yang and Perry, 2013).

In this paper, we first summarize the previous identification of the starch grains (Table 5.2) and then analyse these data using a quantitative approach. First, the identified plants were divided into three major categories: acorns, cereals, and USOs. Then the quantity and ubiquity value of each type of starch grains will be calculated and compared. Ubiquity refers to the occurrence of identified plant taxa amongst the entire artefact sample spectra (Hubbard, 1980). The measurement of ubiquity has increasingly been applied in recent starch research (e.g. Yao et al. 2016; Ciofalo et al. 2019). Results obtained by combing the ubiquity value with the absolute number of different types of starch grain shed light on which group of plants were mainly processed on the grinding tools.

In addition, the grinding tools were subjected to microwear analysis, the results of which were integrated with the results from starch grain analysis. First, all of the artefacts went through a cleaning procedure under running tap water. Then, the used surface of each artefact was determined based on unaided eye observations. Because the grinding tools could not be transported out of the Chinese museums for analysis, casts using Polyvinyl siloxane (PVS) were made at key areas of the tool surfaces. This PVS material can get impressions of the stone surfaces and has been widely used for the study of grinding implements (e.g. Liu et al. 2014b; Fullagar et al. 2017; Li et al. 2018). Six of the grinding slabs had flat and smooth surfaces on two opposing surfaces. In such cases, samples were taken from both sides of the slabs. In total, 33 PVS cast samples were collected. The casts were analysed with a Leica DM 6000m metallographic microscope (under magnifications from 100x to 500x) equipped with a Leica DFC450 camera.

Table 5.2 Starch grains identified on the grinding tools at the site of Tanghu

Tool no.	Triticeae	*Setaria italica*	*Oryza saliva*	*Quercus* spp.	Root of *Nelumbo nucifera*	Unidentified species from USOs
T0113(4):1*	3	1	0	0	5	0
T0113(3):1*	1	0	0	1	0	0
T0314(3):1*	47	91	0	3	6	0
T0314(3):2*	0	1	0	0	0	0
H80*	0	1	0	0	2	0
T0313(3)*	2	24	0	0	6	0
F52*	1	1	0	0	2	0
H74*	15	3	13	2	9	2
Total	69	122	13	6	30	2

Observed microwear features included micro-striations (including their general distribution on the use faces), residues, and micro-polish. Micro-polish was studied in terms of its directionality, the degree of linkage, texture, morphology, reflectivity, and location on the micro-topography of the stone surface (see also descriptions by Adams et al., 2009; Van Gijn and Houkes, 2006; Van Gijn and Verbaas, 2007a). Microwear features are described using a standardized terminology used in our previous publication (Li et al., 2019). The interpretations of the microwear traces are based on the microwear reference collections from the laboratory for Material Culture Studies at Leiden University (e.g. Fig. 3a, b, c, d, e, and f) as well as previous publications (Hayes et al., 2017; Li et al., 2018; L Liu et al., 2014a; Liu et al., 2010; Van Gijn and Verbaas, 2009).

5.4 Results

Starch grain analysis reveals that grinding tools from the site of Tanghu were associated with processing various plant foods (Fig. 5.2 e- j' and Table 5.2), including grass seeds from Triticeae Tribe, foxtail millet (*Setaria italica*) , rice, acorns (*Quercus* spp.), lotus root (root of *Nelumbo nucifera*), and some other undetermined USOs (Li, 2015; Yang et al., 2015). Further quantitative analysis of the starch data reveals that the grinding tools were used for mainly processing cereals, as the quantity and the ubiquity value of starch grains from cereals are both higher than those from USOs and acorns (Fig. 5.4a and b). This result is consistent with the results of the microwear analysis, as all grinding tools apart from one (16 out of 17) show microwear traces resulting from processing cereals (Table 5.1). This type of microwear was characterized by a micropolish with a greasy, granular, and moderately reflective appearance (Fig. 5.2a). It is worth pointing out that to grind different types of cereals produce similar types of use-wear patterns (e.g. Fig. 5.3a and 3f), so it is not yet possible to interpret the exact processed cereals based on use-wear traces. By comparing the microwear traces with the existing reference baseline used for inferring grinding techniques (Fig. 5.3a and 3b), it indicates that a dry-grinding technique (without soaking the processed cereals) was adopted for producing cereals at the site of Tanghu. At the nearby site of Jiahu, the same grinding technique was also employed for cereal processing (Li et al., 2019), possibly suggesting that this was a wider cultural choice.

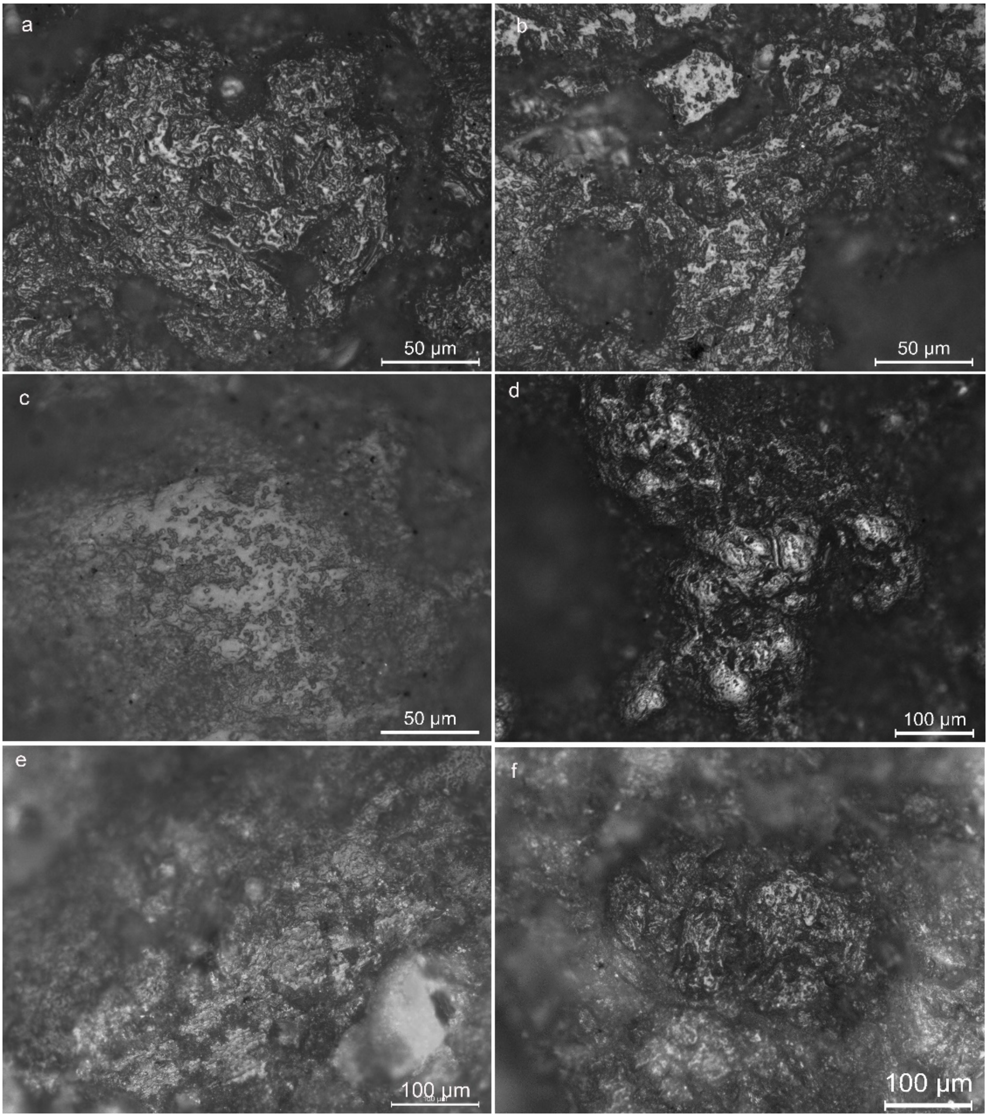

Figure 5.3 Microwear traces from the experimental grinding tools. a) microwear traces resulting from grinding dry millet after180 min; b) microwear traces resulting from grinding soaked millet after 180 min; c) microwear traces resulting from processing soaked bone after 180 min; d) microwear traces resulting from rubbing deer skin after 180 min; e) microwear traces resulting from processing acorns after 180 min; f) microwear traces resulting from processing Einkorn wheat after 180 min. Note: The experimental grinding tools were sandstone cobbles collected from the valley of the Maas River in the southern Netherlands.

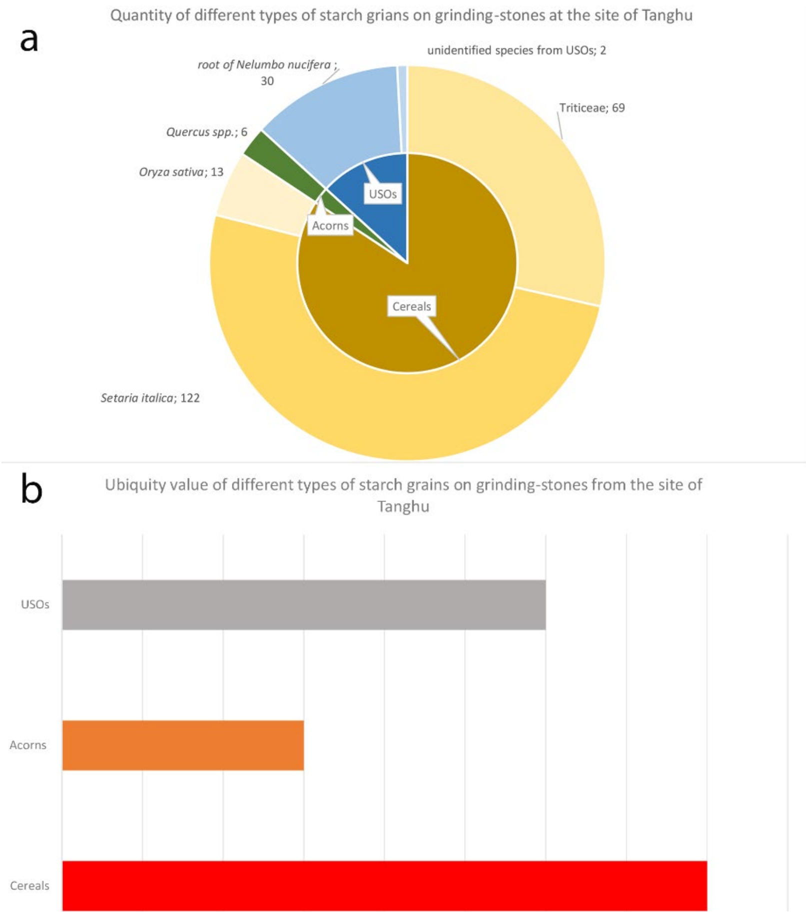

Figure 5.4 Comparison of the quantity (a) and ubiquity value (b) of starch grains from different types of plants at the site of Tanghu.

Additionally, the microwear analysis suggests that the Tanghu inhabitants had placed a piece of hide or animal skin underneath the grinding slabs to facilitate the gathering of the processed cereals. This inference is based on the microwear traces observed on the un-used side of the grinding slabs (e.g. Fig. 5.2d). This type of microwear traces resembles those related to hide processing, characterized by domed and smooth polish, which mainly formed on the higher micro-topography of the sampled stone surfaces (Fig. 5.3d). The formation of this type of microwear traces was probably related to friction between the grinding tools with fallen plant material and the hide placed underneath. Similar microwear traces have been found on grinding tools at the Linear Bandkeramik (LBK) site of Geleen-Janskamperveld in the Netherlands (Van Gijn and Verbaas 2009). A similar practice is observed in different present-day communities, where people gather flour by placing a cloth, plant leaves, or plastic bags underneath grinding tools (Peacock, 2013; Robitaille, 2016; Shoemaker et al., 2017).

Even though both analytical methods confirm that the grinding tool assemblage was closely associated with plant food processing, microwear traces resulting from bone processing were detected on the slab fragment H80 (Table 5.1). A smooth and reflective polish characterizes this type of microwear (Fig. 5.3c). It has a pitted appearance and often displays troughs, and its morphology ranges from sinuous to domed (Fig. 5.2b and 5.2c). Interestingly, the slab fragment H80 also possesses microwear traces consistent with from the processing cereals (Table 5.1). In some cases, it is possible to infer the sequence of the formation of different types of microwear traces based on their distribution and development on the stone surface. However, the two types of microwear traces on the fragment H80 are located in different locations and do not overlap. Thus, it is not possible to determine which type of microwear traces developed earlier. Nevertheless, two types of microwear traces appearing on the same artefact indicates that this tool has a more complex life history than the other tools. It implies that this tool was probably multifunctional, as it could have been used for processing both bone and plant foods. Another possible interpretation is that this fragment was used as a plant processing tool initially, and then reused as an abrading tool to sharpen bone tools after it broke. Although bone artefacts have not been unearthed at the site of Tanghu so far, animal bones have been unearthed. In addition, bone needles, awls, and arrowheads were frequently encountered at other nearby sites associated with the Peiligang Culture (Ren et al., 1984; Yang et al., 2017; Zhang, 2015, 1999).

5.5 Discussions

Similar to Jiahu (Li et al., 2019, 2018), our study reveals that cereals were the main processed plant foods and a dry grinding technique was preferred at the site of Tanghu. On the other hand, different choices of plant foods can also be detected among the Neolithic communities in the UCHR. For example, acorns were processed at sites of Tanghu, but not at Jiahu; water plants and legumes were found on the Jiahu grinding tools, yet not on the grinding tools from Tanghu. Furthermore, at the sites of Egou, Shigu, and Peiligang in the same region, acorns were suggested to be the primary processed material on the grinding tools (Liu et al., 2010; Zhang et al., 2011). Similarities and differences in the plant food practices among different Peiligang Culture sites suggest that while cultural links between these communities are inferred through dietary and culinary practices, they also seem to possess their own distinctive characteristics. This proposition is further supported by other material traditions observed in this region. For instance, the sites of Tanghu and Jiahu show similarities in terms of their stone tool (e.g. grinding slabs with feet, stone sickles, and axes) and pottery assemblages (e.g. cooking vessels). However, fermented beverages (McGovern et al., 2004) and the earliest examples of Chinese inscriptions and tonal flutes (Li et al., 2003; Zhang et al., 2004, 1999) have been exclusively found at Jiahu.

Apart from plant food processing, ethnographic and archaeological research worldwide indicates that grinding tools are involved in multiple daily tasks, such as processing of bone, antler, ivory, pigments, stone material, animal hide, clay, fibre and more (e.g. Adams, 1988; Dubreuil et al., 2019; Hamon and Le Gall, 2013; Hayes et al., 2018; Procopiou et al., 2011; Robitaille, 2016; Rosenberg and Golani, 2012; Tsoraki, in press; Tsoraki, 2008, 2007). The presence of microwear traces associated with bone processing in the Tanghu grinding tool assemblage highlights that at least in some occasions these tools were multifunctional. At the nearby site of Jiahu, another different use of grinding tools was reported, where the grinding slabs with feet were mainly associated with processing wood-like material (Li et al., 2018). Notably, these different uses of the grinding tools from the Peiligang Culture sites were often overlooked in previous studies (e.g. Liu et al., 2010; Yang et al., 2015; Zhang, 2011). Research solely relying on starch grain analysis could easily neglect processed materials without starches. Microwear analysis also has difficulties in determining a multi-functional grinding tool when later developed microwear traces obliterate the previously formed ones on the stone surface. Furthermore, complete grinding tools are not always encountered in archaeological excavations, which means studies grinding tool fragments are hard to provide a thorough account of the function of grinding tools. Thus, as Hamon (2009) has pointed out, the multi-functional uses of grinding tools are very likely underrepresented in the archaeological record.

5.6 Conclusion

The results from the microwear and starch grain analysis show a strong correlation between plant processing and grinding tools from the site of Tanghu, which enable us to picture plant food production during the Neolithic period. Flours were produced from various plants, but mainly from cereals, which include both rice and foxtail millet. In addition, a dry-grinding technique was preferred for cereal processing. The neighbouring sites shared similar food processing practices, but also exercised different choices toward plant foods. Nevertheless, as Gokee and Logan (2014) have argued that food and craft activities could not be separated; one of the reasons is because tools were shared between different tasks. Apart from food processing, different uses of the grinding tools were detected at sites of Tanghu and Jiahu in the same region (Li et al., 2018), where some of the tools were associated with processing bone and wood-like material. These unique findings highlight that grinding tools were not only central for the study of ancient culinary practices but also hold the potential to reveal different household activities such as craft production.

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Chapter 6 Foodways of the earliest farmers in the Huai River Basin, China

The inhabitants at the site of Jiahu have been considered as the earliest farmers in the Huai River Basin because of the findings of the domesticated rice there (Zhang and Hung 2013). Jiahu is also the most thoroughly studied site in the research region of this project (see Chapter 1.4). Over the past decades, scholars have applied multiple scientific methods to this site and produced large amounts of data relating to foodways. Furthermore, the previous chapters of this dissertation provide more information on culinary practices through the study of the Jiahu grinding tools. These conditions make Jiahu an ideal site to explore the early Neolithic foodways in the research region. The first objective of this chapter thus is to discuss Jiahu's foodways by combining the findings from the grinding tools with other related data from the site. Second, changes and continuities of foodways overtime at Jiahu are discussed.

6.1 Food procurement: plants, animals, and tools

According to Hastorf (2017), food procurement refers to hunting-gathering, while food production pertains to agriculture, horticulture, and animal husbandry. In this chapter, food procurement is considered as all kinds of ways to obtain food, which includes cultivating plants, rearing animals, as well as hunting, fishing, and gathering of wild food resources. People at Neolithic Jiahu had a diverse diet that relied on a variety of plants and animals including fish (Zhang 1999; Zhang 2015; Yang et al. 2017). The following section starts with introducing the plants and animals that were utilized at the site. Then the toolkits associated with agriculture, hunting, fishing, and gathering are discussed in order to consider how these food procurement activities were conducted.

6.1.1 Plants

Plant-based foods are a major part of human nutrition and health. Studies on past procurement of edible plants are largely based on macro- and micro-botanical remains, and on tools used in plant procurement activities. Systematic flotation work was carried out at Jiahu during the 2001 and 2013 excavation seasons (Zhao and Zhang 2009; Zhang et al. 2018). In total, 13, 800 L of soil samples were taken from the houses, graves, pits, as well as areas outside houses attributed to different phases. In addition, 43 soil samples (5 grams for each sample) were taken from the Jiahu residential area for phytolith analysis (Chen 2001; Zhang et al. 2018). Starch grain analysis has been applied to 15 grinding tools and 11 pottery sherds (Fig. 6.1) and initial results have been published in Chinese (Li 2015; Zhang 2015).

Figure 6.1 Recovered pottery sherds from Jiahu sampled and analysed for starch content (after Li 2015).

It should be noted that plant remains do not always preserve in optimal conditions due to complex post-depositional processes (Celant et al. 2015). At Jiahu, rice remains were discovered during the flotation work in 2001, the occurrence rate of rice macrofossils account for 15% of the total macrobotanical remains, while no rice remains were found in the flotation work carried out in 2013. This variation of recovered plant remains may be due to the nature of the excavated areas in 2013 were primarily human burial areas (Zhang et al. 2018). The discovered rice remains were dated back to 7000 BC, representing the earliest rice remains beyond the Yangtze River area in China (Zhao 2009; Zhang and Hung 2013). Studies have shown that the dimension of rice remains from Jiahu increased from phase I to III (Liu et al. 2007a; Liu et al. 2009), suggesting rice cultivation was initiated at the site. In the soil samples where rice remains occur, wild grasses were also abundantly recovered and identified from Panicoideae taxonomic subfamily, such as *Digitaria sanguinalis* (L.) Scop., *Digitaria ciliaris* (Retz.) Koeler, and *Echinochloa colona* (L.) Link. Nowadays, these wild grasses are common in rice paddies. Thus, it has been proposed that these wild grasses were very likely harvested together with rice and then brought back to the site (Zhao et al. 2001). Soil samples from outside of the residential areas for phytoliths to locate potential rice paddies (Yin 2015). Unfortunately, so far, no firm evidence of rice paddies has been found. Apart from rice, another 23 types of macrobotanical remains were recovered during flotation, which can be divided into five categories of fruits (e.g. grapes and sour jujube), underground storage organs (USOs, e.g. lotus roots), nuts (e.g. acorns), water plants (e.g. water caltrop), and wild soybeans (*Glycine max subsp. soja*) (Zhao et al. 2001). These species were considered as wild and could be obtained from nearby mountains or riverbeds in the southwest of the site.

Starch grain analysis confirmed the existence of rice extracted from the Jiahu grinding tools (Zhang 2015). Furthermore, starch grains from Job's tears (*Coix lacryma-jobi*) have been identified on the grinding tools and pottery sherds (Li, 2015). Job's tears are rich in nutrients and their grain sizes are bigger in comparison to rice and millet. Job's tears are widely cultivated in Asian countries and its starch remains have been recovered from many Chinese archaeological sites (e.g. Yang and Jiang 2010; Liu et al. 2015; Yao et al. 2016; Wang et al. 2016; Liu et al. 2018b; Wang et al. 2019), with the earliest evidence from at least 26,000 BC at the site of Shizitan (Liu et al. 2018a). However, the macrofossil remains of Job's tears have only been found sporadically from about seven sites from the Neolithic to the Han dynasty (Liu et al. 2019), which exclude Jiahu. Although starch grains from Job's tears have been identified on the Jiahu grinding tools, it remains unclear why macrofossil evidence of Job's tears is scarce in most of the archaeological sites. The other identified species through starch grain analysis include grass seeds from Triticeae tribe, lotus roots (*Nelumbo nucifera*), water caltrop (*Trapa* sp.), beans (*Vigna* spp.), and Chinese yam (*Dioscorea opposita*). The microbotanical (i.e. starch grains) and the macrobotanical remains at Jiahu both indicate that a wide range of edible plants were available and exploited.

6.1.2 Animals

The systematic study of faunal remains was carried out during the seventh archaeological season at Jiahu (Zhang 2015), in which 18,012 pieces of animal remains were subjected to classification and identification. Overall, identified species from the different phases were consistent, implying that wild animal food resources were relatively stable at the site and their use was patterned. These animals were divided into five categories: shellfish, fish, reptiles, birds, and mammals (Table 6.1). Because the number of identified skeletons (NISP) from birds, shellfish, and reptiles account for a small amount, the following sections focus on food resources from fish and mammals.

Table 6.1 Animal remains from fish, mammals, reptiles, birds, and shellfish during different phases at (after Zhang 2015)

	Phase I		Phase II		Phase III	
	Number (NISP)	Percentage	Number (NISP)	Percentage	Number (NISP)	Percentage
Fishes	4827	69.16%	3874	62.80%	3698	76.03%
mammals	1260	18.05%	1918	31.09%	737	15.15%
Reptiles	679	9.73%	323	5.24%	329	6.76%
Birds	206	2.95%	46	0.75%	99	2.04%
Shellfish	7	0.10%	8	0.13%	1	0.02%

Fish remains were abundantly recovered from Jiahu, their NISP accounting for over 60% among the total faunal remains (Zhang 2015). Based on the statistical analysis of age-mortality and species-selection profiles of the fish remains, Nakajima and colleagues (2019) have provided evidence that managed aquaculture of common carp (*Cyprinus carpio*) was present at Jiahu by around 6000 BC in Phase III. It is suggested that the Jiahu inhabitants probably started digging channels and controlling water levels and circulation, so fish could spawn and grow in the managed ecotones. Then, those juvenile fish were harvested in autumn. Nowadays, in the Hunan and Guizhou Province in southwest China, people release baby fish in rice paddies during the spawning season (Celant et al. 2015). These fish feed on rice flowers falling into the water and grow faster than those in the wild. This type of rice-fish farming is believed to have been practised in China for more than 1700 years and constituted a unique agro-landscape (MacKay 1995). Even though it remains unclear whether similar practices were used at Jiahu, fish remains were predominantly recovered throughout the occupation phases (Table 6.1), suggesting that these aquatic animals played a significant role in the diet of the Jiahu inhabitants.

The second-largest group of faunal remains is from mammals, in which pigs (*Sus scrofa domesticus Brissonand*) and dogs (*Canis familiaris* L.) have been identified as domesticated animals (Zhang 2015). Most of the pig skeletons were distributed randomly in the residential areas and only pig mandibles were recovered from human burial caches (Zhang 1999). Further faunal analysis indicates that most pigs (92.1 %) were killed before they were two years old (Zhang and Luo 2008), suggesting they were raised for meat. Among the 130 identified mammals at the site (2418 faunal remains), 12 of which are identified as pig. The others were identified as remains of 3 dogs, 88 deer, 3 cattle, 1 unidentified large carnivore, 18 small carnivores, 1 animal from the Felidae family, 2 badgers, and 2 rabbits. According to these data and the estimated size of these animals, it has been proposed that pork accounted for around 27 % of meat resources used at Jiahu. In the Yangtze River region, pig skeletons were also found at the site of Kuahuqiao (c. 6200-5000 BC) (Jing 2017), showing different features from the Jiahu pigs. Accordingly, the Jiahu pigs resemble wild pigs from northern China, while the pigs from Kuahuqiao are similar to wild pigs from southern China. Thus, it has been suggested that the inhabitants from Jiahu and Kuahuqiao domesticated pigs independently in their own habitats.

China has a long history of eating dogs, whose meat was considered as delicacy for the upper class in the Shang (1558-1046 BC) and Zhou (1046-256 BC) dynasties (Li et al. 2017). Dog meat is still consumed in certain regions of present-day China, such as the Yulin city of the Guangxi Province in south China, bordering Vietnam (Rubin 2015). However, no firm evidence indicates these animals were killed for consumption at Jiahu. Unlike pigs, no fragments of dogs have been recovered from the residential area of Jiahu. The dog remains were only encountered in burial contexts (Zhang 1999). For example, a dog was found in the human grave (M341), in which the dog skeleton was placed by the left foot of the buried human. This burial suggests the dog had a close relationship with the person. In addition, another ten dog burials were found near the human burials or beside houses (Zhang 1999). According to ethnographic accounts, the Hani people in southwest China believe dogs are the protectors of their villages and thus often sacrifice dogs as offerings to ensure the protection of their village (Bouchery 1996). Zhang and Cui (2013) thus proposed that some of the Jiahu inhabitants probably treated their dogs in a similar way.

Other mammal remains found at Jiahu, include deer, cattle, unidentified small and large carnivores, and rabbit, were all classified as wild animals (Zhang 2015). The minimum number (MNI) of identified deer compose the largest proportion (around 60%) of the identified mammal assemblage, suggesting deer were the main hunting targets. From phase I to phase II, the NISP of deer that can be confirmed are stable and then decrease in phase III (Table 6.2). Differently, the NISP and MNI of pigs were relatively stable during phase I and II, and then increased slightly from Phase II to phase III. This changing trend suggests that the Jiahu inhabitants probably relied less on wild animals such as deer in phase III but more on domesticated pigs.

In summary, the Jiahu inhabitants made use of the local plant and animal resources. Through a broad-spectrum subsistence strategy, they could obtain both cultivated crops and wild plants, along with managed fish and pigs, as well as wild animals.

Table 6.2 Percentage of NISP and MNI of pigs and deer among the total identified mammal remains from Jiahu (after Zhang 1999)

	Pig		Deer	
	NISP	MNI	NISP	MNI
Phase I	9.79%	9.76 %	68.39 %	46.34 %
Phase II	9.82 %	11.11%	66.14 %	40.00%
Phase III	14.05 %	13. 79%	41.43 %	27.59 %

Note: NISP refers to the number of the identified animal remains; MNI refers to the minimum number of the animals that can be identified

6.1.3 Tools used in food procurement

In present-day southern China, denticulate sickles made of iron are still used for harvesting rice (Fig. 6.2e). Stone sickles with similar shapes were unearthed at Jiahu (Zhang 1999, 2015). These artefacts are made of schist and slate, and are characterized by denticulated edges (Fig. 6.2a). Fullagar and colleagues (2012) have carried out experiments by using replica sickles with and without denticulate edges to harvest grasses. The results indicate that denticulated sickles are useful for cutting grasses while sickles without denticulate edges are not. Further, microwear analysis conducted on the Jiahu sickles reveals that these tools were adopted to reap grasses (Fig. 6.2b, Cui et al. 2017), which probably include rice. Moreover, fan-shaped and dumbbell phytoliths probably belonging to rice were extracted from the Jiahu sickles (Fig. 6.2c and d, unpublished data from the author). These lines of evidence suggest that the Jiahu sickles were very likely employed in rice harvesting.

It is worth pointing out that the Jiahu stone sickles started to appear during Phase II, implying that a different harvesting method was adopted in the earlier period. Rice normally grows in water and has a deep subterranean root system, so it is arduous to harvest rice by uprooting. Ethnographic accounts and previous research on archaeological sickles from China suggest three methods of harvesting rice are used (Yang 1981; Ma 1986; Zhen and Jiang 2007; Vaughan et al. 2008): a) people can simply collect rice grains by hand or beat and detach rice spikelet into baskets; a similar method has also been documented for harvesting wheat (Anderson 1999); b) when using sickles, reapers can choose to cut rice plants from panicles, in which case rice leaves are not harvested; alternatively, c) reapers can cut from rice stems, which means rice leaves, panicles, and grains are all harvested. These different harvesting techniques result in bringing different parts of rice to end up in the residential area. Different parts of a rice plant produce three distinct types of phytoliths (Lü et al. 1997), including sheet element dumbbells (Fig. 6.3a) and cuneiform bulliform cells (fan-shaped, Fig. 6.3b) from the leaves, and double-peaked glume cells (Fig. 6.3c) from rice husks. Based on the percentage of the different types of rice phytoliths preserved in the residential area, it is possible to infer which method was used for rice harvesting. At Jiahu, Yin (2015) took 34 soil samples (at least 5 grams for each sample) from the residential area (e.g. houses and pits near houses) for phytolith analysis, with at least 9 samples attributed to each phase. Among the identified phytolith from rice, the percentage of double-peaked phytoliths from rice glumes were dominant in Phase I. When it came to the Phase II and III, although phytoliths from glumes were still abundant, the percentage of phytoliths from stems and leaves increased. These data suggest that the local people adopted different methods to harvest rice during different phases. In Phase I, it is likely that only rice grains were harvested using the first method (a) mentioned above, thus few phytoliths from rice leaves and stems were present in the residential area. When it came to Phase II and III, sickles were used and the inhabitants started to cut rice from the stems. As a result, more phytoliths from rice leaves and stems were brought back to the residential areas. Nevertheless, it is worth noting that the number of the phytolith samples from each phase was rather low and most of the samples are from pits near houses (20 out of 34) (Zhang et al. 2018). Thus, more samples from different types of contexts (e.g. interior of houses) are required to further testify the harvesting methods for rice at Jiahu.

Apart from sickles, modern shovels are also closely associated with agricultural activities. For instance, farmers can use shovels to dig, lift, or move bulk materials such as gravel and sand in their farmland. Based on tool typology, stone shovels

(Fig. 6.4a and b) were classified at Jiahu (Zhang 1999; Lai and Ying 2009; Zhou 2014). Further microwear analysis on the Jiahu shovels has proved these objects were indeed involved in earth-working (Cui et al. 2017). Apart from stone shovels, one scapular implement (*gusi* in Chinese) was found at Jiahu (Fig. 6.4d). According to the ancient Chinese book zhouli written during the Han dynasty (206 BC–220 CE), a *gusi* was a type of agricultural tool used for breaking ground and hoe up weeds in paddies. At the sites attributed to the Hemudu Culture (c. 5000-3000 BC) in the Yangtze River, similar types of *gusi* (Fig. 6.4c) have been subjected to microwear analysis (Xie et al. 2017, Fig. 6.4e-h). Although, other activities were carried out with these bone tools as well, such as fibre processing, many were demonstrated to have been employed in earth working. Unlike shovels that have been recovered from phase I contexts, *gusi*s were only found in phase III contexts (Zhang 1999). Meanwhile, compared to the *gusi* (n=1), far more shovels were unearthed (n=87). Thus, it can be implied that shovels were more common at Jiahu throughout the site's occupation and the *gusi* was a later invention or adoption.

In contrast to agricultural tools, direct lines of evidence of tools relating to gathering wild plant species are hard to be archaeologically detected. In terms of hunting and fishing, arrowheads and fishing darts were the primary tools that were used at Jiahu. The number of these tools account for 270 and 127 specimens respectively, much higher than the other types of fishing and hunting tools such as stone balls (n=12) and fishing net weights made of pottery (n=28) (Lai 2009). All these hunting-fishing tools were used throughout the site's occupation except for fishing net weights made of pottery that do not appear until phase II, suggesting a new fishing technique was adopted or invented during this period. The majority of these arrowheads were made from deer limb bones and a few were made from cattle and pig bones (Zhang 1999), which may be due to the fact that deer were the most consumed terrestrial animals at the site. These arrowheads and fishing darts were also made into different shapes (Lai 2009), yet whether these tools functioned differently in hunting and fishing activities (e.g. for big or small targets) has to be investigated further to draw concluding remarks.

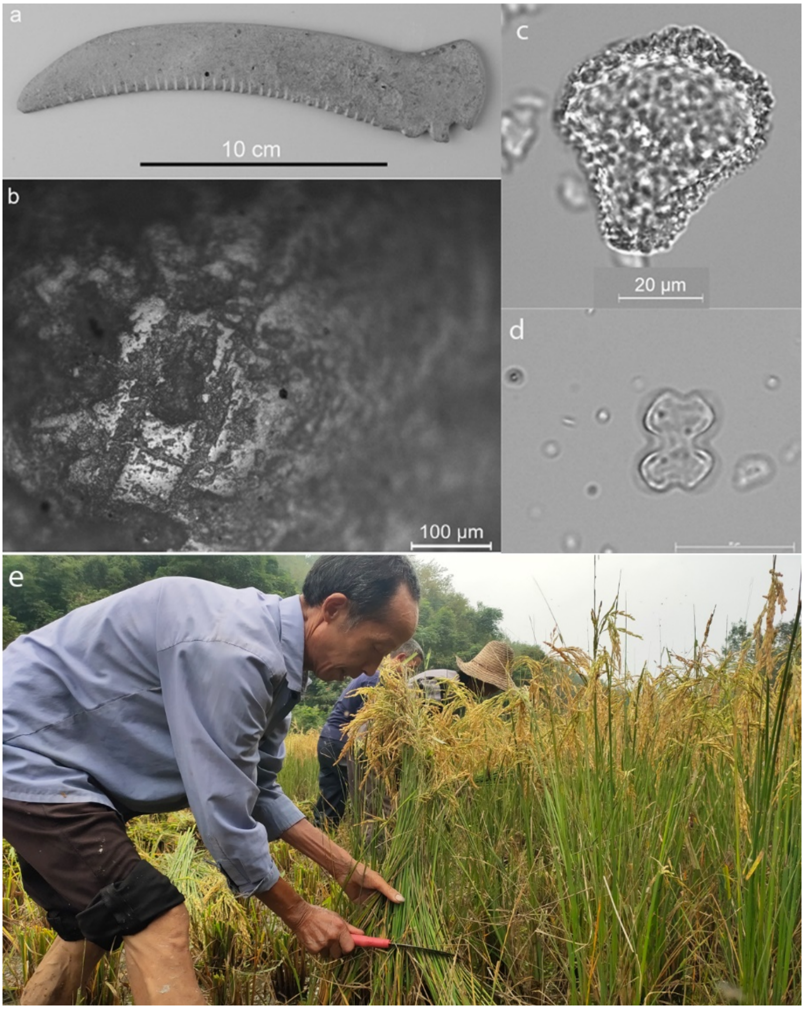

Figure 6.2 Phytoliths and microwear traces on the denticulate sickle from the site of Jiahu. a: An example of a stone sickle from Jiahu; b: the microwear traces associated with cutting grass observed on the cutting edge of this tool; c and d: dumbbell and fan-shaped phytoliths resembling those from rice, extracted from the surface of the Jiahu sickle; e: a local farmer from the Nvwashan village, Ankang city of China using an iron sickle to harvest rice (photo a, b, c, and d © Weiya Li, photo e © Jinzhoulinshi).

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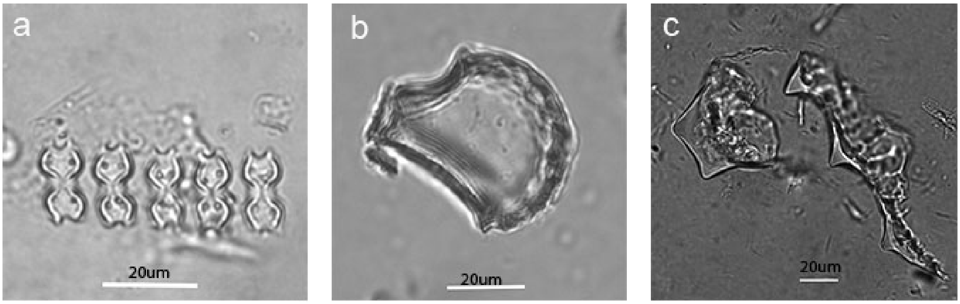

Figure 6.3 Three different types of phytoliths from rice. a: paralleled dumbbell phytoliths from rice leaves; b: fan-shaped phytoliths rice leaves; c: double-peak phytoliths from rice husks (all the pictures © Weiya Li).

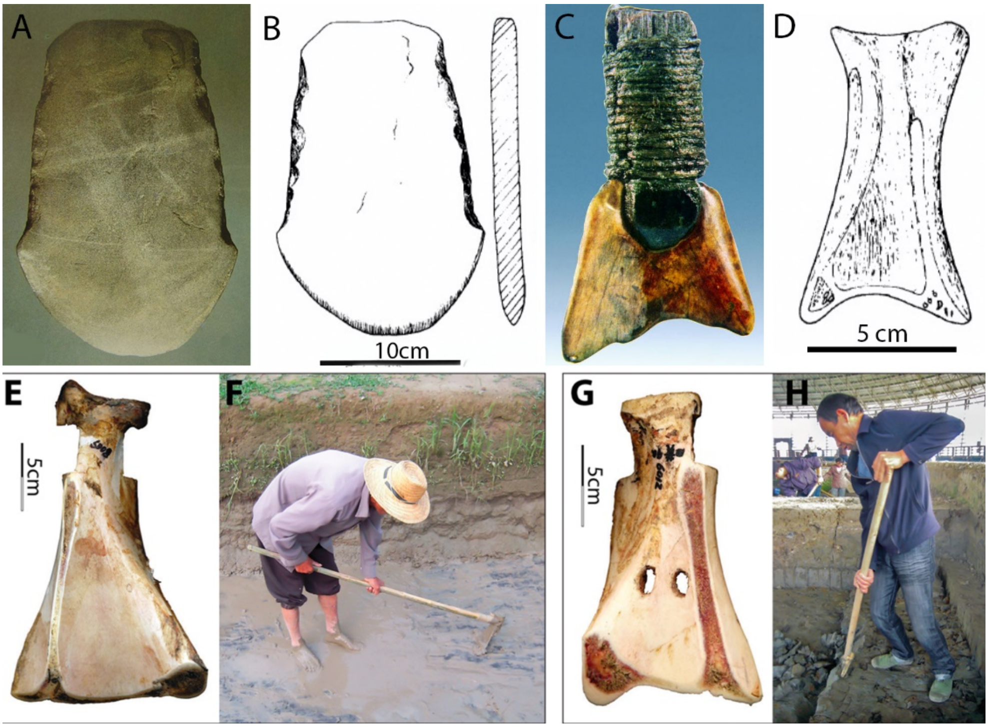

Figure 6.4 Tools associated with earth working. A and B: an example of a stone shovel unearthed from the site of Jiahu (© Juzhong, Zhang); C: a *gusi* implement unearthed at the site of Hemudu (ca. 7000-5000 BP) in the Yangtze River valley, China, note the *gusi* is still attached to a wooden handle with strings (© Encyclopaedia of China Publishing House); D: illustration of the *gusi* unearthed from the site of Jiahu (after Zhang, 1999); E and G: replicas of *gusi* made by Xie and colleagues (2017), F and H: demonstration of the use of replica *gusi* implements by the local farmers in China (© Xie et al. 2017).

A quantitative analysis has been carried out on different types of tools associated with agriculture, hunting, and fishing (Lai 2011, Fig. 6.5). The results show the number of agricultural tools, including shovels and sickles, increased from Phase I to Phase III (Fig. 6.5). In contrast, the number of tools associated with hunting and fishing, i.e., arrowheads and fishing darts, increased from Phase I to Phase II to the highest and then decreased in Phase III. These data reflect that farming was more widely adopted over time and in phase III, the Jiahu people relied less on hunting and fishing.

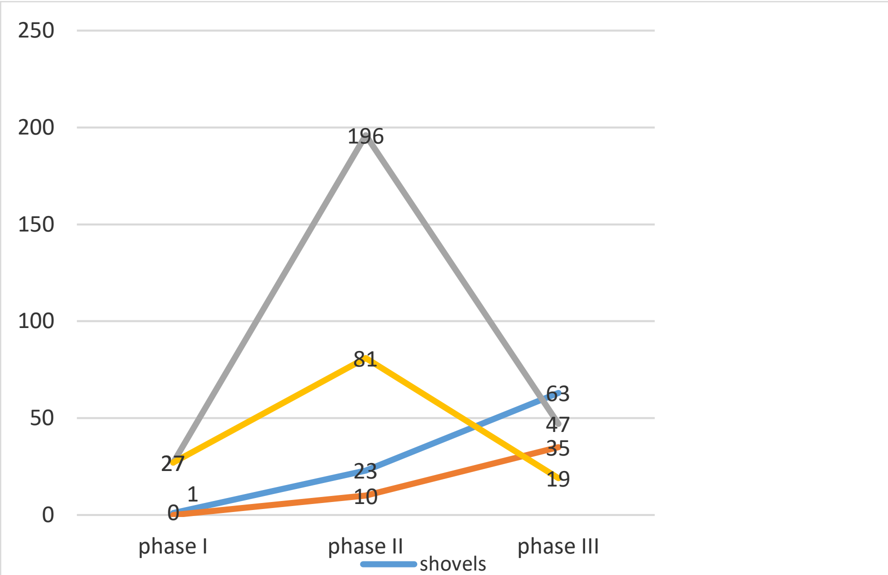

Figure 6.5 Number of shovels, sickles, arrowheads, and fishing darts from different phases at Jiahu (after Zhang, 1999)

6.2 Food processing

Raw foodstuffs often need to be processed for the sake of a longer period of storage, better taste, easier digestion, increased nutrition, or removal of undesirable substances (Stahl 1989; Caplice and Fitzgerald 1999). A wide range of culinary practices have been documented in ethnographic accounts, such as drying, smoking, salting, parching, grinding, pounding, leaching, butchering, brewing, fermenting, rotting, etc. (Katz and Weaver 2003; Li and Hsieh 2004; Speth 2017). People often choose different food processing techniques based on the properties of available ingredients and their own culinary preference (Atalay and Hastorf 2006). At Jiahu, microwear traces on the stone knives revealed that some of these objects were used to work animal bones (Cui et al. 2017), but whether these knives were used to cut bones or scrape meat from the bones was not clarified in this study. In addition, previous studies have not paid much attention to butchering marks on animal bones. Because the evidence for animal food processing is rare at Jiahu, the following sections concentrate on botanical culinary practices at Jiahu, which are inferred from the processed plant remains as well as implements involved in food processing.

6.2.1 Rice Processing

De-husking

During the flotation conducted in 2001 at Jiahu, 402 rice grains were recovered, of which 25 are complete. Most of these rice grains (24 out of 25) were already de-husked (Zhao and Zhang 2009). Ethnographic accounts reveal that wooden pestles were adopted for rice de-husking in China (Zhao and Li 2014). An archaeological example of a wooden pestle has also been unearthed at the early rice agriculture site of Hemudu in the Yangtze River region (Underhill 2013). Yet, wooden pestles have not been discovered at Jiahu, so scholars proposed that alternatively grinding tools were used for de-husking (Xu 2017). Although experimental research reveals that grinding slabs and rollers can be used for rice dehusking, these stone implements are less efficient comparing to wooden mortars and pestles for dehusking cereals (Wang 2008). So far, because the Jiahu grinding tools have not been subjected to phytolith analysis, it is uncertain whether grinding tools were employed for rice dehusking. Meanwhile, the possibility of adopting wooden mortars and pestles for de-husking cereals at Jiahu cannot be excluded due to the limited preservation of organic artifacts from aerobic conditions.

Grinding

Grinding tools have been frequently recovered from archaeological sites, most of which were associated with food processing (e.g. Aranguren et al. 2007; Liu et al. 2010a; Portillo et al. 2013; Portillo Ramírez et al. 2014; Fullagar et al. 2015; Shoemaker et al. 2017; Dietrich et al. 2019). At Jiahu, the results from starch grains indicate that the grinding tools were used for processing various plants, mainly cereals, which include rice, Job's tears (*Coix lacryma-jobi*), and plants from the Triticeae tribe (Zhang 2015). The quantity of cereal starch grains accounted for nearly half of the total starch grains recovered (see Chapter 2). Meanwhile, the ubiquity of the starch grains from cereals is also the highest. Microwear analysis further correlates the results from starch grain analysis, revealing that the majority of the Jiahu grinding tools were primarily used for grinding cereals, probably into flour (Li et al. 2019b). In terms of grinding practices, although both dry- and wet-grinding are commonly practised nowadays (Yang and Seib 1996; Suksomboon and Naivikul 2006; Stock et al. 2016), the Jiahu inhabitants preferred a dry-grinding technique (see Chapter 3). The produced dry flour is quicker to cook, easier to carry and digest, which would have been beneficial to the Jiahu inhabitants, who still relied on mobile subsistence strategies such as hunting and gathering of wild food resources (Li et al. 2019a).

Compared to starch grains from Job's tears, the quantity and ubiquity of starch grains from rice are much lower on the Jiahu grinding tools (Zhang 2015, see also Chapter 2). The scarcity of starch grains from rice has led to the interpretation that rice was not the main processed cereals at the site. However, a further experimental study indicates that dry-grinding could cause heavy morphological changes to starch grains and consequently affects starch grain detection, especially in the case of rice (see Chapter 4) (Li et al. 2020a). This interpretation also suggests that rice starch remains could be underrepresented on the Jiahu grinding tools. In other words, rice could have played a more significant role in the local people's diet than previously suggested. In addition, it is worth noting that one of the most prominent cereals (the highest in both ubiquity and absolute number of recovered starch grains) in the assemblage is Triticeae, which appears to be a wild plant at this time, but the macrobotanical evidence of Triticeae is rare at Jiahu (Zhao and Zhang, 2009; Zhang et al. 2018). This issue has been noticed and pointed out by Yang (2017). Yet, it is still inconclusive why this is the case.

Fermenting

Together with fruits and honey, rice was also fermented to produce a beverage (McGovern et al. 2004). This proposition is inferred from a study carried out on the Jiahu pottery sherds using five analytical methods, which include gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography-mass spectrometry (HPLC-MC), Fourier-transform infrared spectrometry (FT-IR), stable isotope analysis, and selective Feigl spot tests. The Jiahu samples yielded good FT-IR and HPLC, which correlates with different modern wines, including rice and grape wine. Meanwhile, samples in the Jiahu group show uniform presence of an inclusive series of n-alkanes, C^{23}–C^{36}, which may derive from wax and/or beeswax (McGovern et al. 2004). Furthermore, stable isotope analysis indicates the residues were from C_3 plants, such as rice or grape. Integrating these data in the light of the finding of macrobotanical remains at the site, it is interpreted that mixed ingredients, including rice, honey, and fruits (i.e. grapes and hawthorns) were probably fermented together. Nevertheless, no fingerprint compounds associated with fermentation have been found in this study. Thus, subsequent studies using different methods on these vessels should be useful to expand the range of data, and thus, lines of evidence for fermentation practices. For example, a recent study documented the resulting changes of starch grains from 17 species after fermentation (Wang et al. 2017b), which could be applied to indicate fermentation process as well as identify plants potentially used in beverage production. Ion chromatographic (IC) analysis could also be used to reveal the presence of oxalate, which develops during cereal mashing, steeping, and fermentation (Briggs et al. 2004).

The previous study on the Jiahu jars also found that most of the vessels (13 out of 16) possess similar chemical signatures (McGovern et al. 2004), implying a standardized recipe might have been used for beverage production at Jiahu. Unfortunately, the archaeological contexts of these analysed jars were not clarified. Therefore, issues such as recipe standardization in diachronic terms and the meaning of beverage production still need further considerations.

6.2.3 Acorn processing

Common acorns in China include Mongolian Oak (*Quercus mongolica*), sawtooth oak (*Quercus acutissima*), Chinese cork oak (*Quercus variabilis*), and ring-cupped oak (*Quercus glauca*) (Zhao and Zhang 2009). These species all contain tannic acid (also referred to as tannins) that negatively affects human digestion. Ethnographic accounts report different ways to remove the toxic acid from acorns. The procedures often include soaking acorns in cold or hot water, sun-drying, peeling, pounding, and sometimes mashing and boiling (Hosoya 2011). At Jiahu, some of the ethnographic practices can be detected from the discovered acorn remains. First, the macrobotanical remains of acorns found at Jiahu were all fruits without shells, indicating that shells of acorns were removed on purpose. Second, these acorn remains were also fragmented, suggesting that pounding probably was applied to reduce acorn fruits into smaller pieces. Last, from the grinding experiments of fresh acorns (Wang 2008), it is found that fresh acorns need to be dried before pounding or grinding. Thus, the Jiahu inhabitants at least adopted shelling, drying, and pounding before consumption of acorns.

6.2.4 Processing of underground storage organs (USOs)

Roots, rhizomes, and tubers are dietary staples in many parts of the world (Chandler-Ezell et al. 2006), their starch grains were often recovered from archaeological grinding tools (e.g. Piperno et al. 2000; Liu et al. 2014). Nevertheless, sometimes it is controversial whether these USOs were indeed ground by the past populations (Baysal and Wright 2005; Atalay and Hastorf 2006). The concerns mainly come from the fact that the size of some USOs such as lotus roots are not suitable for direct grinding and can be eaten as raw. At Jiahu, starch grains from lotus root and Chinese yam were found on the grinding tools (Zhang 2015), but use-wear traces associated with processing USOs were not identified (see Chapter 2) (Li et al. 2019b). It is thus inferred that USOs were probably occasionally processed on the grinding tools and the associated traces might have been obscured or removed by other grinding tasks, such as cereal processing. Meanwhile, considering airborne starch grains are possible from handling plant or food remains (Laurence et al. 2012; Crowther et al. 2014), it is also possible that starch remains of USOs were cross 'contaminated' on the ancient grinding tools through other culinary practices involving USOs carried out nearby, such as cutting, pounding, or cooking. Although the potential ancient 'contamination' may affect how we understand tool function, it does not change the fact that the starches identified from this context correspond to plants that were present and used (possibly gathered, cultivated, and consumed) by humans during this site's occupation. Moreover, recent experiments have been conducted to document damage patterns of starch grains from USOs associated with grinding, pounding, baking, boiling, and drying (Wang 2015). The results show that starch grains from USOs respond differently to each of the processing methods. These documented damage patterns of USOs create a reference baseline that could be applied to future research on grinding tools, which hold the potential to put further insights into the use of USOs in the past.

6.2.5 Tools used for food processing

The grinding tools from Jiahu have been subjected to use-wear and starch grain analysis (Zhang 2015; Li et al. 2019b). The distribution and character of the use-wear traces, as well as the quantitative analysis of starch grains recovered from the grinding tools from Jiahu indicate a correlation between tool type and function (see Chapter 2). Specifically, the grinding slabs without feet and cylindrical rollers were mainly associated with processing cereals, while grinding slabs with feet were mainly related to processing wood-like materials. Nevertheless, the sample size of the grinding tool assemblage for use-wear analysis is small, with only two grinding slabs with feet. The sample size was too limited to further testify the uses of different types of grinding tools at Jiahu. Future work at the site aims to supplement this study to further explore these themes, as well as examine spatial variation (activity areas) and diachronic continuities and/or changes in food processing practices.

Another interesting phenomenon about the Jiahu grinding tools is that the majority of the complete grinding tools were recovered from human burials, and only a few were encountered in pits that were related to ritual contexts (Zhang 1999; Zhang 2015; Yang et al. 2017). So far, it is inconclusive why all these complete objects ended up in graves or pits. What has been confirmed is that these tools were closely associated with botanical culinary practices (Zhang, 2015; Li et al. 2018). The middle part of the Jiahu grinding slabs and rollers also became relatively thinner, suggesting a prolonged use and maintenance of these implements before being buried in the ritual contexts. The appearance of these artefacts in all phases at Jiahu also suggest their indispensable role to the people in the settlement (Zhang 1999, 2015). Thus, these tools were likely used for quotidian activities rather than only for meals on special occasions.

The Jiahu pottery associated with beverage production were made of local clay without extra tempering materials (Zhang, 1999). These vessels were used in all occupation phases at the site and were well suited to prevent wine volatilization because of their narrow-necks and high, flaring mouths and rims (Fig. 6.6a). Their round base also allows upright storage of beverages by possibly embedding them in soft ground, such as sand. Deposits from beverages can also concentrate on the base. The vessel ears were produced with perforations, making them suitable to be hung from strings. Future research using microwear analysis to analyse ears and base of the Jiahu jars may provide new insights into the storage and fermentation practices at Jiahu.

Figure 6.6 Examples of the potteries from the site of Jiahu. a: an example of a jar associated with beverage production at the site of Jiahu; b: Jiaobaguan vessels used for cooking in phase I; c and d are Ding vessels used for cooking in phase II and III, note the black soot on the surface on the Ding vessel on c (© Juzhong Zhang).

6.3 Storage of food

The storage of food has been considered as an important strategy among early farming communities because it allows preservation and accumulation of food surplus over long periods of time, thus reducing dependency on food seasonality, while increasing food predictability and security (e.g. Kuijt and Finlayson 2009; Laland and O'Brien 2010; Urem-Kotsou 2017). Archaeological studies of food storage and storing technologies are largely based on research of storage facilities and vessels (Bogaard et al. 2009).

At Jiahu, around 400 storage pits were discovered, distributed around 50 houses (Zhang 1999; Zhang and Cui 2013; Zhang 2015; Yang et al. 2017). The Jiahu pits were divided into five main types according to their shape, dominated by pits with round openings. Most of the pits are between one to two metres in-depth, with visible digging traces on the walls in some cases (Zhang 1999). Soil samples taken from these pits provided the largest quantity of carbonized plant remains during botanical flotation recovery (Zhao and Zhang 2009). For instance, over 3000 grass seeds were yielded from 81 floated soil samples from pits, in contrast to only one unidentified charred seed from 18 soil samples from graves. In addition to plant remains, various animal remains were also found, including turtle shells, fish bones, and fragments from other mammals. These findings imply that different types of foods might have been stored in the pits. Pottery containers such as jars might have played a role in food storage at Jiahu as well. In present-day Chinese villages, pottery containers are often used for keeping cereals pickled vegetables (e.g. Fig. 6.7). Yet, residue analysis on pottery containers from Jiahu is still needed to investigate what was kept in these vessels.

Figure 6.7 Pottery vessels used for storing rice and seasoned vegetables at a village located in Jinmen city, Hubei Province of China (© Weiya Li).

During the eighth excavation season in 2013, a well was found outside a house (2013F5) attributed to Phase I (Yang et al. 2017). The use history of this house was divided into two periods. In the earlier period, the structure of the house was a semi-subterranean structure with seven post holes. The house is triangular and approximately $8m^2$ in size. The door of the house faced east. During the second period, the house was expanded and transferred to a surface-level structure. The excavation of this house and of the well did not continue because of time restrictions. Nevertheless, the finding of the well provided important evidence about water management practices of the Jiahu population. Since the early occupation of the site, the local people could obtain water near their houses.

6.4 Cooking and serving

Humans benefit from cooking in the past and the present (Stahl 1989; Stahl et al. 2002; Speth 2015). After cooking, food is often served with different utensils with different forms and materials, which often reflects daily consumption practices (Sahlins 1976). The discussion of cooking practices at Jiahu are mainly based on the cooking facilities found during the excavations, fuel remains left in hearths, and vessels used for cooking (Zhang 1999; Zhang 2015), while serving at Jiahu is inferred from the description of serving utensils unearthed at the site.

Hearths were found both inside and outside of housing structures at Jiahu. Not all the houses were equipped with hearths and the outdoor hearths were in communal areas between individual houses, suggesting some of the households may have shared the hearths. Indoor hearths were normally located in the centre of the houses. For instance, in the house F16 assigned to Phase III, a square-shaped hearth was well preserved. This hearth is around 108 to 126 cm in length, 34 cm in width, and 13 to 15 cm in depth. Plant ashes were recovered from inside of the hearth, from 5 to 7 cm thickness, in which carbonized rice remains were identified, suggesting that rice straws (stems) were used as fuel for cooking in Phase III. Hearths were found in houses attributed to all phases, but the number of these facilities were limited, only 6 hearths were documented in the site report.

Four main types of cooking utensils have been identified on the basis of pottery typology as well as cooking traces (i.e. soot on pottery surfaces) (Fig. 6.6c): a) tripods (Ding in Chinese), which were designed with wide-flaring mouths and three standing feet; b) cooking jars (Jiaobaguan in Chinese, Fig. 6.6b), characterized by an oval-shaped body with two handles; c) a wok-shaped caldron (Fu in Chinese), which has a wide-open mouth but without feet; and d) vessels with holes on their bottoms (Zeng in Chinese), which might be used for steaming food (Zhang, 1999). All these vessels were made of clay, tempered with sand or rice husks. The diverse shape of cooking vessels implies that different methods such as boiling or steaming were employed to cook at the site. In addition, pottery lids have been identified, suggesting that the inhabitants knew how to retain the temperature during cooking. The majority of Jiaobaguan vessels used for cooking were found in the first phase, while Ding vessels were only used in the later phase II and phase III (Fig. 6.6b, c, and d). The development and use of different types of cooking vessels reflect changes in cooking practices at the site.

Based on morphology and analogies, pottery basins, bowls, cups, and ladles have been classified as utensils used for presenting and consuming food at Jiahu. Fragments from basins and bowls were abundantly unearthed (the exact number was not provided in the site report), in contrast to a small number of cups (n=10) and ladles (n=2) (Zhang 1999). The low percentage of ladles and cups suggests that these objects were probably used in specific circumstances or on special occasions (e.g., sharing soups or drinking alcohol).

6.5 Consumption and human diet

Multiple types of artefacts including pottery, grinding tools, and human bones were subjected to analysis at Jiahu, which have provided direct and indirect evidence about what the Jiahu people ate.

Three types of starch grains were identified from the pottery sherds, including those from Job's tears, Triticeae, and lotus roots (Fig. 6.8). It should be mentioned that these pottery sherds were too small for further classification of their types, e.g., a cooking vessel or a container (Li, 2015). Four types of identified starch grains were recovered from the Jiahu grinding tools, including those from rice (*Oryza sativa*), water caltrop (*Trapa* sp.), beans (*Vigna* spp.), Chinese yam (*Dioscorea opposita*) (Zhang, 2015). These data show different assemblages of starch grains on pottery and grinding tools. For instance, starch grains from rice were found on the grinding tools but not on pottery sherds. Thus, these objects were likely in contact with different types of plants. Another possibility to consider is that cooking and grinding could have created damages to starch grains and consequently lead to biased preservations of the plant remains. Cooking experiments have been carried out to explore how starch grains from different species are affected by cooking (e.g. Henry et al. 2009; Ge et al. 2011). A recent cooking experiment was also carried out using a replica of Ding vessels from Jiahu to cook rice (Fig. 6.9a and b), in which the morphological changes of starch grains after cooking were documented (Fig. 6.9c, d, e, and f, unpublished research by the author). Meanwhile, grinding experiments were also carried out to document damage patters of starch grains from different cereals (see Chapter 4) (Li et al. 2020a). These data applied to more research of Jiahu pottery and grinding tools would contribute to a better understanding of the exploitation of plants at the site. Apart from starch grain analysis, other methods including High-temperature gas chromatography (HT-GC) and combined HT-GC/mass spectrometry (HT-GC/MS) on pottery vessels are also needed to reveal more information regarding the consumption of animal foods at the site.

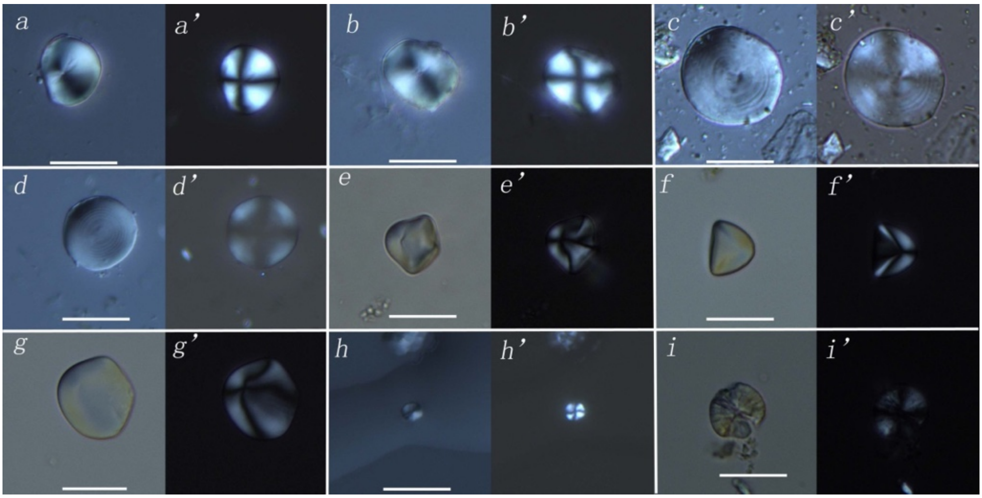

Figure 6.8 Starch grains found on the pottery sherds from the site of Jiahu. a, a', b, and b' from Job's tears; c, c', d', d' from plants belong to Triticeae tribe; e, e', f, f', g, and g' from USOs, probably from the lotus roots; h and h' are small undetermined starch grains; i and i' are damaged starch grains (after Li, 2015).

To reconstruct the human diet at Jiahu, Hu e. al (2006, 2007) carried out stable carbon and nitrogen isotope analysis on 28 human remains attributed to different Phases. The authors suggested that "carbon isotope ratios ($^{13}C/^{12}C$) of bones can be used to estimate the dietary proportions of C_3-based foods such as rice that have low $^{13}C/^{12}C$ ratios, and C^4-based food such as millet that has high $^{13}C/^{12}C$ ratios. Nitrogen isotope ratios ($^{15}N/^{14}N$) increase from plants to herbivores to carnivores, and can be used to reconstruct animal versus plant protein consumption" (Hu, 2006, pp. 1319-1320). Their results indicate that Collagen $\delta^{13}C$ values of the Jiahu samples were low for all the individuals, suggesting the primary dietary sources of these people were predominantly C_3 plants (e.g. rice, Triticeae, USOs, and acorns) as well as C_3-feeding animals. In addition, the correlation coefficient values between Collagen $\delta^{13}C$ and $\delta^{15}N$ are low (r=0.063), suggesting that plant foods account for the main proportion of their diet while animal food was the supplement. This proposition is consistent with another study on Jiahu human teeth, in which 71 individuals from Jiahu were studied. The results indicate that 14 people (19.72 %) assigned to different phases had dental caries, a disease that may result from the consumption of carbohydrates. The proportion of people having dental problems is even higher than that of modern agricultural societies (4.3% to 14.8 %) in northern China (He 2004). It is worth noting that the sample size of 28 is a small proportion of the recovered human remains at Jiahu (n=349 during the first six excavations). Meanwhile, 13 of the samples had completely non-collagenous compositions, so the interpretation of the human diet was based on the remaining15 samples. With limited samples per phase, more studies are still needed to evaluate diachronic trends in the diet at the site. Nevertheless, based on the current data, human remains assigned to Phase II had the highest $\delta^{15}N$ and lowest apatite $\delta^{13}C$ values, implying that people in this period had the highest proportions of animal protein and a larger amount of C_3 plants, which likely include rice.

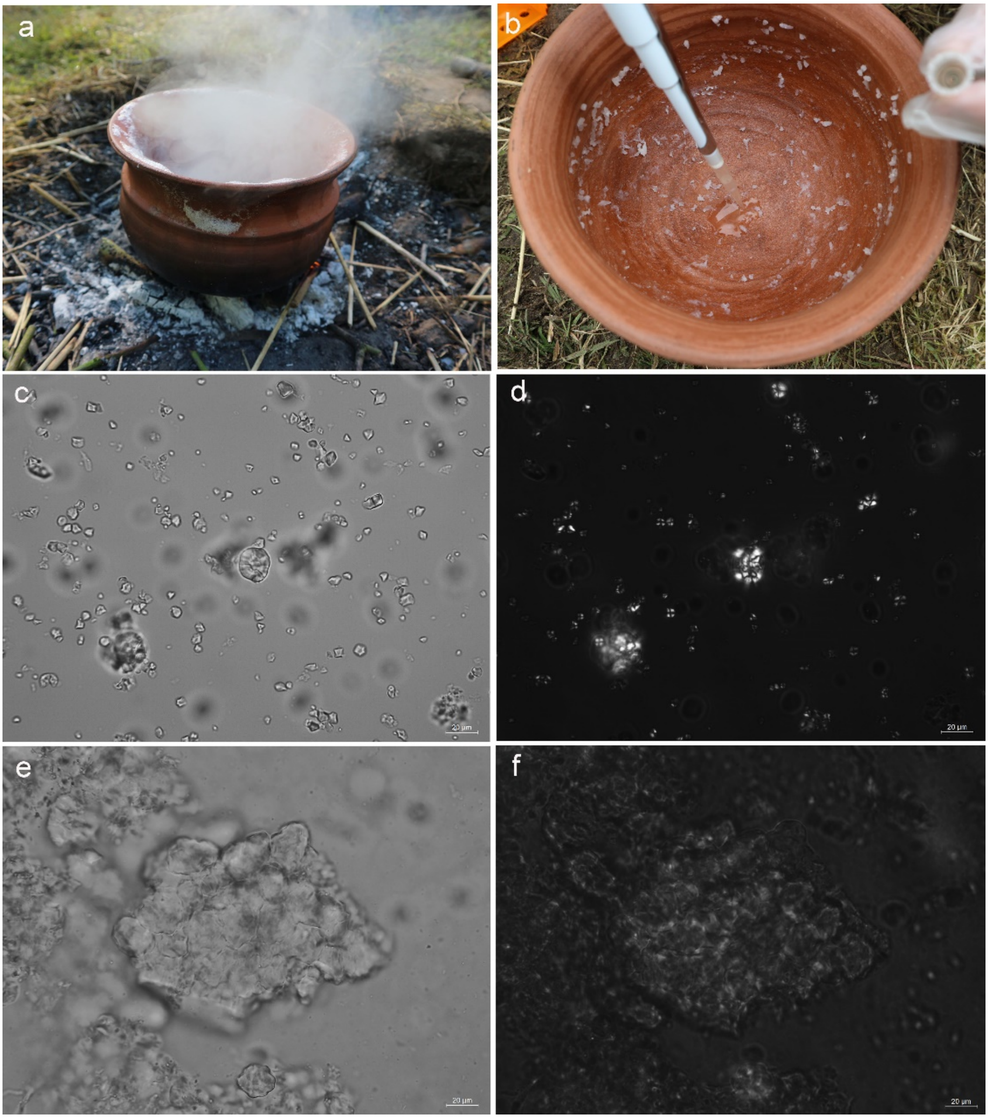

Figure 6.9 Cooking experiment using a replica of Ding vessel from the site of Jiahu. a: cooking experiment using a replica of Ding vessel from the site of Jiahu; b: extracting residue samples inside the Ding vessel after cooking rice, c and d: starch grains from rice before cooking; e and f: the resulting changes of starch grains from rice after cooking (© Weiya Li, unpublished data from the author).

6.6 Discard and recycling of food remains

Activities involved in dealing with food waste provide insights into a society's use of space and their concepts of cleanliness (Hill 1995). At Jiahu, food remains such as fish bones were often recovered from inside of the houses, suggesting food waste was discarded indoors. In addition to discard, recycling of food remains was also detected at the site. For instance, animal bones were made into different types of hunting tools, allowing the inhabitants to hunt for more wild animal resources; Ulnae bones from the red-crowned cranes (Grus japonensis) were made into musical instruments, e.g., flutes (Zhang et al. 1999); turtle shells and pebbles were used in ritual activities (e.g. divination, Zhang 1991). Regarding plant remains, rice husks were used as temper in pottery production as well as in house construction mixed with mud and then used to coat the floors or the walls. It was proposed that the prepared coating after burning is efficient to protect the houses against moisture (Zhang 1999).

The inhabitants from Jiahu might also have fed pigs with their leftover food remains. According to the isotopic analysis of 11 Jiahu pig remains, the $\delta^{13}C$ of the pig samples is 20.17±1.17‰ on average (Zhang 2015), which is similar to the isotopic signatures from the human remains. This result suggests these pigs were mainly fed with C_3 based foods similar to the human diets. In some of the present-day Chinese villages, leftovers from human food, such as rice husks are often crushed and mixed into pig feed. Further research applying starch grain and/or phytolith analysis on human and animal dental calculus may provide more insights on this issue.

6.7 Foodways at Jiahu: chronological trends

The previous sections of this chapter have discussed various culinary practices at Jiahu, from food procurement to processing and storing, from cooking to consuming and discarding. Since Phase I, the inhabitants of Jiahu started using arrowheads and fishing darts for hunting and fishing, grinding tools for cereal processing, specific types of jars were used for beverage production, pits for storage, and hearths for cooking. These tools, vessels, and facilities were used from Phase I throughout Phase II until Phase III, reflecting continuities of the Jiahu foodways throughout the site's occupation. It implies that foodways were not always changing, but sometimes passed down from one generation to the next.

Apart from same traditions in the Jiahu foodways, changes were also notable over different time periods. Studies have refined the climactic sequence from around 8500 to 3000 BP in China (Shi et al. 1992). In Phase I, the climate at Jiahu was transforming from dry cold to warm and wet. It has been calculated that the population in Phase I was around 50-70 people based on the formula P= A× $\mathbf{Sum/T}$ (Zhang, 2015). Sum refers to the total number of the interred in the cemetery in each Phase, A is the average life span of the decedents, T stands for the duration of the cemetery in each phase which is around 500 years. The formula assumes that the population was relatively stable in each phase overall, which might not be the real scenario. Nevertheless, the result can still be used to imply the increase and decline of population size in different phases. In Phase I, the settlement layout was also simple with a few houses and burials distributed in the same area (Zhang, 2015). In this period, the Jiahu inhabitants started agriculture practices on a small scale as suggested by the scarcity of recovered agricultural tools, with the ratio of agricultural tools to tools associated with hunting and fishing being 1.85% (Fig. 6.5).

Phase II was the warmest and most humid period, with the average temperature estimated as 1.4 to 1.7 °C higher than today. More arrowheads and fishing darts were used for hunting and fishing in this period than the previous (Fig. 6.5). The number of agricultural tools also dramatically increased. In addition, several new types of tools were adopted during Phase II, indicating new developments in culinary practices. For example, denticulate sickles were used for harvesting and fishnet weights were a new tool. Food obtained from domesticated and wild resources was probably enough to meet the requirement of the Jiahu population, which increased to around 160-190 people in Phase II (Zhang, 2015). The settlement in this period also demonstrates more planning, with the living and burial areas separated (Zhang and Cui, 2013).

In Phase III, the climate was warm as well and the population stayed approximately the same (Zhang, 2015). Compared to Phase II, the quantity of shovels and sickles both increased (Fig. 6.5). In addition, a new type of agricultural tool, i.e., *gusi*, appeared in Phase III, even though the number of *gusi* was low (n=1). Differently, the quantity of arrowheads and fishing darts declined. The ratio of agricultural tools to tools associated with hunting and fishing to was 133.3% (Fig. 6.5). These changes are also reflected in the decreasing number of wild deer and the increasing number of domesticated pigs (Table 6.2). It is possible that rice agriculture and animal husbandry played more important roles in the subsistence strategies in Phase III, so the Jiahu inhabitants relied less on wild food resources. This proposition correlates with the aquaculture demonstrated at Jiahu, which was first practised in phase III. According to radiocarbon dating and stratigraphic data, it has been proposed that the inhabitants had to abandon the site because of a flood around 5400 BC (Zhang and Cui, 2013). Clearly, during different Phases of site occupation, an interaction was occurring among climatic fluctuations, population growth, and settlement developments, as well as the foodways of the Jiahu people, especially in terms of food procurement.

6.8 Conclusion

With the data related to different food activities, we can picture more clearly the daily lives of the past populations at Jiahu and the region they inhabited. These people started cultivating pigs and rice, with wild plants and animals remaining significant parts of their food resources. After obtaining these foods, various methods and tools were adopted for processing, in which grinding tools played a major role in cereal processing. Foodstuffs were kept in storage pits and/or pottery vessels. Cooking at Jiahu was carried out both inside and outside of houses, and different types of cooking vessels were used in every occupation phase. Evidence of food consumption was found inside the households, where the leftovers such as fish bones were discarded nearby hearths inside of a house during Phase I. This chapter also highlights the variations of foodways at Jiahu, alongside developments of the population, settlement, and tools. However, some aspects of the Jiahu foodways remain unclear, such as methods used to process animals for food. Overall, by combining the research on grinding tools and the information related to other parts of foodways, this chapter provides an effective way to reveal elements of the past society's lifeways.

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Chapter 7 Conclusion

As discussed in Chapter 1, investigating foodways can offer information regarding different aspects of past human societies. From the perspective of foodways, this dissertation aims to reveal the daily life elements of people in the early farming societies in the upper catchment of Huai River (UCHR). This goal has been achieved in two steps.

In the first step, this dissertation focuses on the grinding tools that have been frequently unearthed at the Neolithic sites in the region of UCHR. Before delving into the detailed study of the archaeological grinding tools, experiments were designed and carried out to collect the fundamental data for more accurate interpretations of use-wear traces as well as residues that might have been left during the use of the tool surfaces (see Chapter 2, 3, and 4). Then, the archaeological grinding tools unearthed from the site of Jiahu and Tanghu were subjected to analysis. These two sites are attributed to the Jiahu and Peiligang Culture (see Chapter 2, 3, 4, and 5), which represent the earliest Neolithic cultures in the research region. The studies of experimental and archaeological grinding tools have addressed four specific research issues that have been proposed in Chapter 1, which enrich our understanding of a crucial aspect of foodways: food processing.

In the second step, the findings on the grinding tools were combined with other related data from previous studies to present how the past populations carried out different food-related activities, including food procurement, processing, storing, cooking, serving, consumption, and discarding (see Chapter 6). Chapter 6 also highlights the variations of foodways at the site of Jiahu, alongside population growth, settlement development, and different categories of tools. Different sets of results have been discussed in each chapter and the data were integrated in Chapter 6. The following sections highlight key findings and their implications, followed by an explanation of analysis limitations and suggested future directions.

7.1 Correlation between tool type and function

Neolithic grinding tools in China have often been employed to discuss past subsistence strategies, i.e., agricultural or a broad-spectrum subsistence economy (Chen 1990; Song 1997; Bellwood 2005; Higham 2005; Liu et al. 2010c; Zhang 2011; Dong et al. 2014). Notably, the grinding implements unearthed from the Neolithic sites in the region of UCHR are characterized by various shapes, suggesting that different technological choices were made by their manufacturers during tool production. Chapter 2 answers the question: why these grinding tools were made into various shapes? Different from previous studies that were primarily based on one method, i.e. starch grain analysis (Zhang 2015; Yang et al. 2015b), In Chapter

2, results from microwear and starch grain analysis were integrated to help interpret possible functions of Neolithic grinding tools from the site of Jiahu. Microwear analysis indicates that grinding slabs without feet and cylindrical rollers were mainly associated with processing cereals while grinding slabs with feet were mainly related to processing wood-like materials. Quantitative analysis of the starch data also indicates that grinding slabs without feet preserved more starch grains than the slabs with feet. The results from microwear and starch grain analysis are consistent, suggesting that specific types of grinding tools were used for processing specific kinds of plants. The correlation inferred from this study helps to understand the prehistoric technological choices in tool production. In other words, the past population probably designed different shapes of grinding tools for different use purposes. Thus, different types of grinding tools cannot be used as a whole assemblage to suggest past human practices. Instead, these objects should be classified according to their morphologies first, and then studied in a more detailed manner.

In Chapter 2, the finding of use-wear traces associated with wood-like material also suggests that the Jiahu grinding tools were not only involved in food processing. This proposition has been further attested in another case study at the site of Tanghu in the same region (Li et al. 2020, cf. Chapter 5), where there is limited evidence that grinding tools were involved in modifying bone. Nevertheless, these different uses of the grinding tools were absent in previous studies carried out in the same region (Liu et al., 2010; Yang et al., 2015; Zhang, 2011). Chapter 1 discussed how research solely relying on starch grain analysis could easily neglect used materials that do not produce starch grains. Meanwhile, microwear analysis has to overcome difficulties in determining a multi-functional object, as secondary use can remove or obscure microwear traces previously formed on a tool's surface (see also more discussions by Van Gijn 2014). Additionally, complete grinding tools allow analysts to take more microwear samples from different areas, which is important to provide a more thorough interpretation of a grinding tool's function. However, such complete objects are not always encountered in archaeological excavations. Furthermore, although PVS material can take good impressions of use-wear traces from a tool's surfaces, this method may still lose some information depending on how the sampling was done. For instance, issues such as the numbers of the casts taken in relation to the size of the tool and the number of the use faces should all be considered. Because of these reasons, the different uses of grinding tools are very likely underrepresented in the archaeological record, a suggestion that has also been put forward by Hamon (2009a). To overcome these obstacles, a combined approach of microwear and starch grain analysis have been proven to be more useful in Chapter 2 and 5.

7.2 Choices of food processing techniques in the past

Studies investigating different food processing techniques have shed light on the dietary habits and subsistence strategies adopted by ancient people (Wright 2004; Wollstonecroft 2011). Grinding is one of the basic forms of food processing, with different grinding methods, e.g. dry- or wet-grinding being applied to process different dietary plants. While many studies have focused on what type of material was processed on grinding tools, the grinding techniques employed during food processing have received less attention.

Drawing upon the results presented in Chapter 2 (e.g. the use of the Jiahu grinding slabs without feet primarily for processing cereals), Chapter 3 moves forward to investigate: What kind of grinding technique was adopted to process cereals? Systematic grinding experiments were first carried out to document microwear traces resulting from the dry- and wet-grinding cereals, which turns out to leave distinctive traces. Through this reference baseline it is feasible to infer ancient grinding techniques and it has been applied to the grinding tools from the site of Jiahu. The results reveal that dry-grinding was employed for cereal processing at Jiahu. The same grinding technique was also adopted at the site of Tanghu (Li et al. 2020. cf. Chapter 5). These results suggest that the people from these sites preferred the dry-grinding technique more than wet-grinding.

It is still inconclusive why grinding was adopted in human history for food processing. Hastorf (2017) has proposed several reasons of why grinding was preferred over other ways of food processing and cooking, which could be related to 'not enough fuel' and 'different local traditions'. In the research region of UCHR, the culinary practice of dry-grinding could have been inherited from their ancestors because grinding plants was used by earlier hunter-gatherers in this area (Yang et al. 2016). Another possible reason for choosing a dry-grinding technique could be related to the broad-spectrum subsistence strategy adopted at Jiahu and Tanghu. Compared to wet flour, which is a product that quickly spoils, dry flour is suitable for longer-term preservation. Dry flour is also suited to the preparation of a diverse array of portable foodstuffs, which would have allowed the population to have greater mobility and autonomy. Thus, the dry-grinding technique very likely was a practical choice of early farming societies, when agriculture was practised but hunting and gathering still played important roles (Liu and Chen, 2012, see also Chapter 6). Later, during the Yangshao Culture period (c. 5000-3000BC) in the same region, only a few grinding tools have been discovered (Zhang, 1999). Chapter 3 proposed one of the possible reasons to explain this phenomenon. In the Yangshao Culture period, one of the important social changes was that farming became the primary source of food supply (Liu and Chen 2012). For the Yangshao people, it can be imagined that dry flour probably was not as important because the more sedentary people were in less need of easily portable foods. Also, grinding is not essential for preparing and consuming cereals. Compared to boiling other food processing behaviours such as boiling, grinding is a time-consuming and labour-intensive work. Gradually, grinding and related culinary practices could have been replaced by boiling, which remains the most common method for cooking cereals in present-day China. In this sense, the choice of plant processing technique could be related to subsistence strategy, i.e., foraging or farming.

7.3 Rice processing in the early rice agricultural societies

China has three major regions that are currently considered as the earliest centres for rice domestication, which include the lower catchment of the Yangtze River (Jiang and Liu 2006; Liu et al. 2007a; Fuller and Qin 2009) , the middle catchment of the Yangtze River (Zhao 1998), and the region of UCHR (Zhang and Wang 1998). On the basis of macrobotanical and phytolith research, these regions all possess well-documented evidence for rice domestication during the early Neolithic period (Lu et al. 2002; Liu et al. 2007b; Zhao 2010; Wu et al. 2014). However, when applying starch grain analysis to the archaeological grinding tools from these regions, only a few starch grains from rice have been recovered and identified to date, leading to the suggestion that rice was not the primary ground cereal (Liu et al. 2010b; Yang et al. 2015a; Yao et al. 2016). Chapter 4 tested the following hypothesis: Were starch grains from rice underrepresented on grinding tools because of starch damage during grinding? First, four types of cereals were subjected to systematic dry- and wet-grinding experiments: rice (*Oryza sativa*), foxtail millet (*Setaria italica*), Job's tears (*Coix lacryma-jobi* L.), and barley (*Hordeum vulgare* L.). Then the ground starch samples were observed and their damage features were documented and compared. The results indicate that dry-grinding produces significant damage to starches to the point where they may be undetected in archaeological samples, while wet-grinding causes only slight morphological changes to the starch grains. Moreover, rice starch grains have more substantial alterations than the other plants from dry-grinding, possibly impeding their identification.

The sites of Jiahu and Tanghu are among the sites that possess evidence of rice agriculture but with few starch grains recovered from their grinding tools (Zhang 2015; Yang et al. 2015b). As has been argued in Chapter 3 and 5, the dry-grinding technique was adopted at both sites of Jiahu and Tanghu, and this could have consequently caused the relative scarcity of rice starch grains recovered from the grinding tools. Thus, previous interpretations of starch analyses need to be reconsidered because rice was possibly ground to a larger extent than we thought before. For example, in the Yangtze River basin in Eastern China, where rice cultivation and domestication also took place, starch grain analysis has also been carried out on the grinding tools from the sites of Xiaohuangshan (c. 7000-5000 BC) (Liu et al. 2010b; Yao et al. 2016) and Shanshan (Yang et al. 2015a). Similarly, few starch grains from rice were recovered from these grinding tools. If dry-grinding was employed at these sites, it might have adversely affected the preservation and potentially the recovery of ancient rice starch grains. These findings imply that starch grains from rice can be underrepresented in the archaeological record because of dry-grinding.

In future studies of Neolithic grinding tools, it is imperative to investigate different grinding techniques and consider the damage patterns of starch grains after processing, because these practices will lead us towards a more nuanced interpretation of how rice and other cereals were processed in the past.

7.4 Foodways in different Neolithic communities

As mentioned in Chapter 1, the sites attributed to the Jiahu Culture and the Peiligang Culture are in the same region, the UCHR. These two cultures share many similarities in their material remains (see Chapter 1). For instance, both cultures possess unpainted pottery assemblages that are characterized by various cooking, serving, and storage vessels. Their ground stone tools, including axes, adzes, sickles and grinding tools, also show similar morphological features. Unlike some of the Peiligang Culture sites that are in hilly areas, Jiahu is situated on a larger alluvial plain with thicker cultural deposits. Jiahu also possesses some unique material remains such as the domesticated rice and flutes. Considering these differences and similarities, Liu and Chen (2012, p144) classified the site of Jiahu to the Peiligang Culture but stands for a different type because it “may have had higher levels of sedentism and more complex social organization”. In contrast, other scholars argue that Jiahu represents a different culture altogether (Zhang 1989; Chen 2014, see also Chapter 1). The Chinese archaeologists who focus on the differences tend to think that the site Jiahu stands for different Culture, while those who focus on the similarities, attribute Jiahu to the Peiligang Culture albeit as a sub-type. The study of foodways provides valuable insights into a community and often reflect elements of group identities (Wing 1981; Lyons 2007; Ishak et al. 2013). The following sections explore the relationship between the Jiahu and other Peiligang Culture sites from the perspective of their foodways.

Most of the Peiligang Culture sites were excavated in the 1980s and the unearthed material remains have not been intensively studied. At present, it is therefore not possible to present a comprehensive study of Neolithic foodways in the entire region. Nevertheless, some differences and similarities among these Neolithic archaeological cultures can be briefly discussed here. In terms of tools used for food procurement, it is noticed that most of the artefacts unearthed from the Peiligang culture sites are associated with agriculture, while tools used for hunting and fishing are rare (Zhang 1989). Differently, tools used for agricultural and foraging practices were equally abundant at the site of Jiahu. In addition, millet agriculture was practised at most of the Peiligang Culture sites (Lee et al. 2007; Zhang 2011; Wang et al. 2017a), except for the site of Tanghu that is located on an alluvial plain, where both rice and millet were cultivated (Zhang et al. 2012). It has been argued that different local landscapes might have contributed to different agricultural practices (Wang et al. 2017a): sites located in hilly areas are more suitable for cultivating short-season crops such as millet, while some of the sites (e.g. Tanghu) on an alluvial plain are ideal to grow both rice and millet. The exception is the site of Jiahu, which is located to the South of the main Peiligang Culture settlements, with two rivers and a lake nearby. It is believed that the wetland environment of Jiahu was not suitable to cultivate millet, instead only rice was cultivated (Wang et al. 2017a). Even though different crops were cultivated at Jiahu compared to the majority of the Peiligang Culture sites, similar types of tools, including denticulate sickles and shovels, were adopted in both cultures for food procurement practices (Li 1979; Ren et al. 1984, cf. Chapter 6).

In regards to food processing at Peiligang Culture sites of Egou in a hilly area and Shigu on an alluvial plain, starch grain analysis indicates their grinding tools were primarily used to process acorns (Liu et al. 2010c). Whereas at the Peiligang culture site of Tanghu as well as the site of Jiahu, the sampled grinding tools were mainly employed for cereal processing with a dry-grinding technique (Li et al. 2019; Li et al. 2020b, cf. Chapter 3 and 5). Apart from dietary plant processing, some of the grinding tools from Jiahu and Tanghu were used for processing a wood-like material or bone. These different uses of grinding tools have not been documented in any other Peiligang Culture sites. Although the sites of Jiahu and Tanghu seem to share many similarities, distinctions between the sites of Jiahu and Tanghu have also been reported. For example, a few starch grains from acorns (n=6) were recovered from Tanghu grinding tools (Li, 2015), but none of them have been recovered from Jiahu grinding tools (Zhang, 2015). Additionally, starch grains from aquatic plants and legumes were only recovered from Jiahu grinding tools and not from Tanghu grinding tools (Li et. al. 2020b, cf. Chapter 5).

From a foodways perspective, it can be concluded that the site of Jiahu was like Peiligang Culture sites in several ways, which is especially noticeable in a comparison to the site of Tanghu that is also located on an alluvial plain. The distinctions among the site of Jiahu and most of the Peiligang Culture sites are mainly reflected in their different subsistence strategies in terms of cultivated crops (rice versus millet) and the materials grinding tools processed (cereals versus acorns). However, Tanghu was one of the few Peiligang Culture sites that cultivated both rice and millet (Zhang et al. 2012; Bestel et al. 2018). These variations could be related to different ecological landscapes and food resources at these sites. In addition, Jiahu was occupied a few hundred years earlier than the site of Tanghu and some of the other Peiligang Culture sites (cf. Chapter 1), which could be a contributing factor for different foodways. Overall, a comparison of foodways from

Jiahu and the Peiligang Culture sites suggests both similarities and differences between these two cultures, reflecting the intangible cultural boundaries and interactions among these Neolithic communities.

7.5 Limitations and future directions

Clearly, some issues need to be considered for future studies on grinding tools using use-wear and/or starch grain analysis. First, the use-wear analysis on grinding tools in this dissertation is primarily based on the experiments designed to study grinding tools made from sandstone. It has been acknowledged that the raw stone material of tools is a key factor that could affect the development of use-wear traces (e.g. Lerner et al. 2007; Delgado-Raack et al. 2009). Thus, the reference baseline may not be applicable to grinding tools made from different types of stone (e.g. granite). Moreover, each experimental tool in this study was used for processing one specific type of plant or material, and use-wear traces developed during the processing of multiple contact materials were not investigated. The latter aspect should also be explored as ethnographic accounts indicate that grinding tools can be used for processing multiple types of plants or materials. A series of further experiments focusing on processing different types of materials (e.g. wood-like material and dried lotus root) and their associated traces would improve our understanding of the types of materials processed and the nature of practices involved with grinding tools.

Second, in terms of starch grain analysis, this dissertation compared the starch damage patterns of cereals after dry- and wet-grinding in relation to Chinese archaeological sites. This research can be expanded to include the effect different processing techniques have on the modification and preservation of starch grains from other plants such as other seeds than rice as well as acorns or underground storage organs.

Third, by comparing the dimensions of complete grinding tools, it is possible to make inferences about the scale of flour production in the past (e.g. Tsoraki, in press). Yet, no complete grinding tools have been recovered from the site of Tanghu. The number of complete grinding tools from the site of Jiahu considered in this research, unfortunately, is too small to draw similar inferences. Further research on the complete grinding tools from Jiahu or other sites will provide further insights into the scale of flour production.

Fourth, it has been clarified in the introduction chapter that the current dissertation focuses on one crucial aspect of foodways: food processing. Thus, the research of the cooking experiments is only summarily explored and presented in Chapter 6. Nevertheless, these cooking experiments are closely associated with the issue regarding starch taphonomy, which also contributes to a better understanding of ancient ways of cooking. Due to time restriction, the analysis of cooked starch grains still needs to be further explored and the results will be presented in detail in the future.

Last but not least, archaeologists have combined the results from microwear and starch grain analysis on grinding tools with contextual analysis to address more research issues; such as, the location of grinding activities (Tsoraki 2007), feasting models (Wright 2014), and ritual practices (Tsoraki 2018), which all contribute to a better understanding of past foodways. Nevertheless, addressing these issues relies heavily on information regarding spatial distribution, completeness, and raw materials of grinding tools as well as other types of ground stone tools (Tsoraki 2007; Tsoraki 2008). However, in the case studies of Jiahu and Tanghu, the contexts of the grinding tools were not always documented in a detailed manner. For example, in the site report of the latest excavation at Jiahu, only one pair of the grinding tools was described in terms of their morphology (Yang et al. 2017). In addition, the completeness and raw material of each grinding tool was not specified or studied in most of the archaeological site reports in China, which include the sites of Tanghu and Jiahu (Kaifeng Cultural Relics Management Committee of Xinzhen 1978; Zhang 1999; Zhang et al. 2008; Xin et al. 2010; Zhang 2015). Because of these obstacles, contextualizing the results of the current study for discussing the aforementioned issues will be more feasible for future research.

In summary, this study adopts an integrated approach of use-wear and starch grain analysis to study the experimental and archaeological grinding tools. The results provide new insights into several archaeological issues, including the correlation between tool type and function, choices of food processing techniques, rice processing of early farming societies, and other culinary practices of different Neolithic communities. These strands of information all contribute to an enhanced understanding of one crucial aspect of ancient foodways: food processing. By integrating these new data with previous foodways' research, this dissertation revealed a more detailed view of early farmers' lifeways in the central plane of China.

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Appendix I Explanations of the variables used for describing microwear traces on grinding tools

1.1 Micro-striations

The term "striation", was first used by Semenov (1964) to describe traces found on archaeological artefacts and ethnographic objects. Striations refers to grooves and scratches of varying dimensions (Jensen 1988). Striations on ground stone tools are usually "caused by the movement of a harder surface across a softer one" (Adams et al. 2009:49). Linear traces such as micro-striations, gouges, and troughs are often encountered by microwear specialists on grinding tools associated with processing hard materials (e.g. metal and flint, Figure 1 and 2). Micro-striations can also form on grinding tools associated with cereal processing, especially near the margins of the tools due to direct contact between upper and lower grinding tools (Adams et al 2009; Li et al. 2019). Micro-striations can be described according to their length, width, and depth as long, short, narrow, wide, shallow, or deep (Table 1). The directionality of striations can be described as parallel, or multi-directional (Figure 3, Table 1). The directionality of parallel striations (e.g. parallel or perpendicular to the long axis of the tool, Table 1) can be used to indicate the grinding motion (e.g. reciprocal or rotary motion).

1.2 Micro-polish

Micro-polish was first observed on flint tools and studied by a number of scholars (Semenov 1964; Newcomer and Keeley 1977; Keeley 1980; Vaughan 1985; Van Gijn 1990). Following Plisson (1985), Adams et al. (2009:54) defined micro-polish as "a modification of the microtopography of a tool's surface taking the form of a smooth and even sheen that reflects light differently than an unmodified rock". The framework established for analysing flint tools can be adapted to study archaeological grinding tools, as proposed by Dubreuil and Savage (2014). In the present dissertation, different types of micro-polish are documented in terms of their topography, texture, general appearance, location, polish development, degree of linkage, brightness, and directionality.

Terms such as flat, sinuous, domed, and irregular are used to describe the topography of observed micro-polish (Table 1, Figure 4). For instance, micro-polish associated with processing stone and metal materials is flat (Figure 1), while micro-polish resulting from processing, wood, bone, and hide has a sinuous to domed topography (Figure 5 and 6). Contact with clay results in the development of a dull micro-polish of rough texture and irregular morphology (Tsoraki et al. in preparation) (Figure 7).

The texture and general appearances of various types of polish can be described as smooth, rough, pitted, spider-web like (Van Gijn and Verbaas 2007), or greasy. For example, the texture of micro-polish developed from contact with bone and wood is smooth while hide micro-polish is smooth on the higher micro-topography and appears rough in the lower micro-topography (Figure 5, 6, and 8). These three different types of micro-polish can be further distinguished according to other features (e.g. location, brightness, and presence of linear features etc., see below)(Adams et al. 2009; Hayes et al. 2018; Tsoraki et al. in preparation).

Polish can develop in different locations on stone tool surfaces (e.g. higher micro-topography, intermediate area, lower micro-topography). In the case of bone and wood processing, polish appears mainly on the higher micro-topography due to the hardness and inflexibility of the processed materials (Figure 5 and 8). Polish resulting from contact with hide, however, occurs on the higher and lower micro-topography (Figure 6).

Brightness of polish can be described as dull, medium reflective, or highly reflective. For instance, polish resulting from processing clay is typically dull (Figure 7), while polish resulting from processing metal has a highly reflective appearance (Figure 1). Comparing to polish resulting from wood processing (Figure 8), polish associated with processing dry bone is more reflective, especially for the well-developed polish (Figure 5). Bone micro-polish can also be associated with troughs (linear features) (Figure 5).

Polish can develop on tool surfaces in different ways, i.e., on individual grains (localised distribution), in patches (of linear or random disposition), band/ streak, continuous across a large surface (Tsoraki et al. in preparation) (Table 1). Processing cereals with grinding tools usually develops polish in individual grains and gradually forms patches (Figure 9). Differently, processing clay forms polish that is continuous across a large surface (Figure 7). For polish that has formed in patches, a degree of linkage can be used to describe whether these patches are separated or well-linked. The degree of linkage can be judged by looking at the distributions of different patches (Figure 10).

Similar to directionality of striations, directionality of polish can also be used to indicate different types of grinding motions. For example, a grinding slab and roller used with a back and forth motion, the direction of the resulting polish is parallel to the long axis of a grinding slab and perpendicular to the long axis of the corresponding grinding roller.

In addition to striations and micro-polish, other features such as micro-fractures, grain (edge) rounding, and levelling of grains also allow microwear specialists to interpret the contact material (Dubreuil et al. 2015; Tsoraki et al. in preparation). Furthermore, documentation of residues while doing microwear analysis enriches our understanding of the potential possessed material as well as post-depositional processes of an artefact (Dubreuil et al. 2015).

For microwear analysis, as has been discussed by Semenov and many others (e.g. Semenov 1964; Keeley 1980; Levi Sala 1986; Jensen 1988), the cleaning procedures are essential before the observation of experimental implements. In the current dissertation, as some of the experimental grinding tools were also subjected to starch grain analysis, sampling for starch was conducted immediately after the completion of the grinding experiments (see Chapter 1, 3, and 5) and prior to cleaning. Following residue sampling, the experimental tools were cleaned in an ultrasonic bath. These tools were then washed with soap under running tap water in the Laboratory for Material Culture Studies at the Faculty of Archaeology, Leiden. The observations of the microwear traces were carried out after the experimental tools were completely dry.

Table 1: Wear features recorded

Variables		Description
Micro-striations	Directionality	parallel or vertical to the long axis of the tool
	Morphology	Wide, narrow, deep, shallow, long, short
Polish	Morphology	flat, sinuous, domed, irregular
	Texture and general appearance	smooth, pitted, rough, granular, spider-web like, greasy
	Location	higher micro-topography, intermediate area, lower micro-topography
	Brightness	dull, medium reflective, highly reflective
	Polish development	localised (limited distribution either on individual grains or on a small number of coalescing grains/grain aggregates), in patches (of linear or random disposition), band/ streak, continuous across a large surface
	Degree of linkage	well-linked patches or not
	Directionality	parallel to long axis, diagonal to long axis, or perpendicular to long axis

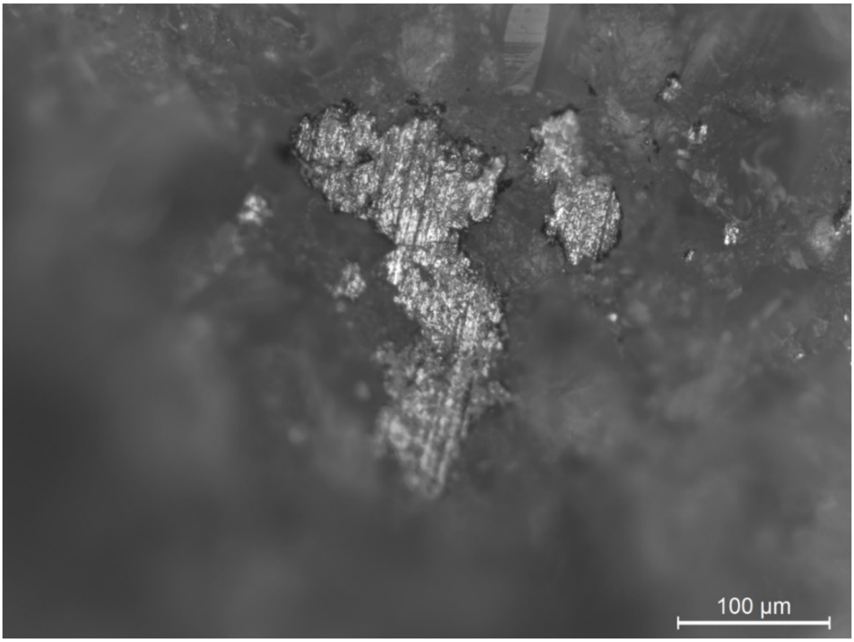

Figure 1 Microwear traces associated with the contact of bronze. The sandstone tool was used for polishing a bronze knife for 240 min (Experiment No. 1439, Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

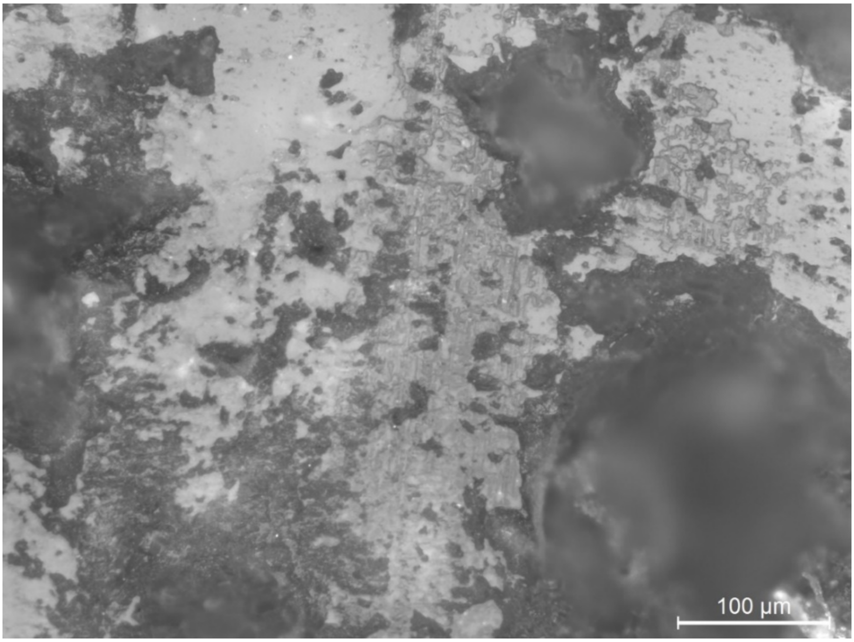

Figure 2 Microwear traces associated with the contact of flint. The sandstone tool was used for grinding flint for 180 min with water. (Experiment No. 1322, Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

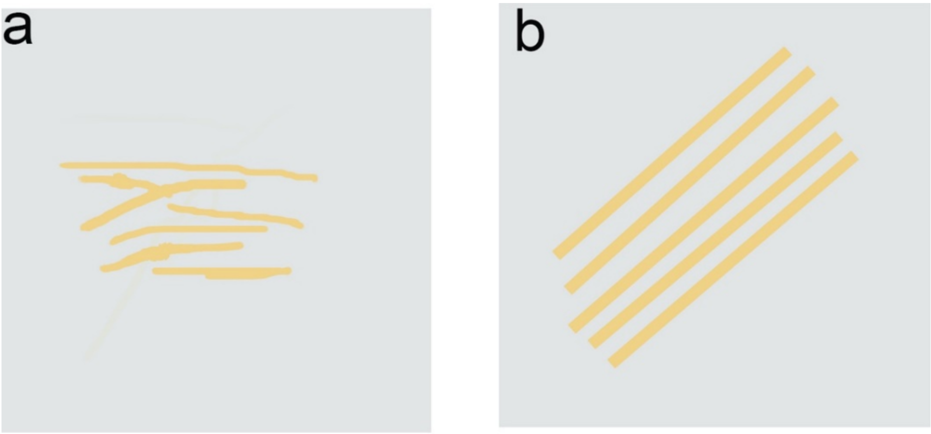

Figure 3 Illustrations of irregular striations (a) and paralleled striations (b) (After Wang, 2019)

Figure 4: Illustrations of micro-polish with (a) flat, (b) domed and sinuous, and (c) irregular topography (After Wang, 2019)

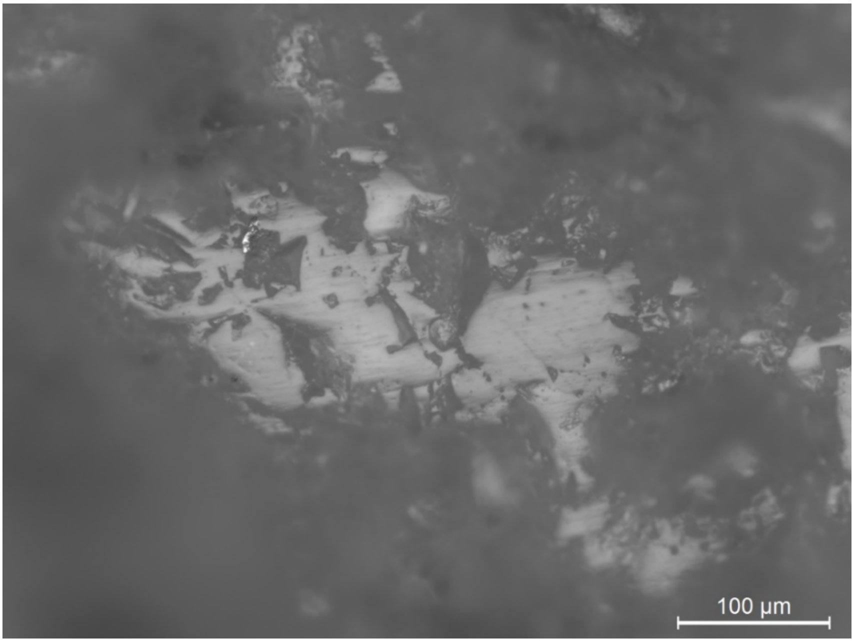

Figure 5 Microwear traces associated with the contact with dry bone. The sandstone tool was used for grinding dry bone for 180 min. (Experiment No. 3032, Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

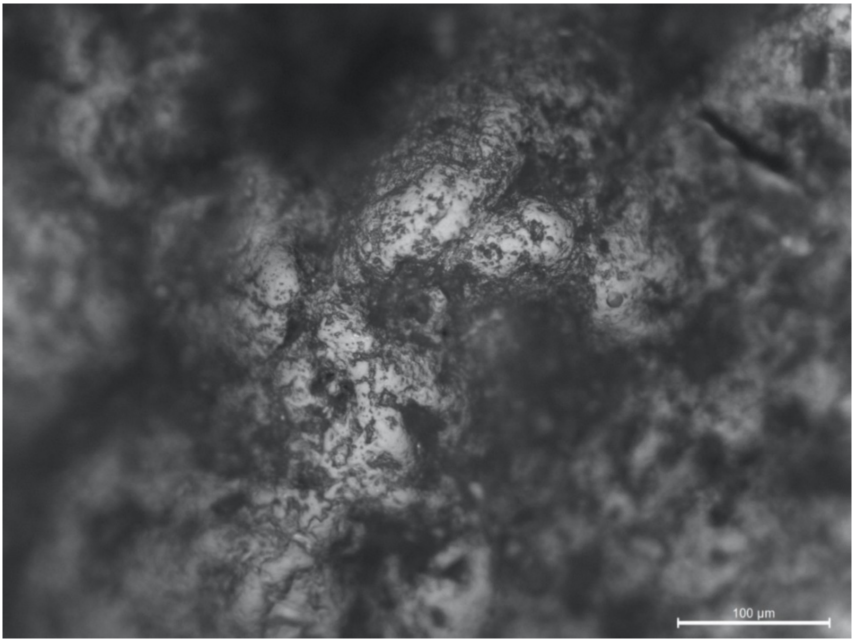

Figure 6 Microwear traces associated with hide processing. The sandstone tool was used for smoothing hide for 180 min. (Experiment No. 2586 Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

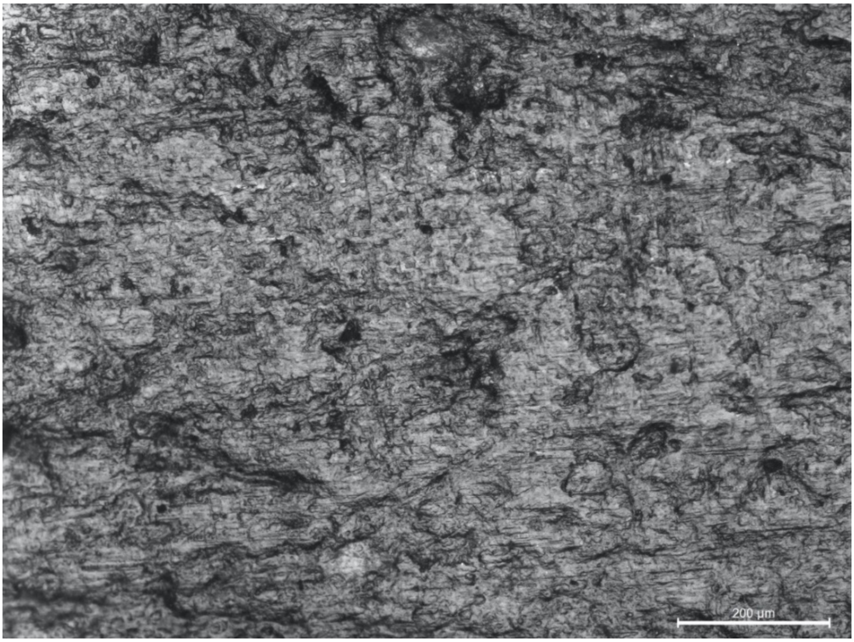

Figure 7 Microwear traces associated with processing clay. This sandstone tool was used for polishing clay for 325 min. (Experiment No. 983, Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

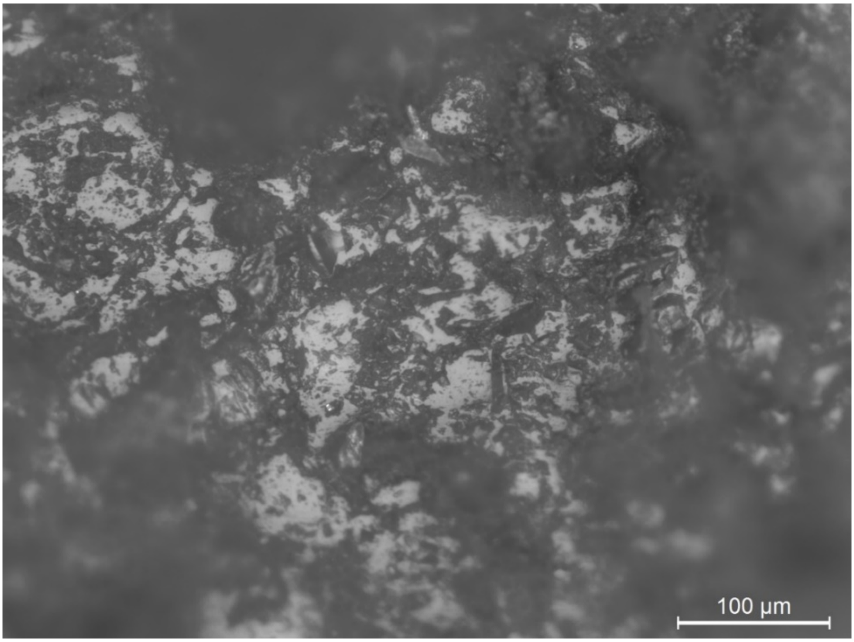

Figure 8 Microwear traces associated with wood processing, 3200 strokes (time unknown) in experimental machine load used 1.25 kg, sandstone tool (Experiment No. 1368, Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

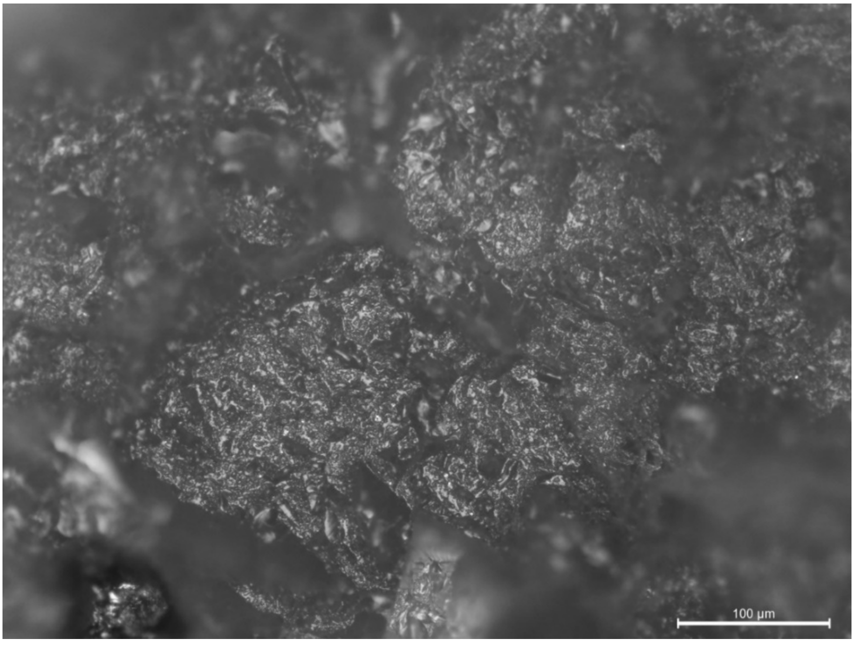

Figure 9 Microwear traces associated with processing foxtail millet for 180 min, sandstone tool (Experiment No. 2468, Laboratory for Material Culture Studies at Leiden University, © Weiya Li).

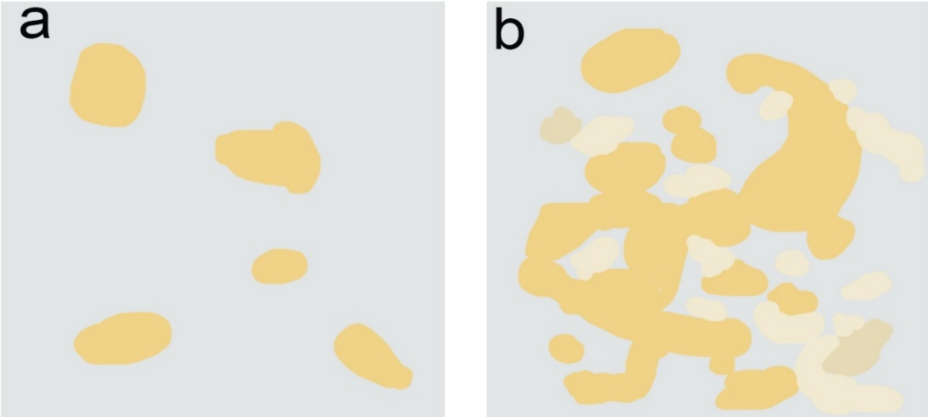

Figure 10 Illustration of polish patches that are separated (a) and polish patches that are well linked (b) (after Wang, 2019).

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Appendix II Supporting data for Fig. 4.3b in Chapter 4

Table S4.1: Number of different types of starch grains after dry-grinding

Starch type / Plant species	Type I	Type II	Type III	Total
rice (n=6)	0	0	6	6
foxtail millet (n=60)	26	21	13	60
Job's tears (n=69)	47	6	16	69
barley (n=53)	19	11	23	53

Note: The images below (from Fig. S4.5 to Fig. S4.23) are the supporting data for table S4.1 and Figure 4.3b, the blue numbers in the images are used to count the total single starch grains, the yellow numbers are used to count Type I starch grains, and the red numbers are used to count Type II starch grains, the rest are Type III starch grains.

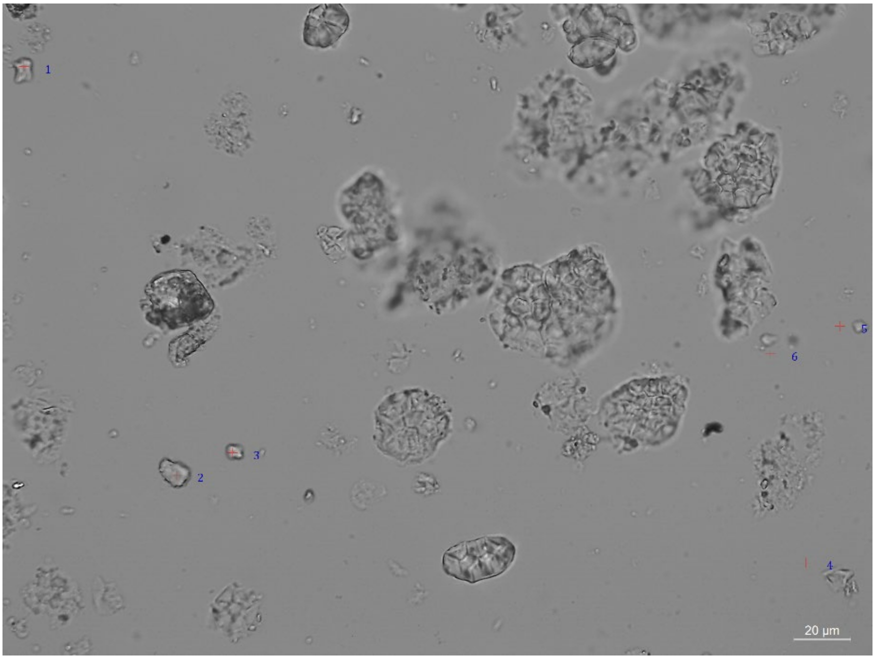

Figure S4.5. Starch grains from rice after dry-grinding under the bright field, Total number of single starch grains (n=6).

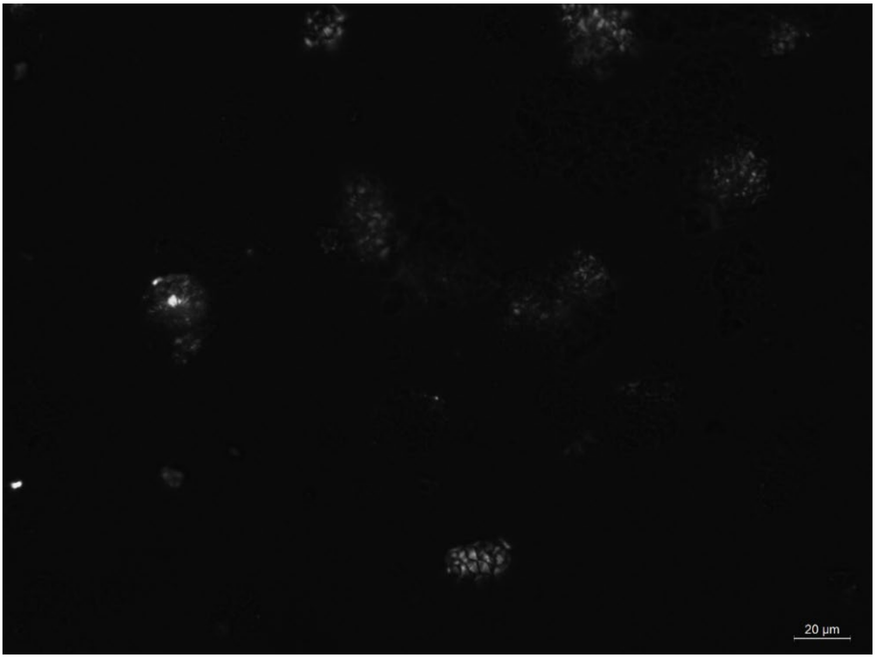

Figure S4.6. Starch grains from rice after dry-grinding under polarized light, note that all the single starch grains lost their extinction crosses. Type I starch grains (n=0); Type II single starch grains (n=0); Type III starch grains (n=6).

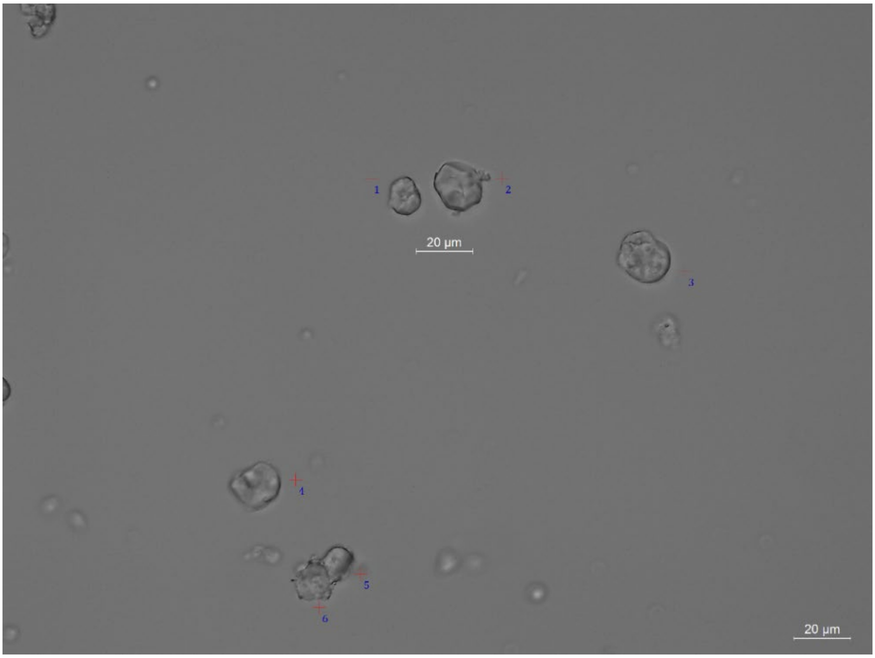

Figure S4.7. Starch grains from foxtail millet after dry-grinding under the bright field, Total number of single starch grains (n=6).

Figure S4.8. Starch grains from foxtail millet after dry-grinding polarized light, Type I starch grains (n=0); Type II single starch grains (n=4); Type III starch grains (n=2).

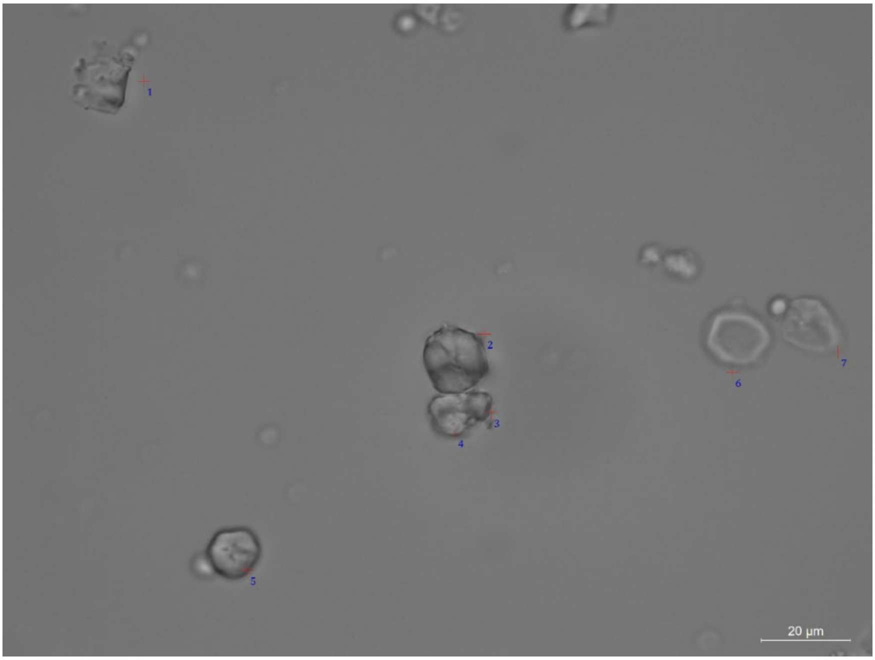

Figure S4.9 Starch grains from foxtail millet after dry-grinding under the bright field, the total number of single starch grains (n=7).

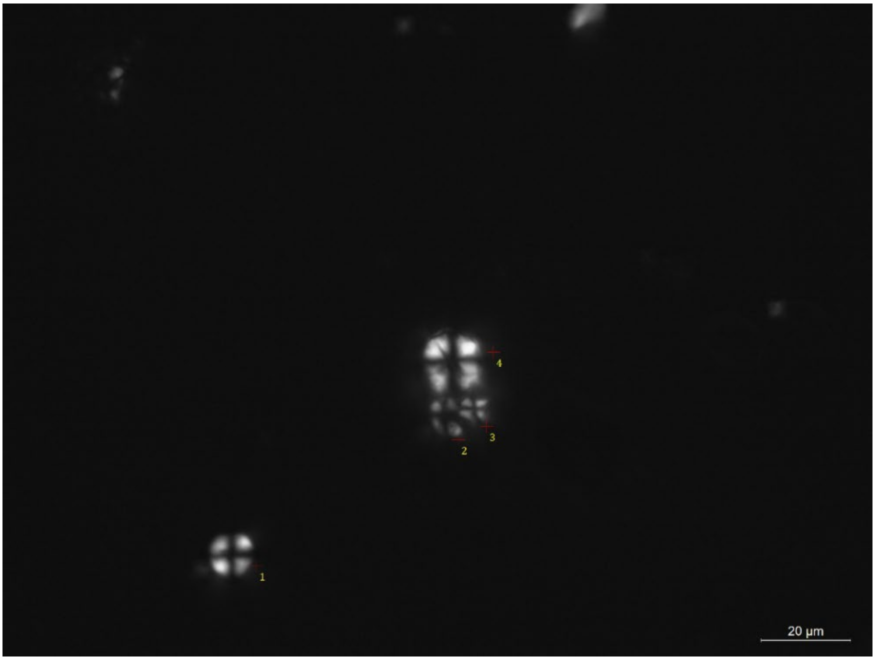

Figure S4.10 Starch grains from foxtail millet after dry-grinding polarized light, Type I single starch grains (n=4); Type II single starch grains (n=0); Type III starch grains (n=3).

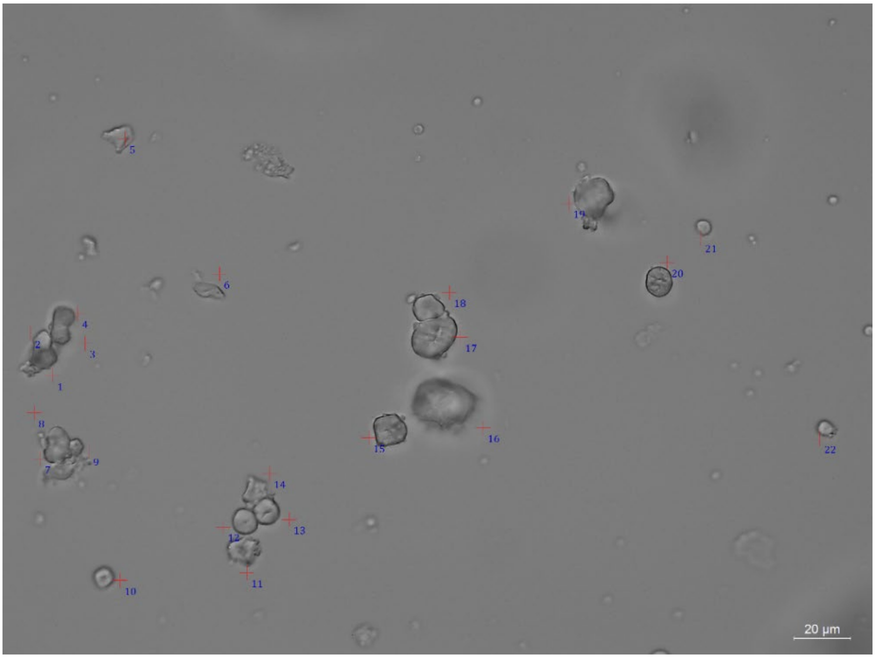

Figure S4.11 Starch grains from foxtail millet after dry-grinding under the bright field, the total number of single starch grains (n=21).

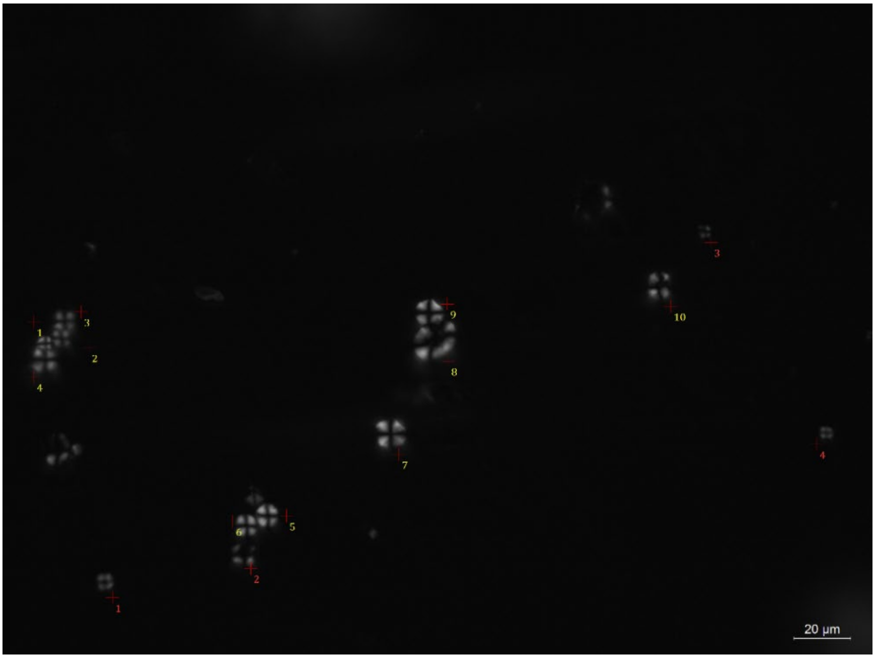

Figure S4.12 Starch grains from foxtail millet after dry-grinding polarized light, Type I single starch grains (n=10), Type II single starch grains (n=4); Type III starch grains (n=7).

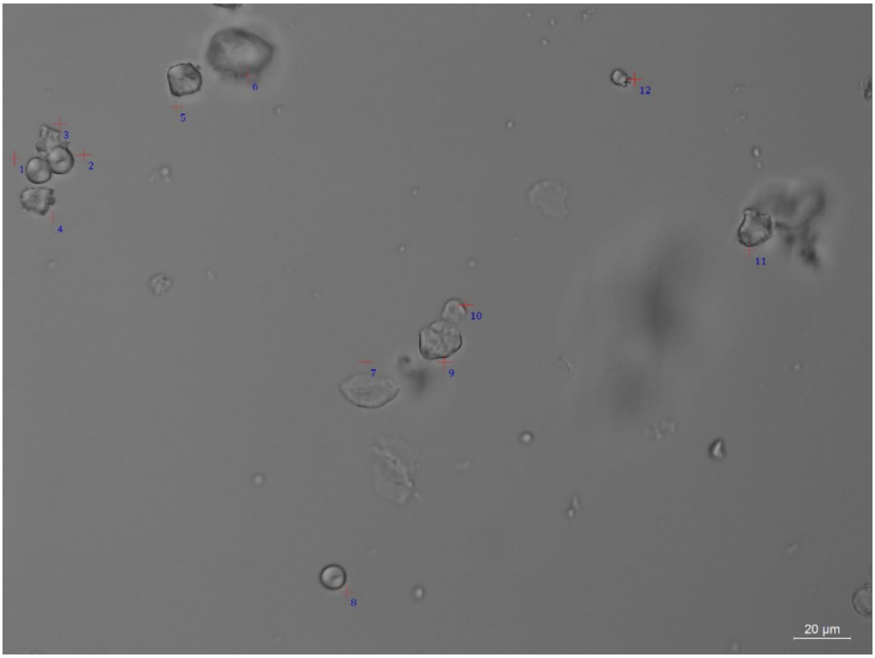

Figure S4.13 Starch grains from foxtail millet after dry-grinding under the bright field, the total number of single starch grains (n=12).

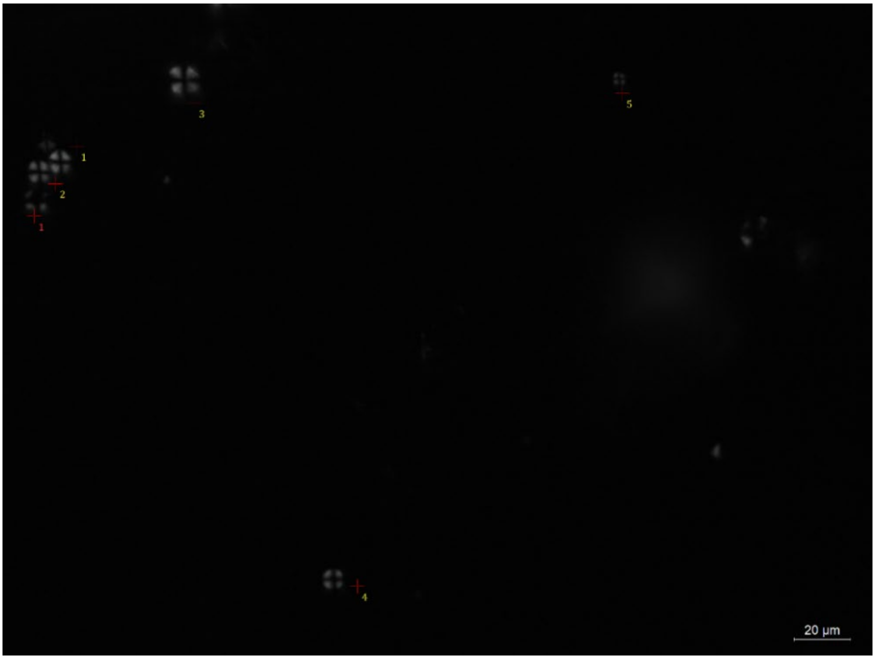

Figure S4.14 Starch grains from foxtail millet after dry-grinding polarized light, Type I single starch grains (n=5), Type II single starch grains (n=1); Type III starch grains (n=6).

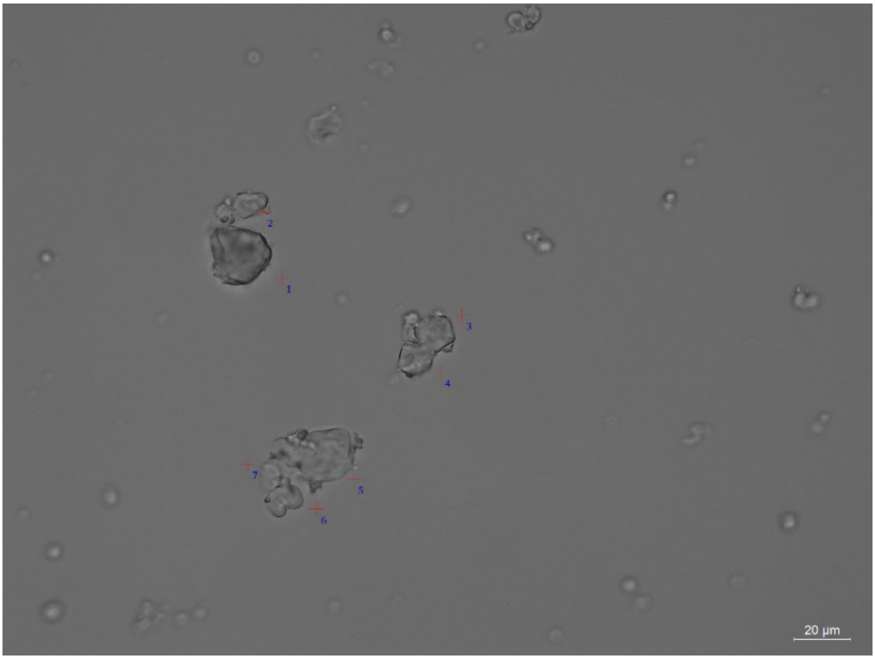

Figure S4.15 Starch grains from foxtail millet after dry-grinding under the bright field, the total number of single starch grains (n=7).

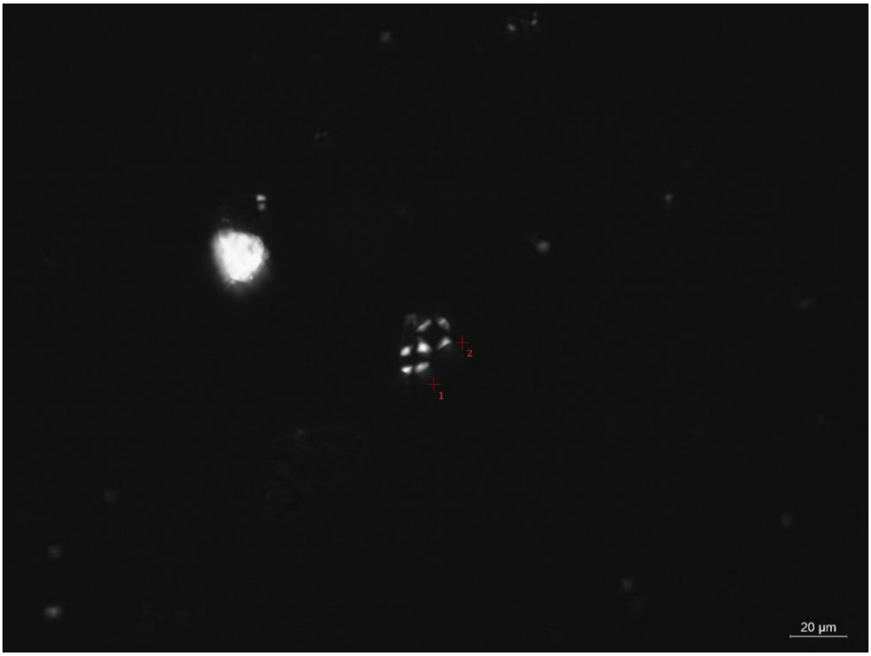

Figure S4.16 Starch grains from foxtail millet after dry-grinding polarized light, Type I starch grains (n=0); Type II single starch grains (n=2); Type III starch grains (n=5).

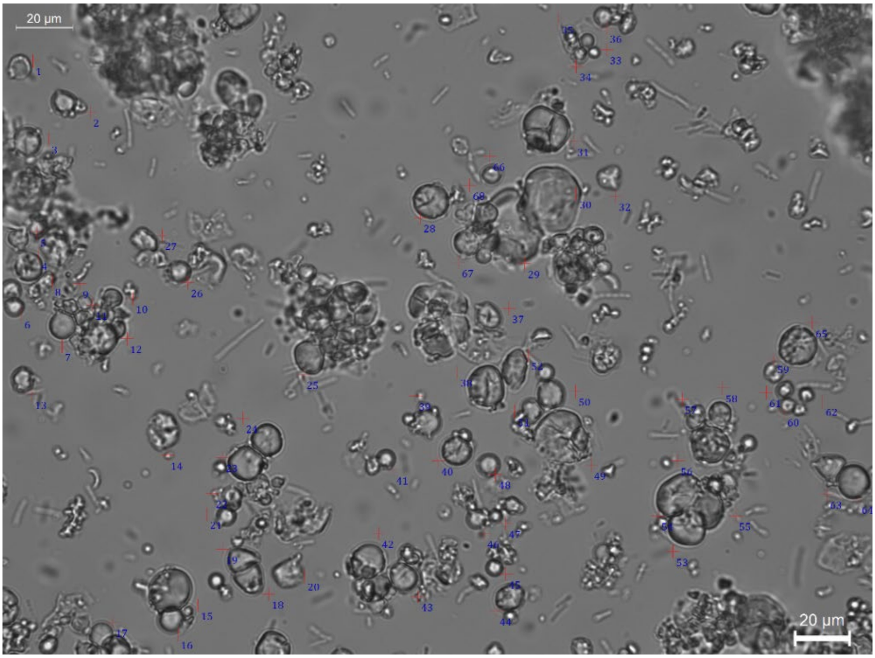

Figure S4.17 Starch grains from Job's tears after dry-grinding under the bright field, the total number of single starch grains (n=69).

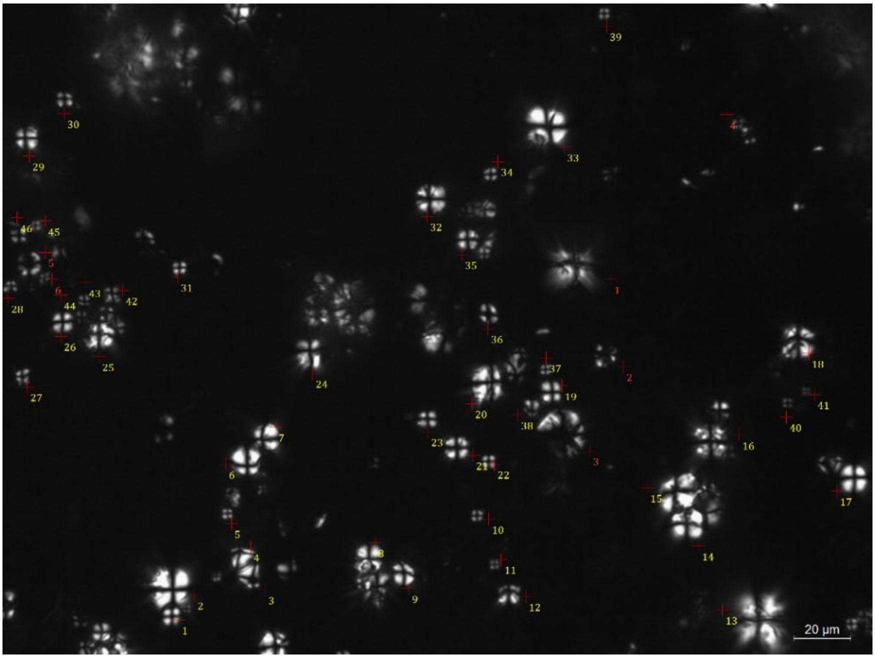

Figure S4.18 Starch grains from Job's tears after dry-grinding under the bright field, Type I single starch grains (n=47), Type II single starch grains (n=6); Type III starch grains (n=16).

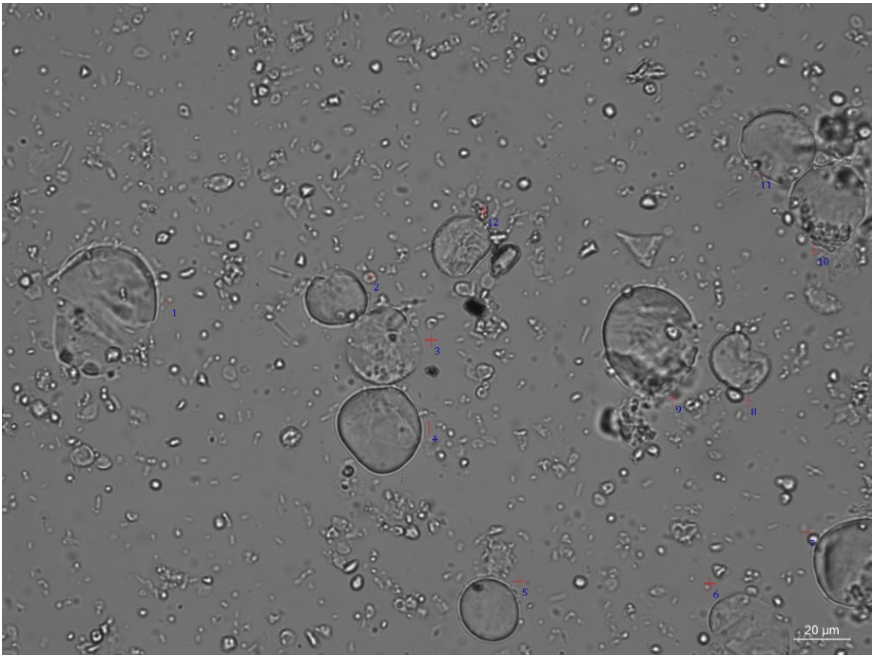

Figure S4.19 Starch grains from barley after dry-grinding under the bright field, the total number of single starch grains (n=12).

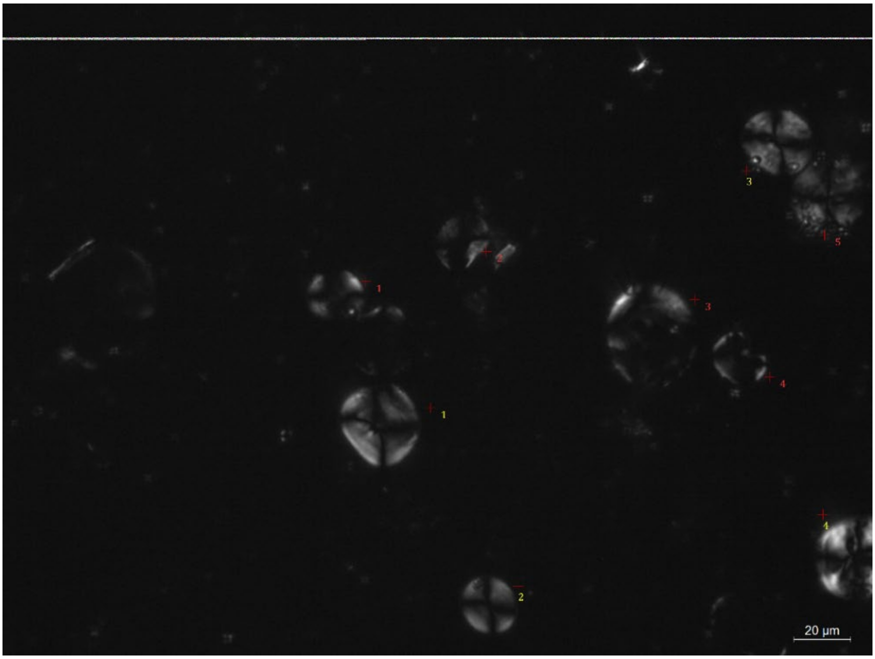

Figure S4.20 Starch grains from barley after dry-grinding under the bright field, Type I single starch grains (n=4), Type II single starch grains (n=5); Type III starch grains (n=3).

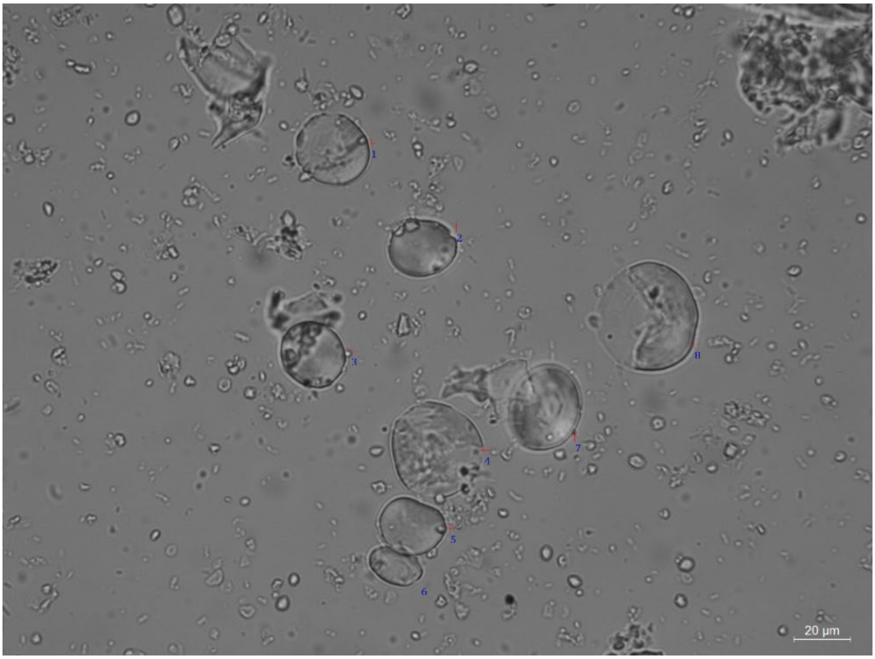

Figure S4.20 Starch grains from barley after dry-grinding under the bright field, the total number of single starch grains (n=8).

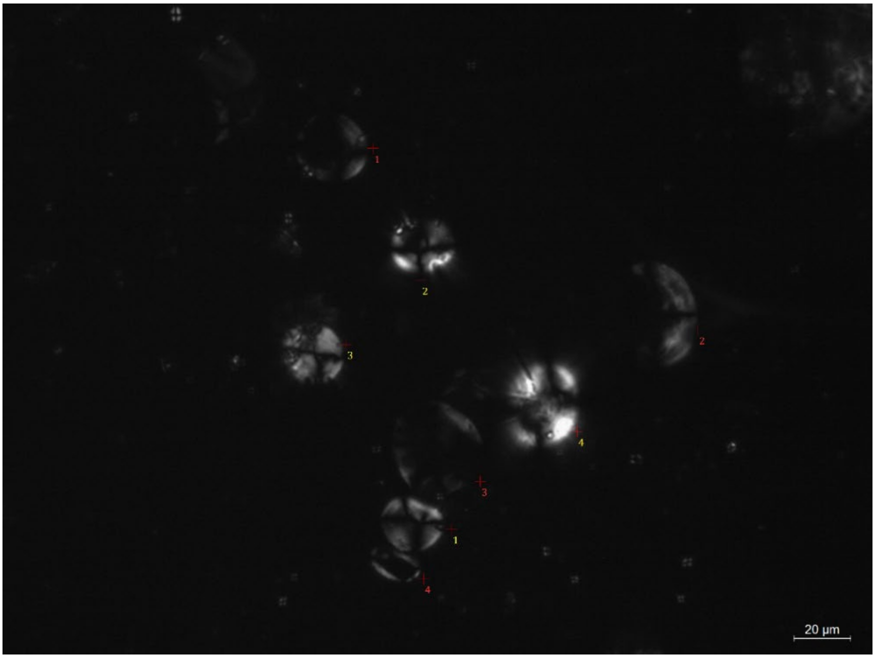

Figure S4.21 Starch grains from barley after dry-grinding under the bright field, Type I single starch grains (n=4), Type II single starch grains (n=4); Type III starch grains (n=0).

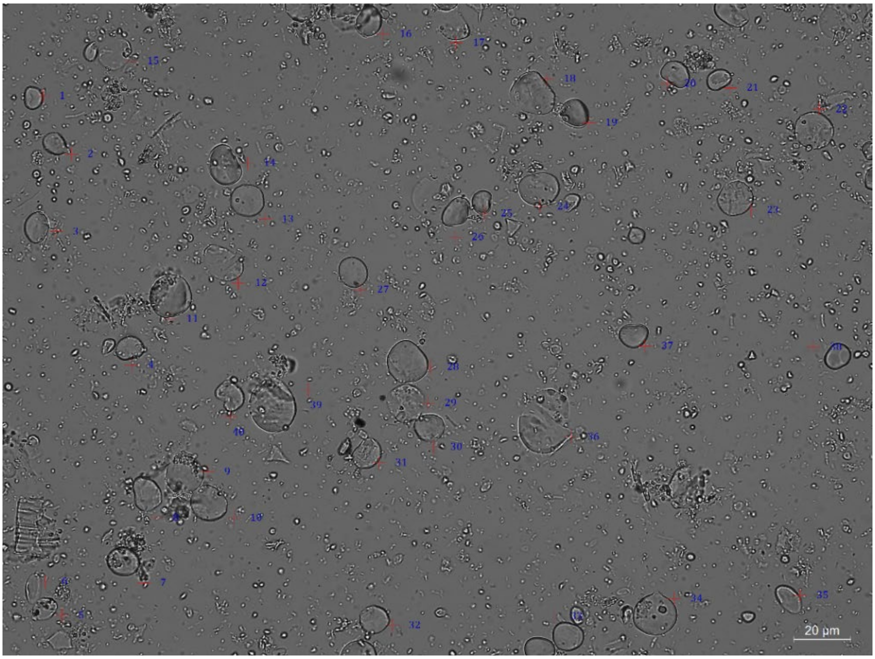

Figure S4.22 Starch grains from barley after dry-grinding under the bright field, the total number of single starch grains (n=40).

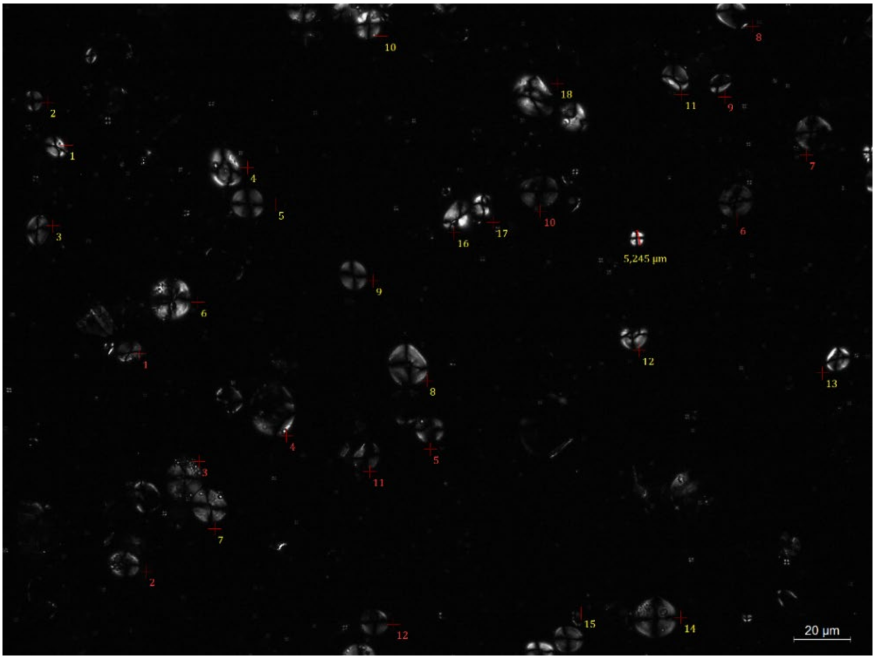

Figure S4.23 Starch grains from barley after dry-grinding under the bright field, Type I single starch grains (n=18), Type II single starch grains (n=12); Type III starch grains (n=10).

English Summary

China was one of the world's primary centres of independent agricultural development. This dissertation offers further insights into the foodways of the earliest farmers in the upper catchment of the Huai River in Central China. Chapter 2 combines two different analytical methods, use wear and starch grain analysis, to investigate the uses of different types of grinding tools. At the site of Jiahu in the research region, use-wear traces associated with processing cereal and wood-like material were identified. This result provides substantial evidence of cereal processing in the early Neolithic period. It also reveals the diversity of functions in the grinding tool assemblage. Interestingly, the use-wear distribution indicates that grinding slabs without feet and cylindrical rollers were mainly associated with the cereal processing, while grinding slabs with feet were primarily related to wood-like material processing. 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 has been argued that specific types of grinding tools were used for processing specific kinds of material. Chapter 3 explores further which grinding techniques were employed for cereal processing by the Jiahu inhabitants. The experiments carried out for Chapter 3 reveals that the micro-polish developed from dry- and wet-grinding of cereals is different in terms of the resulting texture and morphology. This result offers an approach to infer past food-processing techniques by analysing the used areas of the ancient grinding implements. Although wet- and dry-grinding are both common processing practices nowadays in China, the analyses indicate that the Jiahu population preferred to grind dry cereals. Comparing to wet-grinding, Chapter 4 discovers that dry-grinding causes more significant morphological changes to starch grains and consequently affect starch grain recognition and identification, especially in the case of starch grains from rice. This finding suggests that the scarcity of starch grains from rice on grinding tools from many of the early rice farming societies such as Jiahu could probably have resulted from plant processing using the dry-grinding technique. Thus, rice was probably processed with Neolithic grinding tools to a more considerable extent than previously considered. Chapter 5 investigates dietary plant food processing at the site of Tanghu, another Neolithic community in the research region. The results reveal that flour-based foods were produced from various plants at Tanghu, but mainly from cereals. Similar to the site of Jiahu, a dry-grinding technique was preferred for cereal processing at Tanghu. Apart from food processing, the Tanghu grinding tool assemblage was associated with processing bone. These findings provide more data on the Neolithic culinary practices and different uses of grinding tools, allowing a consideration of ancient foodways more broadly in the research region. Chapter 6 consolidates the results from the study of archaeological grinding tools and previous research on food and food-related activities to discuss the

foodways of the Jiahu population. In Chapter 7, a comparison of foodways at the site of Jiahu and sites attributed to the Peiligang Culture suggests similarities and differences among these communities, reflecting the intangible cultural boundaries and interactions between these two Neolithic cultures. Overall, this dissertation highlights that the Neolithic grinding tools played different roles in early farming societies, especially in food processing practices. By combining the research on grinding tools and the information related to food and food-related activities, it also demonstrates an efficient way to reconstruct elements of lifeways of early farmers through studying their foodways.

Samenvatting

China was een van's werelds eerste centra van onafhankelijke landbouwontwikkeling. De papers en hoofdstukken die deel uitmaken van dit proefschrift bieden meer inzicht in de voedselgebruiken van de eerste boeren in het bovenste deel van het stroomgebied van de Huai rivier in Centraal-China. Hoofdstuk 2 combineert twee verschillende analytische methoden, namelijk gebruiksslijtage- en zetmeelkorrelanalyse, om het gebruik van verschillende soorten maalwerktuigen te onderzoeken. Op de site Jiahu in de onderzoeksregio werden gebruikssporen geïdentificeerd die in verband zijn gebracht met de verwerking van granen en houtachtig materiaal. Dit resultaat bevestigt substantieel bewijs voor graanverwerking in de vroege neolithische periode. Het toont ook de diversiteit aan functies in een assemblage van maalwerktuigen. Interessant is dat de distributie van gebruiksslijtage aangeeft dat maalstenen zonder voeten en cilindrische rollen voornamelijk werden gebruikt voor de verwerking van granen, terwijl maalstenen met voeten voornamelijk gebruikt werden voor de verwerking van houtachtig materiaal. Kwantitatieve analyse van de zetmeeldata geeft ook aan dat maalstenen zonder voeten meer zetmeelkorrels bevatten dan de maalstenen met voeten. Daarom wordt beargumenteerd dat specifieke soorten maalwerktuigen werden gebruikt voor het verwerken van specifieke soorten materiaal. In Hoofdstuk 3 wordt verder onderzocht welke maaltechniek door de Jiahu-bewoners werd gebruikt voor de verwerking van granen. De experimenten die in dit hoofdstuk zijn uitgevoerd, laten zien dat de micro-polish of 'glans', die ontwikkeld is tijdens het droog of nat malen van granen, verschilt in de resulterende textuur en morfologie. Dit resultaat biedt een aanpak om voedselverwerkingstechnieken uit het verleden af te leiden door de gebruikte delen van oude maalwerktuigen te analyseren. Hoewel nat- en droog malen tegenwoordig beide gangbare verwerkingsmethoden zijn, geven de analyses aan dat de Jiahu-bevolking de voorkeur gaf aan het malen van droge granen. In hoofdstuk 4 wordt beschreven dat, in vergelijking met nat malen, droog malen grotere morfologische veranderingen in de zetmeelkorrels veroorzaakt, wat de herkenning en identificatie van zetmeelkorrels beïnvloedt, met name in het geval van zetmeelkorrels van rijst. Deze bevinding suggereert dat de schaarste aan rijstzetmeelkorrels op maalwerktuigen van vele samenlevingen met vroege rijstboeren- zoals Jiahu - waarschijnlijk het gevolg zou kunnen zijn van plantverwerking door middel van de droge maaltechniek. Op de neolithische maalwerktuigen is dus waarschijnlijk in grotere mate rijst verwerkt dan eerder werd gedacht. In hoofdstuk 5 wordt plantverwerking onderzocht van de site Tanghu, een andere neolithische gemeenschap in de onderzoeksregio. De resultaten laten zien dat het op meel gebaseerde voedsel in Tanghu werd geproduceerd uit verschillende planten, maar voornamelijk uit granen. Net als op de site Jiahu, kreeg de droge maaltechniek in Tanghu de voorkeur voor de verwerking van granen.

Naast voedselverwerking werd de Tanghu-assemblage van maalwerktuigen gebruikt voor het verwerken van bot. Deze bevindingen verschaffen meer gegevens over neolithische culinaire praktijken en verschillende toepassingen van maalwerktuigen, waardoor een bredere beschouwing van oude voedselgebruiken in de onderzoeksregio mogelijk wordt. In hoofdstuk 6 worden de resultaten van onderhavige studie van archeologische maalwerktuigen geconsolideerd, alsmede eerder onderzoek naar voedsel en voedselgerelateerde activiteiten, om zo de voedselgebruiken van de Jiahu-bevolking te bespreken. In hoofdstuk 7, tenslotte, suggereert een verdere vergelijking van voedselgebruiken op de site Jiahu enerzijds, en sites die worden toegeschreven aan de Peiligang-cultuur anderzijds, overeenkomsten en verschillen tussen deze gemeenschappen. Deze weerspiegelen de ontastbare culturele grenzen en interacties tussen deze twee neolithische culturen. Over het geheel genomen benadrukt dit proefschrift dat de neolithische maalwerktuigen verschillende rollen speelden in vroege landbouwsamenlevingen, vooral in culinaire activiteiten. Door het onderzoek naar maalwerktuigen en de informatie met betrekking tot voedsel en voedselgerelateerde activiteiten te combineren, wordt door het bestuderen van voedselgebruiken een efficiënte manier gedemonstreerd om de gebruiken van een samenleving uit het verleden te onthullen.

Curriculum vitae

Weiya Li (李为亚) was born in Tongcheng, Anhui Province in China. In June 2012, he obtained a Bachelor of Science in Applied Chemistry from the Suzhou University in China. In September 2012, he started a Research Master in Archaeological Science at the University of Science and Technology of China (USTC) with a full scholarship for three years. In June 2015, he was honoured as the "Outstanding Master Graduate student of USTC" as well as the "Outstanding Master Graduate student of the Anhui Province". In November 2015, he was granted the China Scholarship Council-Leiden University joint scholarship for four years and commenced his PhD research at the Laboratory for Material Culture Studies at Leiden University. His dissertation investigates foodways in early farming societies, in which he integrated microwear and starch grain analysis to study the grinding tools unearthed from the Neolithic sites located in Central China. The results from this research have been presented at several international conferences and published in several peer-reviewed, international journals, such as Quaternary International, Journal of Archaeological Science-Reports, Archaeometry, and Lithic technology. In addition to the doctorate research, he co-supervised three Masters students' internships and one Master's thesis. He also acted as the teaching assistant for several courses, including "Seminar Material Culture Studies: Crafts and Society" and "Material Culture 1". From November 2019 to March 2020, he worked as a researcher at Leiden University. In that period, he joined the Shire Archaeological Project in northern Ethiopia as the specialist on stone objects.