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Plant food sources and stone tools' function at the site of Shunshanji based on starch grain analysis

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Abstract The upper-middle Huai River valley (HRV) is located in the transition zone in the middle of eastern China. Previous studies have shown that the past populations in the upper HRV obtained plant food through gathering and cultivation of both rice and millet during the middle Neolithic. However, for the middle HRV it is not very clear what methods were used by humans to obtain plant food in that time. In this paper, starch grain analysis was carried out on 17 stone tools and 29 cauldron pottery sherds unearthed at Shunshanji (8.5–7.0 kyr BP), which is known as the earliest Neolithic site in the middle HRV excavated so far. Here, ancient starches from *Coix lacryma-jobi*, Triticeae, *Oryza sativa*, *Trichosanthes kirilowii* and one unidentified specie were recovered. This study contributes to the limited knowledge of food strategies as observed in the middle HRV. It demonstrates that both gathering and cultivation of rice took place during the middle-Neolithic. Among the identified species, *Coix lacryma-jobi* appears to have been the main plant food at Shunshanji. Moreover, it is clear that *Oryza sativa* was not consumed as much as other plant species according to the occurrence frequency of different starch grains. Starch grains were also found on the used surfaces of grinding stone implements as well as pestles, which means that these stone tools were used for food processing. In addition, axes from Shunshanji may also have been used for food processing as well as wood working because starches were also found on the edge of axes. Information about subsistence strategies and tool use at Shunshanji will also be helpful to understanding the utilization of plants and agricultural development in the middle HRV during the early-middle Neolithic period.

Keywords Shunshanji, Starch grain analysis, Utilization of plants, Development of agriculture, Function of stone tools

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1. Introduction

The relationships between the past populations and the natural plant resources as well as the origin and development of agriculture were highly concentrated in the middle and lower area of the Yellow and Yangtze rivers, two vital areas for early development of civilization in China (Zhao, 1998; Jin and Wang, 2006; Yang and Jiang, 2010; Li, 2013; Wu et al., 2014). The Huai River valley (HRV) is considered a transitional area in terms of climatic conditions, and cultural- and agricultural practices owing to its specific position between the Yellow and Yangtze Rivers. Hence, the study of plant utilization and early agriculture in the HRV has the potential to increase knowledge about human adaptations in changing environments. Previous archaeobotanic studies have been systematically done at the upper HRV, covering the archaeological culture development from 9.0 to 4.0 kyr

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BP (Zhao and Fang, 2007; Zhao and Zhang, 2009; Qin et al., 2010; Liu and Fang, 2010; Zhang et al., 2011; Zhang et al., 2012; Chen et al., 2012; Yang et al., 2015). According to the previous research results at the upper HRV, it is understood that cultivation of both rice and millet occurred there during the middle Neolithic. In contrast, at the middle HRV only little archaeobotanic research has been completed studying the Neolithic period. Dong et al. (2014) carried out starch grain analyses on stone stools at the site of Shishanzi, where they found species which were probably gathered such as yam and lotus root. Agricultural crops like rice and millet were not found. Because of this evidence, they came to the conclusion that gathering still played an important role at Shishanzi. However, still at the middle HRV, Zhang et al. (2004) discovered the imprint of rice husks in fired soil samples from Shuangdun, which indicates that the past population at the middle HRV may have already started rice cultivation seven thousand years ago. Above all, at the middle HRV, it is still not clear how people got their plant food in the early-middle Neolithic period.

The site of Shunshanji is 400 meters away from Daxinzhuang, Meihua town, Sihong city, Jiangsu Province (33°34′34.23″N, 118°10′11.44″E). It lies twenty to thirty meters above sea level and covers 175000 m^2 (Figure 1) (Yin and Zhang, 1964; Lin et al., 2013). Nanjing Museum excavated Shunshanji between 2010 and 2012 and found out Shunshanji is the largest and earliest moat settlement site in the middle HRV. Three phases of occupation could be distinguished based on their calibrated radiocarbon dates. These phases are I and II from 8.5 to 8.0 kyr BP, and phase III from 8.0 to 7.0 kyr BP (Lin et al., 2013, 2014).

Stone tools unearthed at Shunshanji include disc-shaped grinding platforms (metates), round handstones (manos), elongated pestles and axes. The metates and manos were discovered at some archaeology sites south of Zhejiang Province, but were not found at sites near the upper-middle HRV or near Shandong Province. Experimental study indicates that these artifacts were used for dehusking, but it is still inconclusive if this was their only function because different opinions were proposed by other researchers (He et al., 2012; Wang, 1996). In regards to the pestles, use-wear traces were apparent to naked-eye observation, but no functional study has been done on this kind of stone tool so far.

Information about the utilization of plant resources and agricultural development will be helpful to understanding the agricultural patterns and development during the early-middle Neolithic period at the middle HRV, which can be provided by archaeobotanic analysis at Shunshanji. However, owing to poor preservation of macrobotanical remains in the contexts, the flotation work at Shunshanji only recovered seeds from Portulacaceae, Chenopodiaceae, *Mollugo stricta, Rumex*, and Asteraceae (Zhang et al., 2014). Starch grain analysis is another archaeobotanic method that is used to analyze plant resources, tool use, and the origin and spread of domesticated crops (Piperno et al., 2000; Perry, 2002; Torrence and Barton, 2006; Yang et al., 2012, 2013; Liu L et al., 2013). In this study, different types of stone tools and cauldron pottery sherds were subjected to starch grain analysis to better understand the utilization of

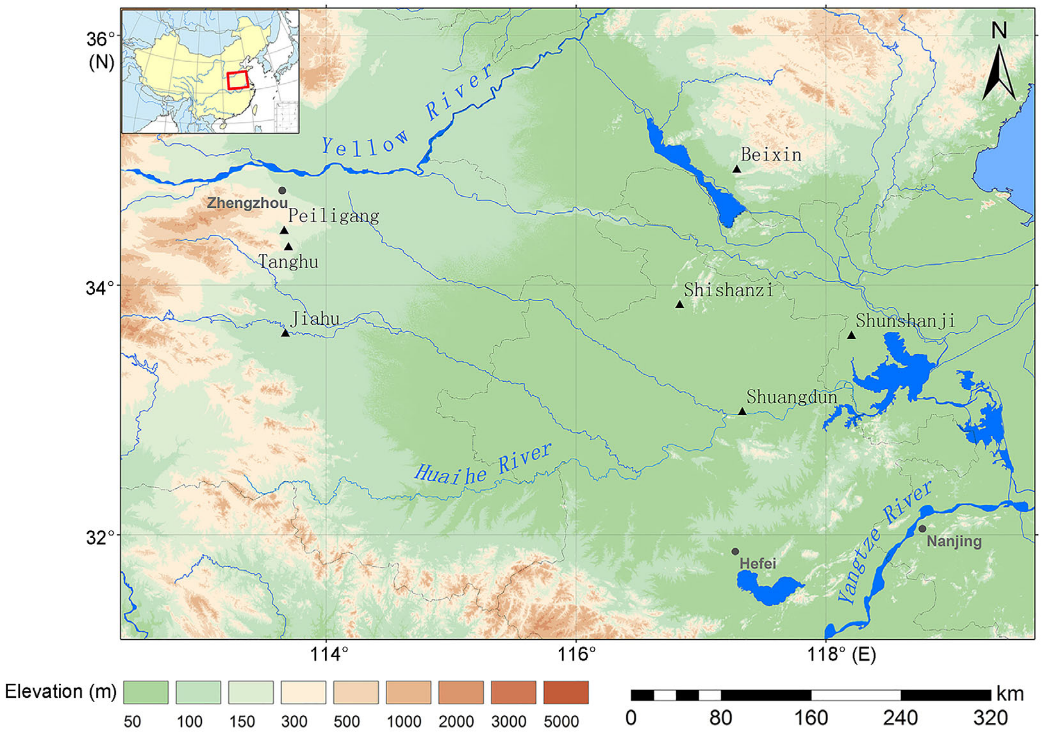

Figure 1 Location of the site of Shunshanji and nearby middle Neolithic sites.

plant resources, agriculture development and the function of stone tools in the research area.

2. Materials and methods

2.1 Study materials

Residue samples were collected from 17 stone tools which included seven round handstones, six axes, two pestles, one metate, one adze (cutting tool), and 29 cauldron pottery sherds (Figure 2). All artefacts were recovered from archaeology contexts, primarily from the stratigraphic layer, but two pottery sherds were recovered from the ash pit H27.

2.2 Research method

Residue sampling of the stone tools was completed in the field laboratory near the archaeology site. Sediment around the artefacts could not be collected because the excavation had finished before the residue sampling took place. First, the used and unused surfaces of the artefacts were identified by naked-eye observation and distilled water was used to clean each surface separately. After that, liquid samples were gathered from both used and unused surfaces with an ultrasonic brush and kept in separate test tubes. Further extraction was carried out at the University of Science and Technology of China (USTC) Bio-archaeology lab. Pottery cauldron sherds were selected at the field laboratory and brought back to the USTC for sampling. Each of the sherds was put into different glass beakers for an ultrasonic bath; liquid samples from the inner and outer side of the pottery sherds were gathered separately and kept in test tubes for further extraction. Glass beakers were all sterilized at high temperature before use.

The liquid samples were treated with 10% HCl and 5% $(NaPO_3)_6$ in order to get rid of carbonates and minerals accordingly. Then heavy liquid (CsCl, a density of 2.0) was used for the centrifuge procedure. In addition, control samples from laboratory consumables were analyzed.

Identification of ancient starch grains was based on previous morphological analysis of modern starch grains and our own modern reference collection from most of the common plant species used for food during the middle Neolithic in China (Torrence and Barton, 2006; Yang et al., 2009; Ge et al., 2010; Yang and Perry, 2013), covering fifty species from twenty genera, including Poaceae, Leguminosae, Fagaceae, and other roots and tubers (Figure 3).

3. Results and analysis

Among 17 stone tools analyzed in this experiment, four of them did not yield any starch grains, five of them showed starch at both unused and used surfaces, and the remaining

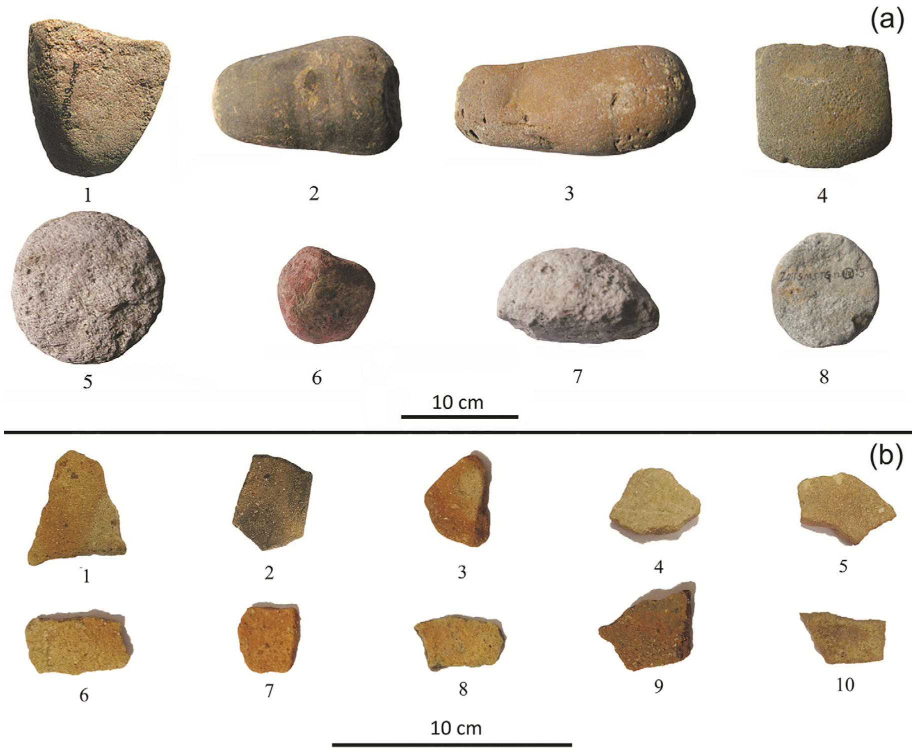

Figure 2 Stone tools (a) and pottery cauldron sherds (b) used in this experiment. (a) 1, Pestle TG12⑤:6; 2, pestle TG10③a:3; 3, pestle TG9③b:6; 4, axe T3358②:1; 5, round handstone TG7⑤:4; 6, round handstone T5085③:1; 7, round handstone TG11⑪:3; 8, round handstoneTG12⑩:5. (b) 1, T4985③; 2, T4984③; 3, T4784③; 4–6, T4784②; 7–9, TG13⑥; 10, H27.

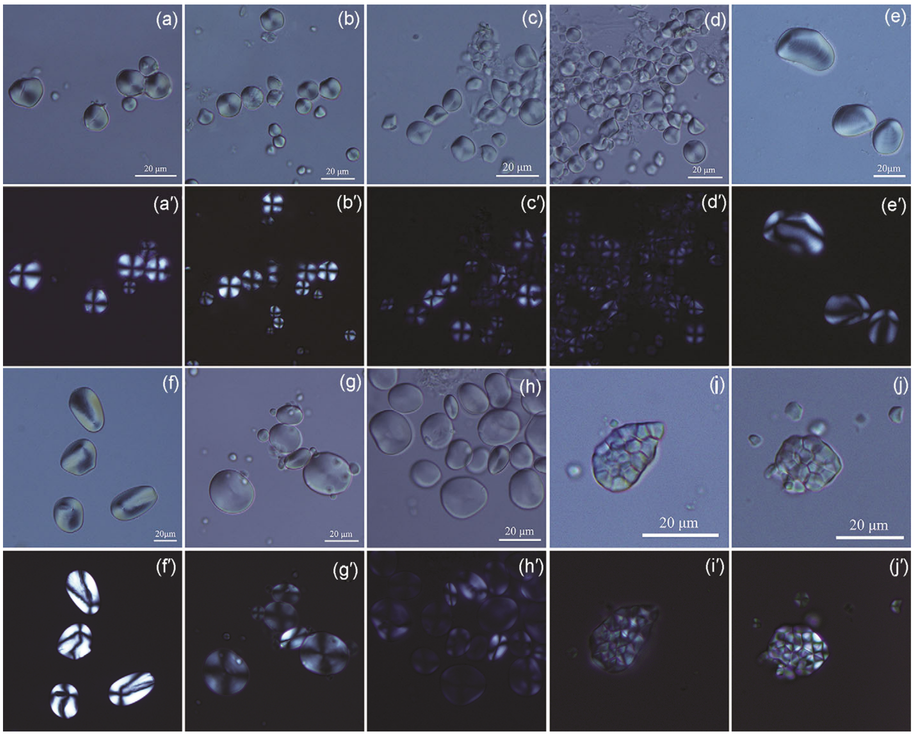

Figure 3 Examples of starch grain morphology from the modern reference material. (a), (a′), (b), (b′) *Coix lacryma-jobi*, range from 5.83 to 21.18 µm, median 13.16±3.50 µm (*n*=100); (c), (c′), (d), (d′) *Trichosanthes kirilowii* (snakegourd roots), range from 6.09 to 31.89 µm, median 13.39±5.77 µm (*n*=100); (e), (e′) *Dioscorea opposite*, range from 18.20 to 54.33 µm, median 34.31±8.33 µm (*n*=100); (f), (f′) *Nelumbo mucifera*, range from 9.43 to 77.29 µm, median 31.49±15.27 µm (*n*=100); (g), (g′), (h), (h′) *Triticum aestivum L.* range from 5.13 to 41.29 µm, median 18.77±6.38 µm (*n*=100); (i), (i′), (j), (j′) *Oryza sativa*, range from 2.60 to 10.28 µm, median 5.45±1.26 µm (*n*=100). Photos from (a′)–(e′) and (f′)–(j′) were taken under polarizing light.

eight showed only starch on the used surfaces.

Previous research indicates that contamination during the deposition can be avoided using the water cleaning process on the surfaces of artefacts (Hart, 2011). In this study soil samples could not be collected, and all of the artefacts were treated with distilled water prior to sampling for contamination control. Also, samples from both used and unused surfaces were gathered during the ultrasonic procedure, but starches found on the unused surface will not be included in this paper because their source is uncertain. Because starches found on the used surface of tools were more likely to have been utilized by past humans, we only chose to analyze starches found on the used surfaces of the eight stone tools. Similarly, starches found on the inner side of ten pottery sherds were chosen for further analysis, because starches were not found on seven of the sherds, and the other eleven sherds also yielded starches on the external side. Excluding damaged starches without diagnostic features, 175 and 239 starches were found on the eight stone tools and ten pottery sherds, respectively, which can be divided into five categories, described in detail below (Table 1).

Type A: starch grains (*n*=219), most of the starches are sub-round, a few are polygonal. Type A starches are also characterized by a centric hilum, linear fissures, invisible lamellae, and a curved extinction cross under polarizing light (Figure 4a, a′, b, b′). The range of the type A size is 7.85–25.3 µm. All of the characteristics comply with starches from *Coix lacryma-jobi* and/or millet. Meanwhile, some apparent “Z” shaped cross arm can be observed in type A starches, which is a unique characteristic of *Coix lacryma-jobi* (Liu et al., 2014a). So type A starch grains most likely come from *Coix lacryma-jobi*.

Type B: starch grains (*n*=133) are mostly eccentric and can be divided into sub-type B1 (*n*=97) and B2 (*n*=36) according to their morphological differences. Type B1 starch grains are sub-round or bell-shaped, show no visible fissures or lamellae, have a very clear extinction cross, and just a few of them have an invisible hilum (Figure 4c, c′, d, d′). The size range is 7.4–27.84 µm. The previously listed characteristics can be found on starches from several plants’ roots, such as *Trichosanthes kirilowii and Pueraria lobate Ohwi*. It is possible that the granules with these characteristics and at this site belong to *Trichosantes krilowii*, since its early prehistoric utilization has been proved at the sites Niubizi (6000 yr BP) and Shizitan (ca. 13800–8500 cal yr BP) (Liu L et al., 2013, 2014b). Type B2 starch grains are sub-round with a clear fissure near the hilum. They also have a curved cross under polarizing light and only a few of them have visible lamellae (Figure 4e, e′, f, f′). The size range is 11.97–45.47 µm. These kinds of starch grains are similar to the ones from lotus root and yam. According to the morphological study of starch grains from yam (Wan et

Table 1 Number of starch grains found on the used surfaces of ground stone tools and internal surfaces of pottery sherds (unit: grains)

Tool No.	Tool type	Excavation unit	Phase	A	B		C	D	Damaged	Total
					B1	B2				
SQ1	Pestle	TG12⑤	III	1	2	1	0	0	0	4
SQ2	Pestle	TG10③a	II	1	0	0	0	0	0	1
SQ3	Pestle	TG9③b	II	2	2	1	0	1	0	6
SQ4	Axe	T3358②	II	31	24	9	25	19	10	118
SQ5	Round handstone	TG7⑤	II	7	5		0	7	1	20
SQ6	Round handstone	T5085③	II	3	1	1	0	1	0	6
SQ7	Round handstone	TG11⑪	II	1	0	0	0	0	4	5
SQ8	Round handstone	TG12⑩	II	16	8	1	0	5	4	34
TQ1	Pottery sherd	T4985③	I	100	3	0	0	0	1	104
TQ2	Pottery sherd	T4984③	I	7	1	0	0	2	4	14
TQ3	Pottery sherd	T4784③	I	1	1	0	0	1	0	3
TQ4	Pottery sherd	T4784②	II	1	9	4	0	0	2	16
TQ5	Pottery sherd	T4784②	II	41	13	9	0	0	4	67
TQ6	Pottery sherd	T4784②	II	0	0	0	0	0	1	1
TQ7	Pottery sherd	TG13⑥	III	0	3	1	0	0	0	4
TQ8	Pottery sherd	TG13⑥	III	4	6	4	0	1	1	16
TQ9	Pottery sherd	TG13⑥	III	2	17	5	0	0	1	25
TQ10	Pottery sherd	H27	III	1	2	0	0	0	2	5
	Total			219	97	36	25	37	35	449

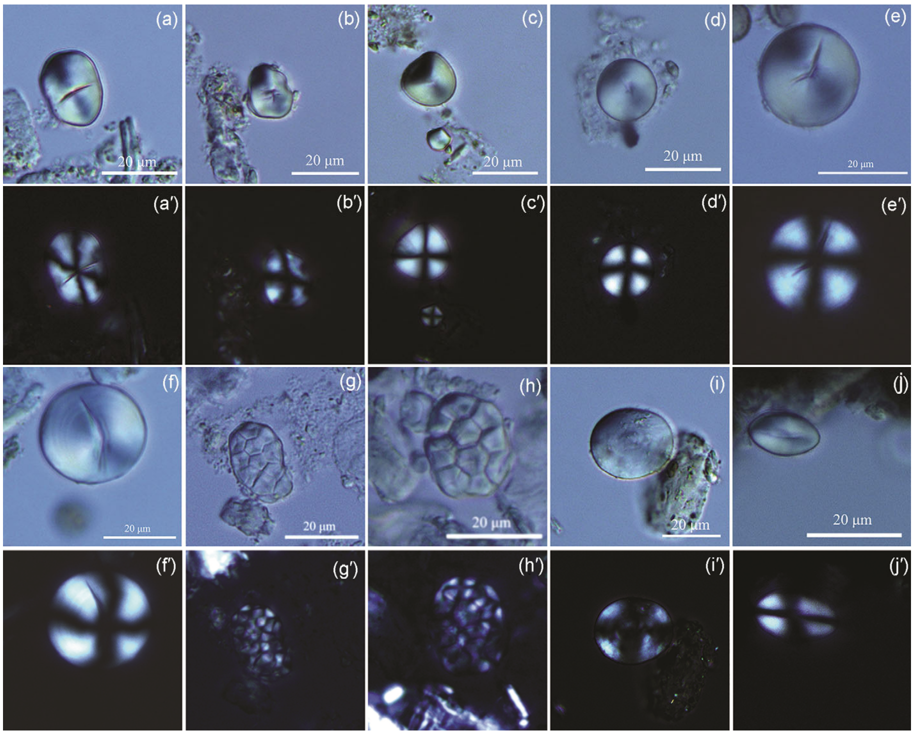

Figure 4 Ancient starch grains found on artefacts at Shunshanji. (a), (a′), (b), (b′) Type A; (c), (c′), (d), (d′) type B1; (e), (e′), (f), (f′) type B2; (g), (g′), (h), (h′) type C; (i), (i′), (j), (j′) type D.

al., 2011), only 10% are sub-round shaped starches. This is incompatible with starches from B2, which are predominantly sub-round. Meanwhile, both yam and lotus roots have typical oblong starches which are not apparent in the type B2 either. Type B2 starches are less likely to come from neither lotus root or yam starches but the identifications are uncertain in this research.

Type C: starch grains (n=25) are compound starch grains because each starch grain becomes closely connected at its amyloplast during the growing process and they also appear as a combined structure even when the envelope of the amyloplast is gone. Type C starch granules are polygonal and show no lamellae or fissures. Under polarizing light, an "X" shaped extinction cross can be observed (Figure 4g, g′, h, h′). The range of a single starch grain's size is 5.9–8.4 μm. Morphological studies of starch grains done at our lab and previous studies of compound starch grains of rice (Wei et al., 2008) in addition to finding macrobotanic rice remains at Shunshanji (Lin et al., 2013), make it evident that type C starches most likely come from *Oryza sativa*.

Type D: starch grains (n=37) are sub-round or oval in two-dimensional shape and have an elongated hemisphere when observed in three dimensions. Type D starches are also characterized by a centric hilum and "X" shaped extinction cross under polarizing light (Figure 4i, i′, j, j′). Type D starch grains range in size from 13.36 to 40.35 μm. According to our own modern reference collection and previous studies of Triticeae (Piperno et al., 2004), type D starches belong to the tribe Triticeae from the Poaceae family. A recent study indicates that identification to the genus and species level within Triticeae is based on the size, pits on the surface, fissures, and lamellae (Yang and Perry, 2013). Although in this study 72.9% of all type D granules were larger than 20 μm, no apparent lamellae or pits were found on the surface. However, studies also show that not all starch grains from Triticeae have pits (Perry and Michael, 2011). A further identification of type D is not appropriate for this research because the described characteristics criteria are not universal to all Triticeaes.

4. Discussions

With the analysis of starches recovered both from the eight stone tools that solely showed starch at the used surfaces and the pottery sherds, the research results have revealed the plant food resources utilized by past populations at the site of Shunshanji.

4.1 The utilization of plant resources by past population at the site of Shunshanji

A variety of plants that include *Coix lacryma-jobi,* Triticeae*, Oryza sativa, and Trichosanthes kirilowii* were exploited by the past people at Shunshanji according to starch grain analysis on stone tools and pottery sherds in this study.

As one of the earliest domesticated crops in China, *Coix lacryma-jobi* originated from the southwest of China (Zhao, 2000) and was one of the documented crops throughout Chinese history. However, carbonized seeds of *Coix lacryma-jobi*, dating to around 7.0 kyr BP, were only found at the site of Hemudu in Zhejiang Province (Yu and Xu, 2000). Previous starch analysis indicates that *Coix lacryma-jobi* was one plant food source used by the past populations at the north of Hangzhou bay, Nanyang and Xichuang (Yang and Jiang, 2010; Liu L et al., 2010; Li et al., 2014). Starches of *Coix lacryma-jobi* were also found on the surfaces of artefacts unearthed at the site of Peiligang, Shishanzi (Zhang et al., 2011; Dong et al., 2014). This indicates that past populations at the upper-middle HRV have already utilized *Coix lacryma-jobi* during the middle Neolithic period. In this study, the starch from *Coix lacryma-jobi* has the highest frequency amongst the plant species on both stone tools and pottery sherds (Figure 5). Results show that *Coix lacryma-jobi* may have been a dominant plant food resource of the past population at Shunshanji. Further archaeobotanic studies need to be done to further research the cultivation and domestication of *Coix lacryma-jobi* in this area.

The root of *Trichosanthes* also shares a common name of 'Tianhuafen' in Chinese, which is from the *Cucurbitaceae genus Trichosanthes*. This kind of root is currently used as a traditional herb medicine and food. Macrobotainc evidence of this plant has never been found during previous excavations in China. In contrary, starch grains of *Trichosanthes kirilowii* were found at the site of Shizitan (23.0–19.5 kyr BP) in Shanxi Province, and Niubizi (8.0 kyr BP) at Wuxiang (Liu L et al., 2013, 2014b). These findings indicate that *Trichosanthes* was utilized by past humans from the late Paleolithic to middle Neolithic at least. In that this study, the frequency of *Trichosanthes*' starch is equal to *Coix lacryma-jobi*, which has been interpreted to mean that this plant was also an important source of food at Shunshanji.

Presently rice is one of the most essential crops throughout the world, and the middle-lower area of Yangtze River is considered as the main region for its origin of domestication which happened around 10.0 kyr BP (Zhao, 1998; Wu et al., 2014). The earliest evidence of rice remains at the HRV was found at the site of Jiahu in the upper HRV and dated to 9.0–7.5 kyr BP (Zhao and Zhang, 2009). Other findings include macrobotanic evidence of rice remains at the site Yuezhuang in the north of Taishan Mountain and Xihe, dated to 8.0 kyr BP (Jin, 2012). This macrobotanic evidence indicates that rice had become a kind of important plant food during the middle Neolithic period 9.0–8.0 kyr BP in the HRV. In this paper, the recovery of rice starches at Shunshanji increases knowledge about the distribution of rice remains at the HRV during the middle Neolithic period. However, it should be noted that starches from rice were only found on one stone tool at Shunshanji and no rice remains were found at the nearby site of Shishanzi (Dong et al., 2014). This indicates that the utilization of rice began in the middle HRV during the middle Neolithic, but also that it was not at a widely utilized food resource.

The Triticeae tribe includes twenty genera in the world, of which twelve spread across China. Most of the Triticeae are used as pasturage nowadays, such as *Agropyron* and *Elymus* (Liu Y P et al., 2013). Starch grain analysis indicates that it has been utilized since 20000 years ago, or the late Palaeolithic in China (Wan et al., 2012; Liu L et al., 2013). In addition, starches from Triticeae were found at many early-middle Neolithic sites in the north and south of

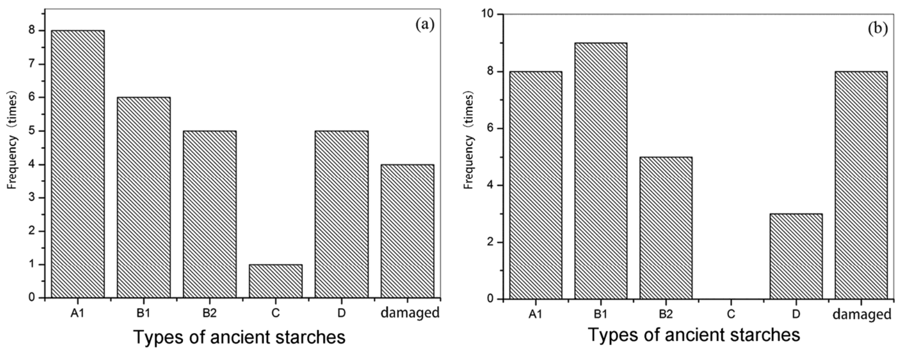

Figure 5 Frequency of different types of starch grains on ground stones tools (a) and pottery sherds (b).

China (Zhang et al., 2011; Yang et al., 2012; Yang and Perry, 2013; Li et al., 2014; Dong et al., 2014; Yang et al., 2015). These findings indicate that some species from Triticeae have always been the main plant food source in the Stone Age. In this study, Triticeae starches were found on both stone tools and pottery sherds but with a lower frequency of occurrence compared with *Coix lacryma-jobi* and *Trichosanthes kirilowii*, which may indicate a less frequent utilization of Triticeae as compared with the above mentioned plants.

9.0–7.0 kyr BP was a critical period for past societies changing from hunting-gathering to early agriculture in China (Liu, 2005). According to the analysis above it can be understood that *Coix lacryma-jobi* and *Trichosanthes kirilowii* account for the larger proportion of the starch remains compared with other species at Shunshanji. Although *Coix lacryma-jobi* is one of the plant food sources in the Neolithic period, its domestication process is still not clear. *Trichosanthes kirilowii* was considered a wild plant food and usually obtained by gathering (Liu et al., 2014b), strengthened by the observation that agricultural tools such as shovels, sickles, and Gusi are very rare at Shunshanji (Lin et al., 2013, 2014). Gathering was thus the main approach for the past population at Shunshanji to gain plant food, while rice cultivation was not well developed yet, which is similar to the Jiahu Culture, Peiligang Culture in the upper HRV as well as Houli Culture and Beixing Culture in Shandong Province. However, each culture was characterized by different ways of plant utilization and different levels of agricultural development because of their various natural environments. Meanwhile, neither micro- nor macrobotanic evidence of millet has been found at Shunshanji, which indicates that the early agriculture at Shunshanji was rice farming. This pattern in the middle HRV is dramatically different from the upper HRV and Shandong Province, where people employed the cultivation of both rice and millet.

4.2 Functional study of stone tools at Shunshanji

Stone tools played an important role in the daily lives of the past population at Shunshanji. The assemblage of stone tools at Shunshanji includes disc-shaped metates, round handstones, pestels, axes, and adzes. The edge of a disc-shaped metate is thick and use-wear traces are apparent by naked eye observation. Round handstones are covered with pits and with one flat up surface and one down arcuated surface (Lin et al., 2013). In this study, starch grains from *Coix lacryma-jobi*, *Trichosanthes kirilowii*, Triticeae and some unidentifiable species were found on the round handstones, which indicates the metate was probably used in conjunction with a handstone which is similar to the combination with the grinding slab and roller unearthed at some archaeology sites correlated with the Peiligang culture. Pestles from Shunshanji were oblong-shaped with scars and pits on both sides. This kind of pestle was made from smooth cobblestone without alteration and has also been excavated at other sites dating to the early-middle Neolithic period in China, such as Jiahu (Zhang, 1999). Because no functional studies were carried out on this kind of stone tool, inconsistent terms were used to describe them such as hammer or pestle. Different types of starches from *Coix lacryma-jobi* and *Trichosanthes kirilowii* are found on the used surfaces of three pestles, which indicates that these stone tools were used for food processing, and their function was probably more similar to that of a pestle. Typically the function of axes has been considered only for wood working, but starches from *Coix lacryma-jobi*, Triticeae, *Oryza sativa*, *Trichosanthes kirilowii* and some unidentifiable damaged starches were found on the edge of one axe in this analysis, which indicates they may also have been used for food processing. Because there were only a few types and low quantity of ground stone tools recovered from the Shunshanji archaeology site, maybe this is a reason why axes had multiple functions.

5. Conclusions

A diversity of plant food resources was detected by starch grain analysis on stone tools and pottery sherds at Shunshanji, including *Coix lacryma-jobi, Triticeae, Oryza sativa*

Trichosanthes kirilowii and some inconclusive species. Among the identified starch grains, the recovery of rice remains indicates that the past population had started to cultivate rice. According to the analysis of the frequency of different species, it seems gathering was still the main strategy for Shunshanji people to obtain plant food. In addition, Shunshanji is believed to have been a rice farming area because no millet remains have been found. The farming of only rice is a difference between Shunshanji and the nearby cultures of Jiahu, Peiligang and Houli, which farmed multiple plants. Furthermore, the discovery of starches at metates, handstones, and pestles at Shunshanji indicates these tools may have also been used for food processing, while the location of starches on the edge of the axe indicates the multifunctionality of this tool.

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