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ORIGINAL PAPER

A regional case in the development of agriculture and crop processing in northern China from the Neolithic to Bronze Age: archaeobotanical evidence from the Sushui River survey, Shanxi province

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Abstract The article presents the results of the analysis of survey archaeobotany samples from the Sushui valley. This provides evidence for changes over time for a region in the proportions of crops, especially rice versus millets. In addition, the composition of samples, both grouped by period and considered on a sample-by-sample basis, are considered as representing routine crop-processing waste, from which it is suggested that typical patterns of routine crop processing (after storage) can be inferred. These patterns, in turn, imply something about processing prior to storage and the social organization of agricultural production, suggesting the hypothesis that crop-processing patterns diversified during the emergence of complex societies with some sites with larger scale practices while others were focused on the household level.

Keywords Paleoethnobotany · Millet · Rice · Storage · Social complexity

Introduction

The agricultural basis of early village societies and later civilization in northern China was based on the cultivation of the indigenous millets (*Setaria italica* and *Panicum miliaceum*) as well as some introduced rice (*Oryza sativa*). While this has long been recognized based on the earliest written sources in Chinese, which relate to the end of the second millennium BC (Ho 1977; Chang 1980), this has come to be documented through systematic archaeobotany in recent years as systematic flotation has been more widely employed (e.g., Crawford et al. 2005; Deng et al. 2015; Lee et al. 2007; Fuller and Zhang 2007; Zhao 2010; Zhong et al. 2016). The potential of systematic archaeobotany is more than just confirmation of the staple crops known from later texts but can provide information on the balance between those crops, how those crops were processed and what this might indicate about the social organization of agriculture, and what arable weeds might imply about cultivation practices. The current study will address some of these issues, especially the implication of changes in crop-processing practices over time.

The evidence reported here comes from the upper Sushui river valley, a tributary that flows into the Yellow River from the north (Fig. 1). This region is important for research on the origin of the state in China since it is adjacent to the core region of Central Plains where the traditional Chinese state originated, and it is suggested to be closely related to the location of the capital of the earliest legendary Emperors Shun and Yu who predated the Emperor Qi of the Xia dynasty. The archaeological chronology in this region is well established; however, there is no previous systematic research on settlement archaeology and little research on the Sushui in relation to the origins of the state and civilization. In addition, there is a salt lake (called Yanchi in Chinese) and abundant copper resources in this region which may have been

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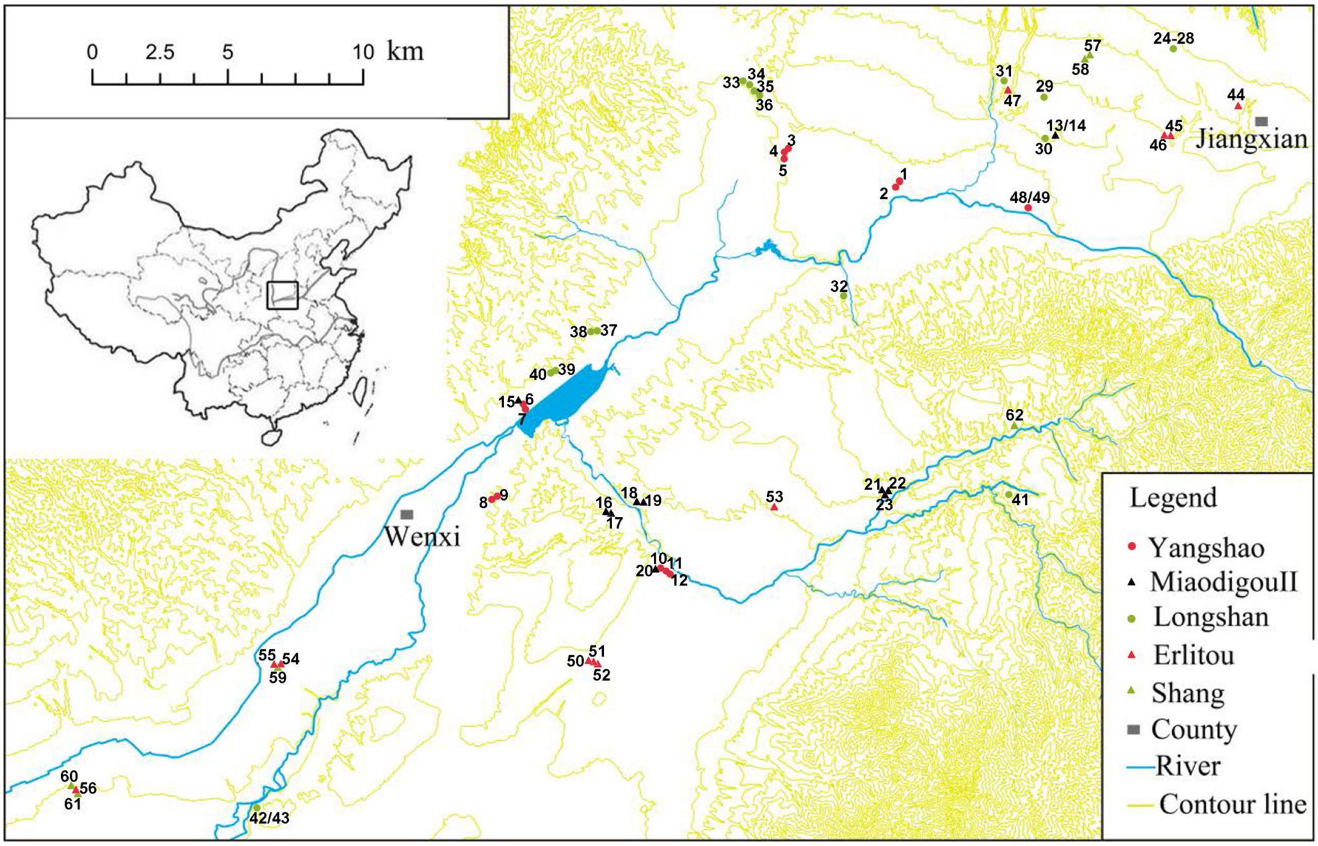


Fig. 1 Map of Sushui valley. Shang samples include all the samples from Erligang period and one sample from late Shang period. Sites numbered as per Table 1

exploited as Bronze Age raw materials. It is important to explore when these resources began to be utilized and controlled, and what role they played in the processes of social evolution and the origins of complexity in this region. Therefore, it was surveyed by a joint archaeological team in order to investigate the distribution and evolution of settlements and development processes of social complexity in this region (Research center of field archaeology, National Museum of China et al. 2011). The survey result indicates that five periods of culture were present in this region including the Yangshao (7000–5000 BP), the Maiodigou II (4900–4800 BP), the Longshan period (4600–4000 BP), the Erlitou period (3900–3500 BP), and the Erligang period (3600–3300 BP). Yangshao is the earliest Neolithic culture in this region. The emergence of social complexity might have begun in the middle Yangshao period through the Miaodigou II period evidenced by grouping in the distribution of settlements, the presence of large central settlements in each group. However, each settlement group may be roughly equal with no indication of a hierarchical regime at the regional level.

Fundamental changes occurred during the Longshan period when this region was first integrated into a large regional regime. The emergence of a polity is exemplified by the growth of a super large settlement the Zhoujiazhuang site into a regional central settlement in the upper Sushui valley which was interpreted as a complex chiefdom at the very least. During the Bronze Age (Erlitou and Erligang periods), there is a dramatic decline in settlement number and scale and social structure seems to be simpler. Although there are still some large settlements, there is no super large settlement similar to the one (Zhoujiazhuang site) in the Longshan period which probably integrated and controlled the whole region. This was interpreted as the loss of independence because this region might have been under the control of the Xia and Shang dynasties in the Central Plain (Research center of field archaeology, National Museum of China et al. 2011).

The evidence from the Sushui valley can be compared to growing body of archaeobotanical evidence from the greater Yellow River region. Over the past decades, there has been a concentration of surveys and excavation projects pursuing "the origins of Chinese civilization" (e.g., Liu et al. 2002; Yuan and Campbell 2009), and this has meant archaeobotanical data has been collected from several site excavations and a number of regional surveys. Data from similar survey archaeobotany includes that from the Yiluo valley (Lee et al. 2007) and from the upper Ying valley (Fuller and Zhang 2007; Zhang et al. 2010), both regions that are implicated in the emergence of complex societies and major regional centers. Both regional datasets, as well as that from sites such as Taosi (Zhao and He 2006), Wangchengang (Zhao 2007), Huizui (Lee and Bestel 2007), Xinzhai (Zhong et al. 2016), and Nanjiaokou (Qin and Fuller 2009) indicate the predominance of foxtail millet cultivation followed by broomcorn millet throughout the Yangshao, Longshan, and Bronze Age periods. Rice was present on some, but not all sites, in lower quantities. The Sushui samples allow us to see whether similar patterns hold in a region further north and further from the major recognized centers.

In addition, these data allow us to assess whether a change in the social organization of agriculture, inferred from crop processing evidence in the Ying valley, is repeated in the Sushui valley. It was inferred by Fuller and Zhang (2007) that crop processing during the Yangshao period consistently organized at a larger social scale, as a semi-communal activity (see Fuller and Stevens 2009, on the scales of crop processing). Subsequently, in the Longshan period, sites show diversification with many sites shifting towards a more focused, smaller scale, or household level of labor mobilization. As argued below the evidence from the Sushui shows a similar pattern and, therefore, suggests that this trend may have a general significance in the social changes that accompanied the emergence of social complexity in China.

Materials and methods

Samples were collected for flotation by archaeologists from some of the sites in the Sushui River valley during the survey project. Most samples were collected from stratigraphic sections cleaned on archaeological sites during regional field survey but several samples from the Xijing and Xinzhuang were collected in trial excavations at the sites. The archaeological contexts of the samples are either from trench fills or pit fills, most of which are probably secondary deposition of rubbish; some of the pits may have been storage pits originally but all pits were secondarily filled. The dataset consists of 62 samples from 25 sites, 33 settlements ranging in age from the Yangshao to the Erligang and late Shang period (Table 1; Table S1). Sites and sample contexts were dated based on material culture, primarily ceramics, which have a well-established typological sequence for the region. In total, 835 l of soil were collected, with each sample being between 10 and 15 l. Flotation was carried out in Shanxi using washover bucket flotation. A sieve of 0.3-mm aperture size was used to catch the light fractions. Locations and periods of the sites are given in Fig. 1, while the sample codes and volumes are shown in Table 1. For details of settlements and sites, see Research center of field archaeology, National Museum of China et al. (2011).

Samples were sorted under a low-power binocular microscope. Carbonized plant remains were separated into seeds, seed fragments, non-wood remains, and wood charcoal. Uncharred seeds are considered as modern intrusions and excluded from the seed counts.

Millet crops have been separated into several categories for the purpose of investigating crop processing. Immature grains, mature grains, clean grains, and grains with husk fragments were counted separately, following the suggestions of Fuller and Zhang (2007), and evidence of modern experimental crop processing (Song et al. 2013). In the early stages of crop processing, the proportion of immature grains and grains with husk fragments could be higher than that of mature grains and clean grains. On the contrary, in the later stages of crop processing, the proportion of mature grains could be higher than that of immature grains. However, the proportion of clean grains and grains with husk fragments and the proportion of immature grains and mature grains are biased by different factors. Immature grains are more frequent in early processing (winnowing waste) but immature types may also increase with poor harvests, due to drought years, poor soils, or early harvests due to adverse weather (You 1995, 72–76; Li 1979, 197,394). The proportion of clean grains and grains with husk fragments relates to crop processing but may also be biased by charring conditions, with some conditions destroying husk and artificially increasing the clean grain ratio; much as is the case with the differential destruction of wheat glumes versus grains in wheat (Boardman and Jones 1990) and has been demonstrated experimentally with *Setaria italica* by Castillo (2013). Therefore, these different factors must be kept in mind when assessing these two ratios and interpreting them in terms of crop processing.

As for rice, spikelet bases were counted in addition to counting rice grains (including some incomplete grains). Three categories of rice spikelet bases were separated according to established identification criteria (Fuller and Qin 2008; Fuller et al. 2009, 2016), i.e., domesticated type, immature type, and wild type.

Results and discussion

More than 40,000 items including indeterminate millet fragments have been identified with an uneven distribution between individual samples and different periods (Fig. 2; full dataset in Table S2). It varies between 8 and 17,908 within individual samples and between 1741 and 24,351 between the different periods. The large count in the Miaodigou II period is mainly due to one very large sample ($n = 17{,}908$), which may be regarded as a special context. Several big samples from the Erlitou period also contributed large numbers of seeds.

There is also variation between periods and samples in terms of the density of seeds (Fig. 3). The average density in all samples is 52.61 seeds/L of sediment floated while individual samples range from 0.53 seed/L to 1193.87seeds/L.

Table 1 Samples collected in Sushui survey. Further details in Table S1. Site locations in Fig. 1

No. in Fig. 1	Sample no.	Settlement	Site	Soil vol.	Period	Age (BP)	Sample collection
1	LQI1N	LiuquanI1	LiuquanI	10	Yangshao	7000–5000	Survey
2	LQI1S	LiuquanI1	LiuquanI	15	Yangshao	7000–5000	Survey
3	CD3N	Cangdi3	Cangdi	15	Yangshao	7000–5000	Survey
4	CD3M	Cangdi3	Cangdi	10	Yangshao	7000–5000	Survey
5	CD4S	Cangdi4	Cangdi	15	Yangshao	7000–5000	Survey
6	DD1M	Dingdian1	Dingdian	15	Yangshao	7000–5000	Survey
7	DD1S	Dingdian1	Dingdian	10	Yangshao	7000–5000	Survey
8	SSW1W	Shangshaowang1	Shangshaowang	15	Yangshao	7000–5000	Survey
9	SSW1E	Shangshaowang1	Shangshaowang	10	Yangshao	7000–5000	Survey
10	DTB1N	Diantoubao1	Diantoubao	15	Yangshao	7000–5000	Survey
11	DTB1M	Diantoubao1	Diantoubao	10	Yangshao	7000–5000	Survey
12	DTB1S	Diantoubao1	Diantoubao	15	Yangshao	7000–5000	Survey
13	ZJZ5A	Zhoujiazhuang5	Zhoujiazhuang	15	Miaodigou II	4900–4300	Survey
14	ZJZ5B	Zhoujiazhuang5	Zhoujiazhuang	10	Miaodigou II	4900–4300	Survey
15	DD2N	Dingdian2	Dingdian	10	Miaodigou II	4900–4300	Survey
16	SCIW	Suncun1	Suncun1	15	Miaodigou II	4900–4300	Survey
17	SCIE	Suncun1	Suncun1	15	Miaodigou II	4900–4300	Survey
18	SCV2W	SuncunV2	SuncunV	15	Miaodigou II	4900–4300	Survey
19	SCV2E	SuncunV2	SuncunV	15	Miaodigou II	4900–4300	Survey
20	DTB6	Diantoubao6	Diantoubao	15	Miaodigou II	4900–4300	Survey
21	HGII2W	HougongII2	HougongII	15	Miaodigou II	4900–4300	Survey
22	HGII2E	HougongII2	HougongII	15	Miaodigou II	4900–4300	Survey
23	HGII2S	HougongII2	HougongII	15	Miaodigou II	4900–4300	Survey
24	05JXH3	Xijing3	Xijing	15	Longshan	4600–3800	Excavation
25	05JXG②	Xijing3	Xijing	15	Longshan	4600–3800	Excavation
26	05JXG①	Xijing3	Xijing	15	Longshan	4600–3800	Excavation
27	05JXH4	Xijing3	Xijing	15	Longshan	4600–3800	Excavation
28	05JXG③	Xijing3	Xijing	15	Longshan	4600–3800	Excavation
29	ZJZ11N	Zhoujiazhuang11	Zhoujiazhuang	10	Longshan	4600–3800	Survey
30	ZJZ11S	Zhoujiazhuang11	Zhoujiazhuang	15	Longshan	4600–3800	Survey
31	JJB3	Jiajiabao3	Jiajiabao	15	Longshan	4600–3800	Survey
32	SYK3	Shangyukou3	Shangyukou	10	Longshan	4600–3800	Survey
33	HC4W	Hucun4	Hucun	15	Longshan	4600–3800	Survey
34	HC4N	Hucun4	Hucun	15	Longshan	4600–3800	Survey
35	HC4S	Hucun4	Hucun	15	Longshan	4600–3800	Survey
36	HC4E	Hucun4	Hucun	15	Longshan	4600–3800	Survey
37	ZJZE	Zhangjiazhuang	Zhangjiazhuang	15	Longshan	4600–3800	Survey
38	ZJZW	Zhangjiazhuang	Zhangjiazhuang	10	Longshan	4600–3800	Survey
39	CJZ2E	Chengjiazhuang2	Chengjiazhuang	10	Longshan	4600–3800	Survey
40	CJZ2W	Chengjiazhuang2	Chengjiazhuang	10	Longshan	4600–3800	Survey
41	NBS3	Nanbaishi3	Nanbaishi	15	Longshan	4600–3800	Survey
42	SN3H1	Shuinan3	Shuinan	15	Longshan	4600–3800	Survey
43	SN3H2	Shuinan3	Shuinan	15	Longshan	4600–3800	Survey
44	GXI4	GouxiI4	GouxiI	15	Erlitou	3900–3600	Survey
45	BY4E	Beiyang4	Beiyang	15	Erlitou	3900–3600	Survey
46	BY4W	Beiyang4	Beiyang	15	Erlitou	3900–3600	Survey
47	JJB5	Jiajiabao5	Jiajiabao	10	Erlitou	3900–3600	Survey
48	XXH24	Xinzhuang1	Xinzhuang	15	Erlitou	3900–3600	Excavation
49	XXH30	Xinzhuang1	Xinzhuang	15	Erlitou	3900–3600	Excavation

Table 1 (continued)

No. in Fig. 1	Sample no.	Settlement	Site	Soil vol.	Period	Age (BP)	Sample collection
50	DZII2W	DazeII2	DazeII	10	Erlitou	3900–3600	Survey
51	DZII2M	DazeII2	DazeII	10	Erlitou	3900–3600	Survey
52	DZII2E	DazeII2	DazeII	10	Erlitou	3900–3600	Survey
53	NW4	Nanwang4	Nanwang	15	Erlitou	3900–3600	Survey
54	GJZ1E	Guojiazhuang1	Guojiazhuang	15	Erlitou	3900–3600	Survey
55	GJZ1W	Guojiazhuang1	Guojiazhuang	10	Erlitou	3900–3600	Survey
56	YYBI1	YueyabaoI1	YueyabaoI	15	Erlitou	3900–3600	Survey
57	XZ3N	Xiaozhang3	Xiaozhang	15	Erligang	3600–3300	Survey
58	XZ3S	Xiaozhang3	Xiaozhang	15	Erligang	3600–3300	Survey
59	GJZ2	Guojiazhuang2	Guojiazhuang	15	Erligang	3600–3300	Survey
60	YYBI2N	YueyabaoI2	YueyabaoI	10	Erligang	3600–3300	Survey
61	YYBI2S	YueyabaoI2	YueyabaoI	10	Erligang	3600–3300	Survey
62	LJZ	Liujiazhuang	Liujiazhuang	15	Late Shang	3300–3100	Survey

The great variation in the density of different periods may be the result of several large samples in the Miaodigou II and Erlitou period.

In addition, significant variation can be seen in sample size in terms of the total number of seeds and fragments. It is assumed that sample sizes have an effect on taxa diversity. The larger the sample, the more taxa are likely to be present but it will not increase infinitely. It will reach a plateau sooner or later in terms of the curve of number of taxa against sample size (Orton 2000, 172). Such a pattern is reflected in the data here (Fig. 4).

Millets

Figure 5 and Figure 6 show the relative frequency and ubiquity of different economic plants and related weeds. It can be seen that *Setaria italica* is the dominant crop with a high relative frequency among all seed remains and a ubiquity score of 100% in almost all periods. *Panicum miliaceum* is the next most recurrent crop species but the number of seeds is much lower (relative frequency 1.67–6.68%). Similarly, total weed seeds and wild Panicoid seeds are also low in frequency but much higher in ubiquities. Overall, it is reasonable to conclude that millets are the principal crops during the Yangshao and Shang periods in Sushui valley, and most weeds, therefore, are likely to derive from millet cultivation and millet harvesting.

Millets, *Setaria italica* and *Panicum miliaceum,* are the principal crops which remained dominant throughout all the periods. In addition, millet-related weeds and wild forms are also significant in the plant assemblages, such as *Setaria* sp. ("*verticlillata*/other"), *Panicum* sp. (of a small wild type), and *Digitaria* sp. This is a widely reported pattern in China from the Yangshao to the Shang periods (Fuller and Zhang 2007) as indicated in Liangchengzhen, Zhouyuan, Wangchenggang, Taosi, Xinzhai, etc. (Crawford et al. 2005; Zhouyuan Site Archeological Team; Zhao 2007; Zhao and He 2006; Zhong et al. 2016),which may suggest a close relationship between these weedy types and millets.

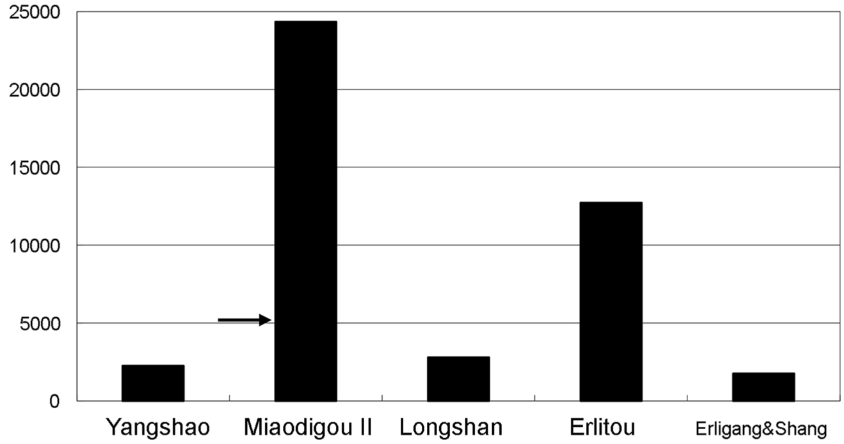


Fig. 2 Total counts of identified items in the preliminary dataset in the Sushui valley. Arrow indicates total for Miaodiou II excluding one very large sample (*n* = 17,908)

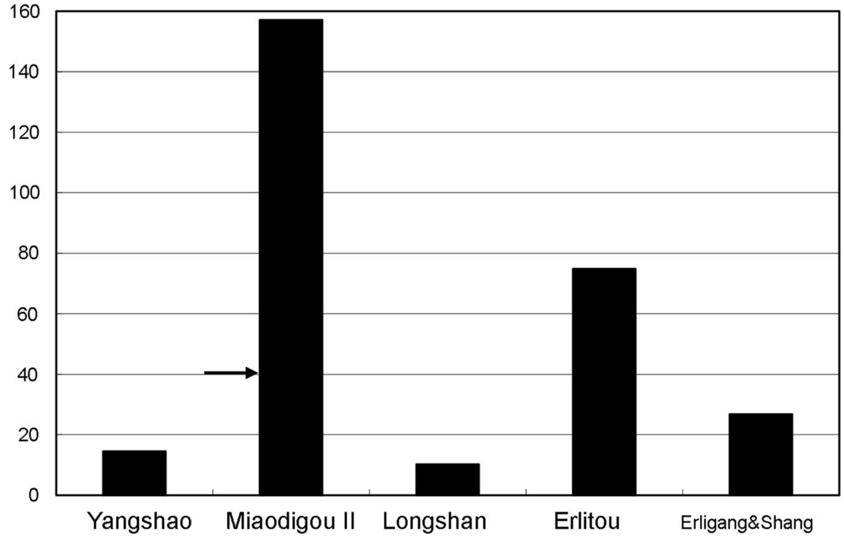


Fig. 3 Density of different periods in the Sushui valley. Arrow indicates density for Miaodigou II period after excluding one very large sample

Rice

Rice was much less common than millets throughout all periods (Fig. 5, Fig. 6). Only 128 rice grains and 382 rice spikelet bases were noted. The largest quantity occurred in Miaodigou II, showing an increase over the Yangshao period but it is mainly based on one large sample in the Yangshao period (*n* = 84) and another large sample in Miaodigou II (*n* = 365), which may not be representative for agriculture throughout these phases. Nevertheless, there appears to be a dramatic drop in rice during the Longshan period and Bronze Age when only 3 rice grains and 12 rice spikelet bases were found. Rice was discovered in the Longshan site Taosi in southern Shanxi, but the quantity (*n* = 30 out of 13,070 seeds) is very small (0.2%) which might indicate rice was extremely rare during the Longshan period in Shanxi (Zhao and He 2006). It is quite different from most of the sites in the lower Yellow River where rice was more frequently discovered in the Longshan period (Jin and Luan, 2006 Jin 2008a,b; Song 2007; Chen 2007). Also south of the Yellow River, while rice is fairly rare, it is still more common than in Shanxi to the north; in the Ying valley survey material, for example, rice was present in 78% of Longshan period samples, accounting for just ~1% of total seeds/chaff (Fuller and Zhang 2007), while in the Wangchengang excavation rice was present in 11% of Longshan samples and 0.7% of seeds (Zhao 2007; Yuan and Campbell 2009). In the Yiluo valley, not a single site produced rice in the Longshan period out of six of that period that had archaeobotanical assemblages (Lee et al. 2007).

The presence of rice spikelet bases suggests the local dehusking of rice, i.e., the final stages of processing, whether this indicates importation of spikelets or local production is ambiguous, but limited local cultivation seems likely. Southern Shanxi may represent nearly the northern limits of rice cultivation during the fourth to early third millennium BC, an era which is generally warmer than present (Zhu 1972; Shi

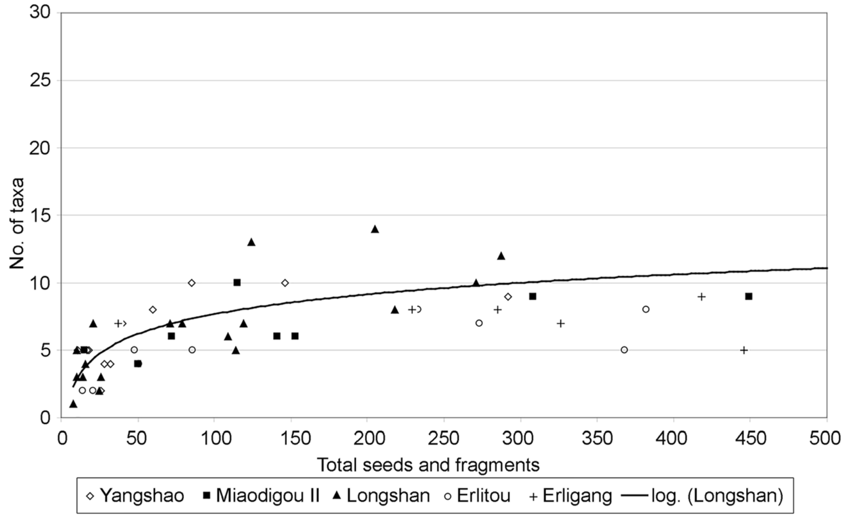


Fig. 4 The relationship between sample size (total number of seeds and fragments) and sample diversity (number of identified taxa) in the Sushui valley. Ten very large samples (*n* > 500) are not shown in the graph as they fall off the right-hand side of the chart. The max = 17,908, Average = 713.4, Median = 117.5 for samples shown in the graph

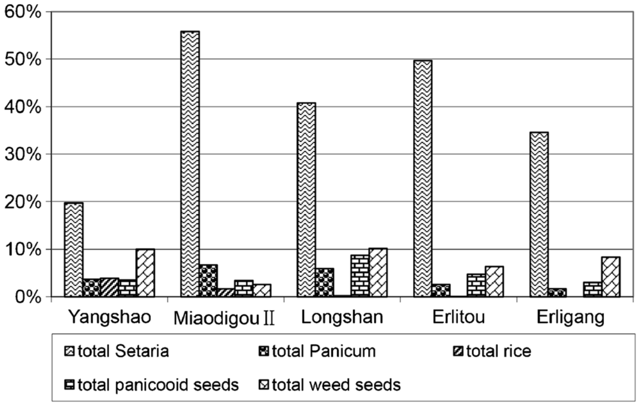


Fig. 5 Relative Frequency of crops or economic plant categories in the Sushui valley

et al. 1992; Xiao et al. 2004). During later historical periods, rice cultivation was also practiced in this region and the scale of cultivation varied in different periods due to climate changes, variations in political policies or farmer's preferences (You 1995). Similar situations might occur during the Neolithic and Bronze Age.

Among the challenges of growing rice in this region is that it would not have initially been well adapted to temperate conditions. Modern temperate japonica varieties have a strong photoperiod response, flowering as days shorten towards the end of summer, thereby linking their cultivation season to the warmest and sunniest months. This appears to be aided by various genetic adaptations, but of the major contributing factors is the gene mutation *DTH-A4*, which is unknown in wild rice and absent from those of southern China and Southeast Asia (Wu et al. 2013). This, therefore, must have evolved under selection in a more northerly environment, and we ask whether this is likely to have occurred before this period. Rice without this mutation has poor seed set under northern conditions, with incomplete grain filling on the order to 20–40% unfilled spikelets (Wu et al. 2013). With this in mind, we can consider the evidence from rice spikelet bases which can be differentiated into domesticated, wild, and immature types (after Fuller et al. 2009).

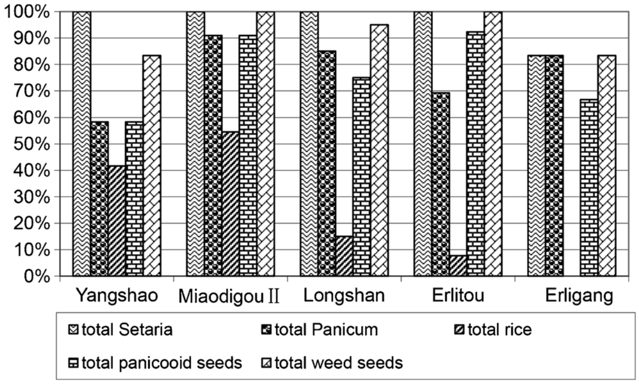


Fig. 6 Ubiquity of crops or economic plant categories in the Sushui valley

Despite the small sample of spikelet bases, they show a high quantity of immature types. While the presence of immature types may be indicative of ongoing domestication (see, e.g., Fuller et al. 2007, 2010, Fig. 4), the levels in the Sushui material are higher still. It is also possible that the high proportion of immature spikelets was due to the more marginal, northerly conditions in which rice plants were less able to successfully fill all their spikelets. Similarly high levels of immature spikelet bases are known from the Chengyao site in the Ying valley, not far to the south, and together with the evidence of the Sushui can be taken to infer that the early rice of northern China, of both the Yangshao and Longshan periods, predate the *DTH-A4* adaptation to temperate conditions (Fuller et al. 2016 88). Rice would thus have been a marginal option for centuries after it first arrived in the north, compounded by declining temperatures over the course of the Longshan era. The decline in the immature proportion into the Miaodigou II period could indicate some improvement in the techniques of rice cultivation or amelioration of climatic conditions.

The proportion of apparent wild rice is also quite high, at ca. 19% from both the Yangshao period to the Miaodigou II period (Fig. 7). Such a percentage is probably consistent with the presence of weedy rice (*Oryza sativa* cf. *spontanea*) which would have accompanied the dispersal of the rice crop and would have infested fields. Indeed, a slightly higher proportion is reported from the lower Yangtze at Liangzhu (ca. 2200 BC), which provides upper estimate of the potential proportion of wild types in an early rice crop (Fuller et al. 2009), although many other early rice sites had lower proportions

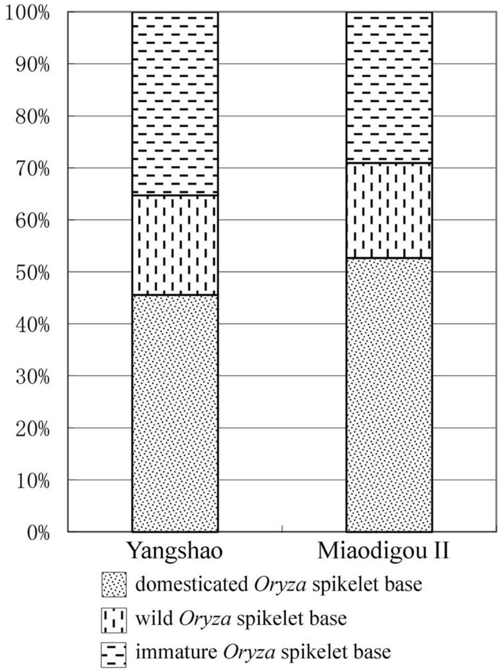


Fig. 7 Proportion of different types of rice spikelet bases in the Sushui valley

(Fuller et al. 2016). While proportions of wild type higher than ca. 20% are likely to represent early rice undergoing domestication, as during the Hemudu culture for example (Fuller et al. 2009), low proportions may be thought of as within the range of weed-infested domesticated rice, with variation in the quantities of wild rice in part reflecting the nature of cultivation traditions for control of weeds. Taken together the high levels of both immature and wild rice suggest that rice production in this region in prehistory was likely to have had poor productivity. Therefore, the fact that rice cultivation in northern China was not stable in historical times (You 1995) might have a deep history since prehistory. This tends to imply that cultivation of rice was likely driven by the crop product itself being seen as desirable or high status compared to the more easily produced millets.

Wheat

Wheat has only been discovered in two samples from the Longshan period represented by a few poorly preserved grains and rachis segments. Wheat was reported in several sites in the Longshan period including Zhaojiazhuang (Jin et al. 2008), Liangchengzhen (Crawford et al. 2005), Jiaochangpu (Zhao 2004), Yuhuicun (Yin 2013), Xijincheng (Chen et al. 2010), Wadian (Liu and Fang 2010), Baligang (Deng et al. 2015), and Xishanping (Li et al. 2007). Among these, only Zhaojiazhuang site has produced direct date on wheat grain with an age of 3905 ± 50 BP (2570–2200 cal. BC). Other dates are all inferred from Longshan period related contexts or from deposition rate of the surveyed profile, and the reliability of wheat dates before 4000 BP can be questioned (Zhao 2015; Deng et al. 2015). The dating result of Zhaojiazhuang wheat has been suggested to be anomalous, and possibly not reflecting a Longshan era arrival of wheat (Stevens et al. 2016). We, therefore, are open to the possibility that wheat finds are intrusive. More direct dating of wheat grains from the Longshan period is necessary to clarify the initial introduction of wheat into different parts of China.

Fruits

A number of tree and shrub fruit remains were recovered, but it is unclear whether these represent gathered or cultivated fruits. Further work on refining identification criteria is needed, but the presence of Jujube (*Ziziphus jujuba*) can be confirmed. One complete rugose stone was recovered in one sample from Erlitou period. The round shape indicates it is likely wild (var. *rugosa*) because cultivated jujubes tend to be elongated (Fuller and Zhang 2007). Five *Pyrus* sp. (pear) seeds were identified but it is not clear whether these are domesticated. One center of *Pyrus* species diversity is in China, where oriental pears evolved (*P. pyrifolia* and *P. bretschneideri*), distinct from those of western Eurasia (Teng et al. 2004). European pears (*Pyrus communis*) are a distinct species, and with their earliest finds are in Southeast Europe (Zohary et al. 2012). Other evidence for the gathering of wild fruits comes from *Malus*/*Crataegus*, *Rosa*/*Sorbus*, *Rubus*, and *Chaenomeles* seed types. One fragment of a possible water lily seed type, cf. *Eurayle*, may indicate some gathering from aquatic environments. This find occurs considerably to the north of the prehistoric focus of *Euryale* finds, which have been reported from the Yangtze Neolithic sites (Fuller and Qin 2010).

Wild/weed species

In addition to cereals and fruits, many other wild plant seed types were identified, most of which are likely to have been weeds infesting the fields of crops. These would have been harvested along with the crops and preserved on the site as part of the stored crop and crop-processing waste (Fuller and Zhang 2007). As the predominant crops were millets, these weeds are likely to reflect cultivation conditions in the millet fields, especially of *Setaria italica*.

Overall, the distribution of weeds is highly consistent in terms of both ubiquity and relative frequency throughout all the periods (Fig. 5, Fig. 6). One exception comes from the sample JJB5 with the highest diversity of species and is, therefore, a unique context. Another significant phenomenon is the relatively high ubiquity of small legume seeds, which has been encountered also in many northern Chinese sites, including Taosi.

Exploration of crop-processing activities

A preliminary attempt was made to investigate possible patterns in crop-processing activities and how these might relate to social changes. Samples likely represent mixed inputs from various activities over a period, which were subject to movement and redeposition, but they should preserve a time-averaged and activity-averaged sample of routine crop-processing patterns (Fuller and Zhang 2007; Fuller and Stevens 2009; Fuller et al. 2014). Such patterns are reported from Europe and the Near East where each sample is dominated by cereal and cereal-related weeds, which can be related to routine crop-processing activities, and the weeds related to field conditions (see also, M. Jones 1985; Stevens 2003; Van der Veen 1992, 2007). While many crop-processing studies have focused on wheat and barley, here we focus on millet processing, which has been summarized from various ethnoarchaeological studies by Harvey and Fuller (2005) and explored experimentally in Song et al. (2013).

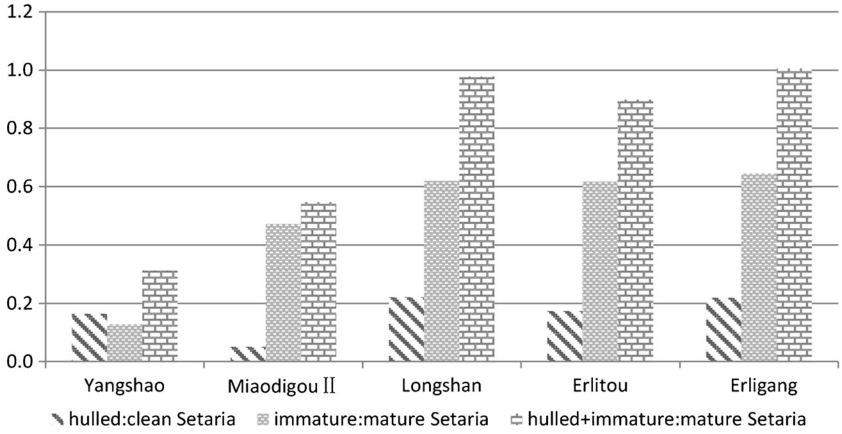


Fig. 8 Ratios of different types of *Setaria* over time in the Sushui valley. Some small and big samples are excluded

Two ratios have been considered in order to examine crop processing: the proportion of millet grains to weed seeds and the proportion of hulled and immature millets to clean mature millet grains (Fig. 8, Fig. 9). Higher proportions of hulled and immature millets are expected in early stages (i.e., winnowing and threshing), while more mature grains might be expected in later stages (i.e., dehusking). Experiments confirm that immature grains from unfilled spikelets are mostly removed during initial winnowing (Song et al. 2013). In addition, although husks may be differentially destroyed during charring, if husk fragments are present, then these grains most likely derive from waste accumulated prior to dehusking, and therefore from early processing stages. As for weeds, some will be removed during winnowing and others after dehusking. In principle, heavier weeds closer in size to millet grains will persist until the final processing stages whereas a higher ratio of weeds to grains is expected in early stages because winnowing will have removed many weeds, especially light-seeded taxa.

From the perspective of period totals, it can be seen that changes happened over different periods. There is a steady increase in the proportion of immature grains from the Yangshao to Longshan and later periods (Fig. 8). This suggests an increase in the input of winnowing waste in Longshan and Bronze Age samples. On the contrary, a decline in the proportion of hulled grains was experienced in Miaodigou II and Erlitou period which may indicate a decline in the input of threshing and winnowing waste. However, the ratio of hulled grains and clean grains is biased by charring conditions, i.e., the husks may be completely destroyed during carbonization and thus increase the proportion of clean grains artificially. The same problem exists in the ratio of immature and mature grains, which may be biased by poor agriculture conditions, i.e., drought years and poor harvests may increase the proportion of immature grains. In terms of the grain crop to weeds ratio, there is an increase within the Longshan period (Fig. 9). However, a more dramatic increase occurred in the Erlitou period which may suggest an increase in the input of dehusking waste. It again declined in the Erligang period. In summary, it is reasonable to conclude that a change occurred starting in the Longshan period when higher proportions of immature and hulled grains as well as total millet grains are

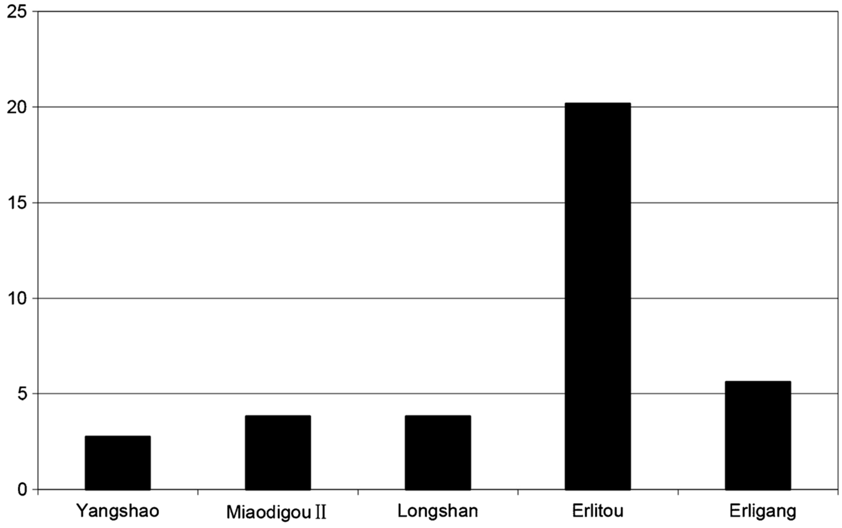


Fig. 9 Ratio of crop grains:weed over time in the Sushui valley. Some small and big samples are excluded

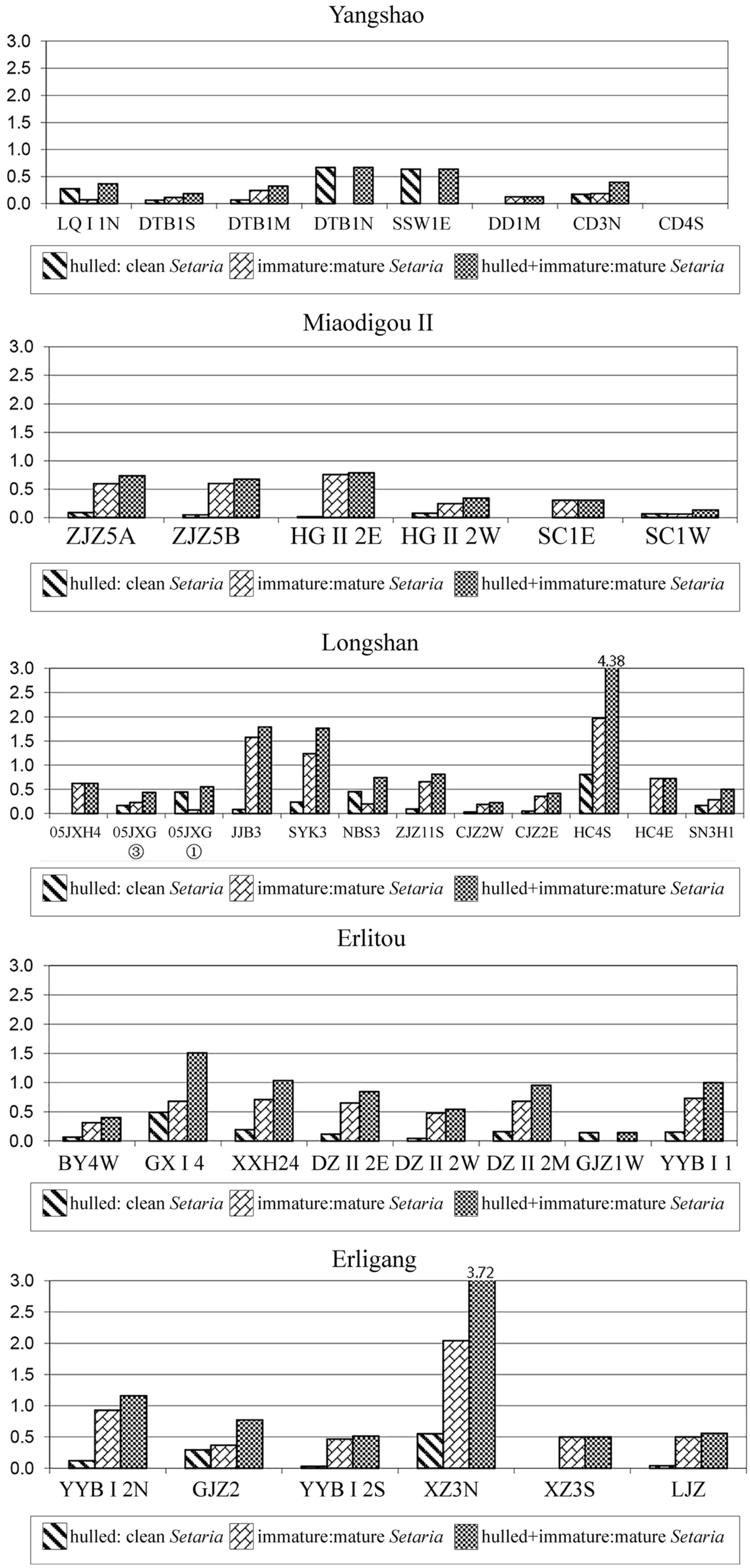
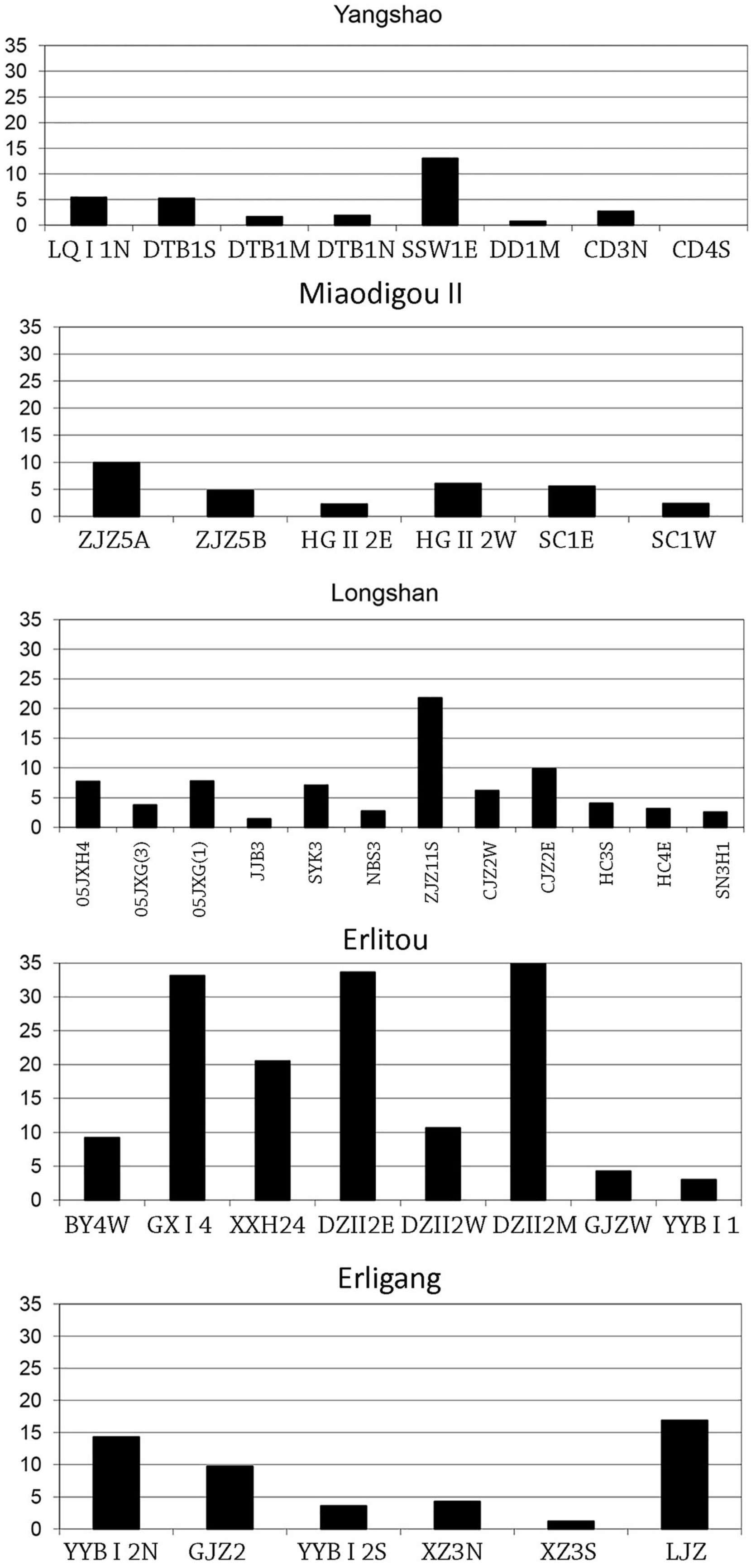


Fig. 10 Different *Setaria* ratios at individual sites from the Yangshao period to the Erligang and Shang period in the Sushui valley


Yangshao

Miaodigou II

Longshan

Erlitou

Erligang

Fig. 11 Grain: weed ratio at individual sites from the Yangshao to the Erligang and Shang period in the Sushui valley

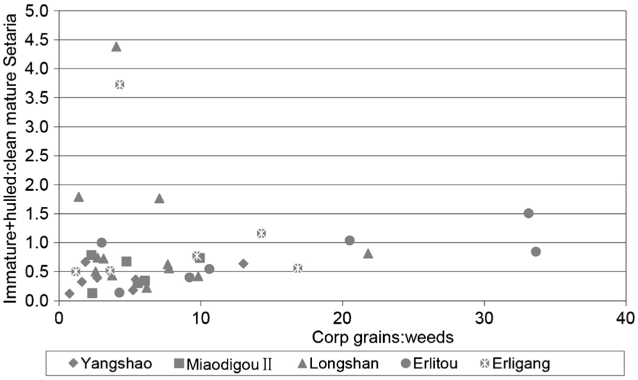


Fig. 12 Scatter plot showing ratio of grain:weed against ratio of hulled + immature:mature clean *Setaria* in the Sushui valley

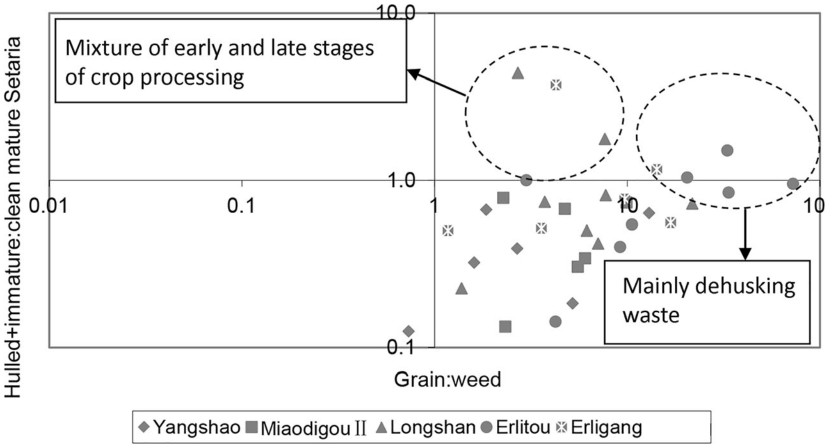
observed. This shift can be explored in further detail through individual samples (Fig. 10, Fig. 11).

Among the Yangshao and Miaodigou II samples, a low proportion of immature grains and hulled grains is shown in the graphs (Fig. 10). In the Longshan and Bronze Age, several samples show similar ratios to those of the Yangshao and Miaodigou II period with low ratios of early crop processing indicators (5JXH4, 05JXG①, 05JXG③, NBS3, ZJZ11S, CJZ2W, CJZ2E, HC4E, SN3H1, BY4W, XZH24, DZII2W, DZII2E, DZII2M, GJZ1W, YYBI1, YYBII2N, YYBII2S, XZ3S, LJZ). Others indicate a higher proportion of early processing indicators (JJB3, SYK3, HC4S, GXI4, XZ3N). Therefore, we see a more consistent pattern during the two earlier periods in which immature grains and hulled millets, i.e., evidence of earlier processing stages, is under-represented. By contrast, we see a diversification of crop-processing patterns in the subsequent periods, in which some sites look similar to earlier periods and other have a markedly higher presence of threshing and winnowing waste. This pattern is similar to that identified in the Ying valley archaeobotanical report between the Yangshao and Longshan periods (Fuller and Zhang 2007).

It is worth noting that some samples from the same site and same period show different indicators of crop processing. For example, the Longshan samples HC4S and HC4E are both from Hucun site but sample HC4S shows higher proportion of immature and hulled *Setaria italica*, which may indicate early processing while sample HC4E does not. A similar pattern can be found in samples from Xinzhuang site (XZ3N, XZ3S) in Erlitou period and Yueyabao I site (YYBI1, YYBI2N) in Erligang period. This may suggest a diversification in crop-processing patterns at individual sites or different activity areas within individual sites, which implies growing social differentiation within these communities. More samples from across these sites are needed to test this, but it may indeed indicate a shift in crop-processing patterns through time in which differences in practice within sites became more common from the Longshan period onwards.

In terms of grain:weed ratios, a pattern is not evident (Fig. 11). Only one sample (ZJZ11S) in Longshan period demonstrates relatively higher proportion of weeds (> 15) and others are similar to those of Yangshao and Miaodigou periods with a lower grain:weed ratio (< 15). However, great changes took place in the Erlitou period. Several samples (GXI4, XXH24, DZII2E, DZII2M) have a very high proportion of grains while others have lower proportion. Some samples from the same site and same period also demonstrate different characteristics, for example, the differences in samples DZII2E, DZII2M, and DZII2W from DZII2 site. This may need to be further explored in combination, in relation to the particular weed taxa present, and with other archaeological information. Overall, it seems to be reasonable to say that a diversification of crop-processing practices happened during the Longshan period and differences between sites further increased in Erlitou period. This pattern may reflect a diversification of labor mobilization strategies in relation to crop processing, in which the earlier communities practiced a more communal pattern practice (sensu Fuller and Stevens 2009), storing millet spikelets semi-clean. By contrast some

Fig. 13 Scatter plot of ratio of grain:weed and hulled + immature:mature *Setaria* in log scale in the Sushui valley



communities shifted towards a smaller scale, and focused level of crop processing, which included some storage before winnowing. Zhang et al. (2010) found that in the Ying valley sites that were more closely networked socially were more likely to have similar patterns in terms of crop-processing patterns. This, in turn, suggests that diversification in crop-processing practices, including many households driven to small-scale practices only, accompanied increasing social complexity. Parallel patterns have been postulated in relation to social evolution in other world regions (Fuller and Stevens 2009).

In order to further investigate crop-processing patterns suggested above, the ratio of hulled and immature:clean mature *Setaria* is plotted against grain:weed ratio for individual samples (Fig. 12). Hulled *Setaria* and immature *Setaria* are summed together and divided by clean mature *Setaria.* Both *Setaria italica* and *Setaria viridis* types are included in the ratio. In Fig. 12, there is a division among individual samples which is suggested to represent samples with regular input of both primary winnowing waste and dehusking waste (towards upper left) versus those mainly dehusking waste (towards lower right). The Yangshao and Miaodigou II samples fall on the left bottom corner and show a general consistency in terms of the grain:weed ratio, below 15, and in hulled and immature to clean *Setaria* ratio, below 1. However, among the Longshan and Bronze Age samples, there is a much greater range of variation. Some are similar to those Yangshao and Miaodigou II samples while some are quite different with a higher proportion of hulled and immature grains indicating early crop-processing waste and others with higher grain:weed ratio showing characteristics of later processing stage. In general, there seems to be a shift from Yangshao and Miaodigou II uniformity, with relatively lower proportion of hulled and immature gains and grain:weed ratio, to the Longshan and Bronze Age periods when there are evident differences between sites, with some having significant inputs of winnowing by-product but others not. The occasional distant outlier, such as the samples on the top left from Longshan period and bottom right from Erlitou period, may represent only winnowing waste or dehusking waste. It may also be the case that samples on the top left that are immature grain rich represent poor harvests, i.e., of crops that have failed to fill their grains well.

If we look at the samples using a logscale (Fig. 13), which can help to highlight distinctions among samples, a shift from the Yangshao and Miaodigou II uniformity to the Longshan and Bronze Age diversity is seen more clearly, and outliers can also be recognized. The Yangshao and Miaodigou II samples show a higher proportion of grains and a lower proportion of immature and hulled *Setaria*, which suggests the late stages of crop processing (i.e., dehusking) are represented. Nevertheless, among the Longshan period and Bronze Age samples, we find some contrary indicators, i.e., a higher proportion of immature and hulled *Setaria* and a higher proportion of grains. In some samples that have a very high proportion of grains, this could indicate increasing presence of dehusking waste or a shift in harvesting method towards panicle cutting that reduces weed acquisition. It also should be noted that there is an exception in the Yangshao samples, which falls in the left bottom rectangle. The composition of the sample may be significant; the majority of seeds in the Yangshao outlier belong to *Chenopodium* and *Portulaceae*, which usually produce large numbers of seeds per plant, which may, therefore, sometimes bias samples towards high representation of these particular weeds. As for the outliers in the Bronze Age, two groups could be separated, one group towards the upper left and the other towards the lower right. The composition of the samples in the upper left group tends to have more immature grains and more weeds which might indicate more input of early stages of crop processing while the group in the lower right shows the characteristic of more grains and less weeds which could represent dehusking waste. The overall pattern shown in this graph could suggest that there are variations in the proportions of immature grains included in the stored crops, for example, the group of samples in the lower right and lower left, both representing mainly late stages of crop-processing waste, show different ratios of immature grains. The greater variation in Longshan period and Bronze Age might indicate the differences in treating immature grains among individual households. Some might incorporate more immature grains by repeating the process to the crop processing by-product. Some might only carry out one-off processing and therefore leave most immature grains as a by-product. Another possibility is the differences between households/communities in terms of field quality meant that some were more prone to poor grain filling and thus had higher levels of immature grains. With the apparent expansion of population during the Longshan period (Wagner et al. 2013), one can expect more pressure on land and some resorting to poorer field conditions. In contrast, during Yangshao and Miaodigou II, crop processing might be conducted on a communal basis, and fields may have been situated in more uniform conditions, and therefore, there was less variation among individual households.

Conclusions

In summary, survey archaeobotany in the Sushui valley indicates that millet agriculture dominated plant subsistence in this region from the Yangshao period to the Bronze Age with foxtail millet as the principal crop followed by broomcorn millet. Rice might be cultivated locally on a limited scale but it declined from the Longshan period. Wheat might be incorporated into the cropping system during the Longshan period but it was apparently a minor component.

A preliminary analysis of crop-processing practices suggests that there might be a division in the organization of agricultural labor from the Longshan period onwards. Overall, a shift from the Yangshao and Miaodigou II uniformity to the Longshan and Bronze Age diversity is seen in these data, in parallel to that suggested for the Ying valley (Fuller and Zhang 2007; Zhang et al. 2010). This is inferred to reflect differences in access to agricultural laborers. The indicators of late stages of crop processing in Yangshao and Miaodigou II may suggest crops experienced early processing on a large scale before being stored and then final crop processing (dehusking) was conducted on a daily basis in different individual households. By contrast in the Longshan period and Bronze Age, the situation was more complex, with variation among sites and or even within sites in terms of mobilization of post-harvest labor and practices in terms of how crops were stored or how much crop processing was necessary on a routine, daily basis. On some sites, crops may have been processed on a large scale at harvest, with fewer stages of crop processing being practiced regularly (post-storage) on site. This was the typical pattern in the earlier (Yangshao and Miaodigou II) periods and suggests a more communal or semi-communal pattern of organization. On some sites of the later periods, some labor mobilization appears to have been on a smaller, focused scale, with less processing achieved at harvest and before storage. It may be the case that crop processing in such cases was conducted on a small scale because it was organized on the individual household basis, in which available labor was limited and more stages of processing had to be done piecemeal as crop was needed. This difference suggests that there was a more restricted ability for mobilizing of larger labor forces at harvest, found at only some Longshan and Bronze Age sites or some sub-groups on those sites. This may, in turn, reflect increasing differences in wealth between households. We have also suggested that some variation, especially in terms of higher levels of poorly filled millets (immature grains), may indicate less ideal field conditions (poorer locations in terms of soil and water) for some households or communities in later periods. The presence of high levels of immature grains also suggests that some fields at least suffered from poor soil conditions, suggesting that soil fertility maintenance, for example through manuring, was insufficient. Therefore, the shifts in crop-processing activity signatures appear to be symptomatic of changes in the social organization and how labor was mobilized, changes which occurred in the Longshan period and continued through the Bronze Age.

The rapidly expanding archaeological record of central China and the increasing inclusion of archaeobotanical sampling has much to contribute to the characterizing economic aspects of the emergence of social complexity and the first Chinese states (e.g., Lee et al. 2007; Yuan and Campbell 2009; Zhao 2010). Given that similar patterns have been found in other parts of the central China (Fuller and Zhang 2007), we conclude that archaeobotanical data, even from survey projects, can contribute not just to characterizing the content of agricultural economies (staple crops and fruit trees) but also to the aspects of the organization of those economies. The archaeobotanical analysis reported above complements other lines of archaeobotanical evidence, including increasing population size (Wagner et al. 2013), increasing site size hierarchy and craft specialization (e.g., Liu 2004; Liu and Chen 2012; Barnes 2015). Other factors include the adoption and increasing importance of cattle and sheep (e.g., Dai et al. 2016). By considering patterns of change in how crops were processed and stored, and inferring degrees of investment in soil fertility, archaeobotany has much to contribute to the study of social change.

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