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

Li, W.

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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).

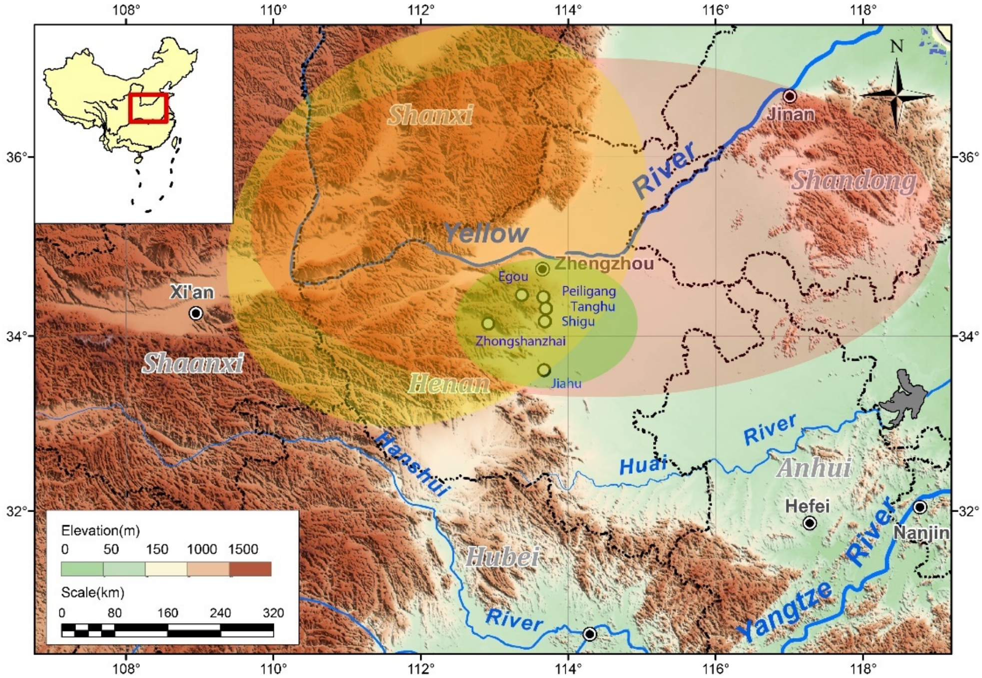

Figure 1.1 The location of the sites attributed to the Jiahu and Peiligang Culture sites. The general distributions of the Peiligang-Jiahu Culture, Yangshao Culture, and Longshan Culture are highlighted in green, yellow, and red colour accordingly (© Weiya Li).

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 timeconsuming, 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.

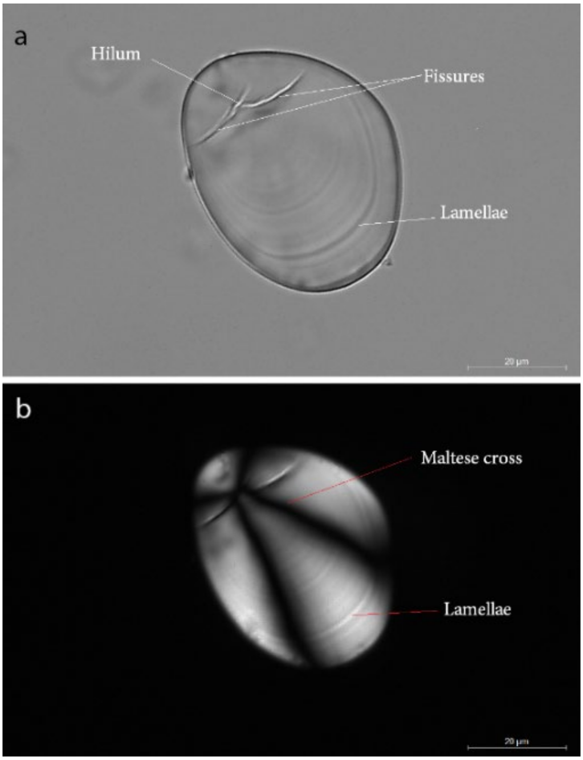

Figure 1.4 Morphological features on the starch grains from potato (*Solanum tuberosum* L.). a: A starch grain with an eccentric hilum, lineal fissures, and concentric lamellae, under normal light and bright field view; b: X-shaped Maltese cross and concentric lamellae under cross-polarized light and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

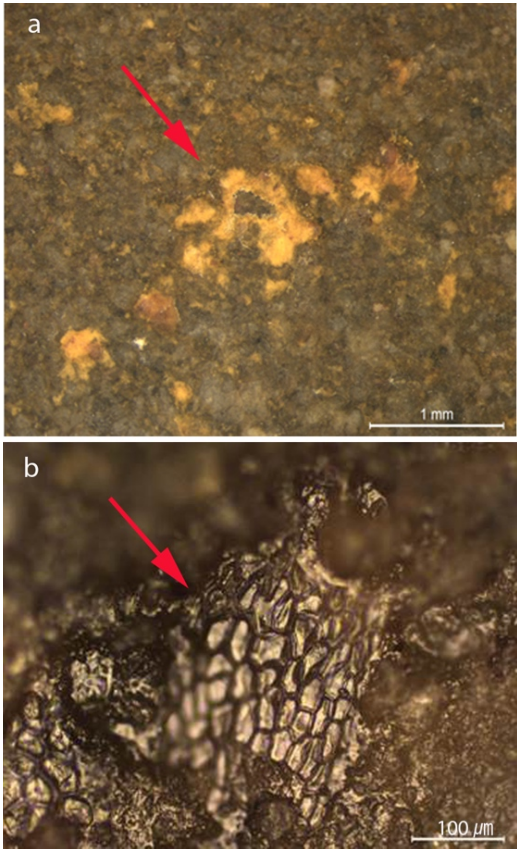

Figure 1.5 Residues on an experimental grinding tool that was used to process cereals (© Weiya Li).

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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