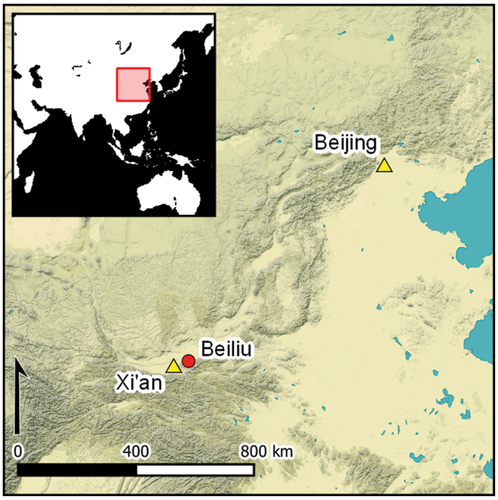
Antiquity 2024 Vol. 98 (402): 1505–1521
https://doi.org/10.15184/aqy.2024.190

Research Article

Early Neolithic plant exploitation in north-western China: archaeobotanical evidence from Beiliu

Hui Zhou[1,2], Xiaoqing Wang[3,*] & Zhijun Zhao[4,*]

[1] Shaanxi Academy of Archaeology, Xi'an, P.R. China
[2] School of Cultural Heritage, Northwest University, Xi'an, P.R. China
[3] Institute of Archaeology, Chinese Academy of Social Sciences, Beijing, P.R. China
[4] Institute of Cultural Heritage, Shandong University, Qingdao, P.R. China
* Authors for correspondence ✉ wxq0270@sina.com & zjzhao@cass.org.cn



China was a centre for early plant domestication, millets in the north and rice in the south, with both crops then spreading widely. The Laoguantai Culture (*c.* 8000–7000 BP) of the middle Yellow River region encompasses a crucial stage in the transition from hunting and gathering to farming, yet its subsistence basis is poorly understood. The authors present archaeobotanical data from the site of Beiliu indicating that farmers exploited a variety of wild and cultivated plants. The predominance of broomcorn millet accords with other Neolithic cultures in northern China but the presence of rice—some of the earliest directly dated examples—opens questions about the integration of rice cultivation into local subsistence strategies.

Keywords: East Asia, Yellow River Valley, Laoguantai culture, archaeobotany, subsistence

Introduction

China is one of the major global centres of early agricultural development (Bellwood 2005). Rather than a rapid change in subsistence, however, research indicates that the transition to farming was a long and complex process (Smith 2006; Fuller 2007; Zhao 2011; Fuller *et al.* 2014a). To explain this 'middle ground' between hunting and gathering and an agricultural way of life, Smith (2001) proposed the concept of 'low-level food production', whereby cultures demonstrate a diverse suite of farming strategies (both with and without domesticated crops and animals) but which nonetheless cannot be considered fully agricultural societies. The origins of agriculture in China span several millennia (Zhao 2014), with evidence for cultivation as early as 10 000 years ago (Jiang & Liu 2006; Liu *et al.* 2011; Yang *et al.* 2012; Zhao *et al.* 2020) and the establishment of full agricultural societies by 5000 years

---

Received: 16 July 2023; Revised: 29 February 2024; Accepted: 6 April 2024

ago (Zhao 2010, 2017). Advances in archaeobotanical research are beginning to reveal the rich 'middle ground' of low-level food production in China.

Early millet farming in northern China is attested by at least five geographically separate but broadly contemporaneous cultural complexes *c.* 8000 cal BP (Xinglongwa, Cishan, Peiligang, Houli and Laoguantai) (Zhao 2014). The Neolithic Laoguantai Culture (老官台, *c.* 8000–7000 cal BP), which pre-dates the better-known Yangshao Culture (仰韶, *c.* 7000–5000 cal BP) was located in the middle Yellow River, extending along both the northern and southern flanks of its tributary, the Wei River (Zhang 2007) (see also online supplementary material (OSM) Table S1; Figure 1). Also called the Dadiwan or Baijia Culture, the Laoguantai is currently the earliest known archaeological culture in the Weihe Plain.

In comparison with the other four early Neolithic culture complexes of northern China, understanding of agricultural production in the Laoguantai Culture is relatively limited (Feng 1985; Ren 1995; Zhao 2005; Lu *et al.* 2009; Crawford *et al.* 2013). Sparse evidence of broomcorn millet from the Dadiwan site serves as the only definitive evidence for the cultivation of crops (Zhang & Lang 1983; Liu *et al.* 2004; Liu 2006; Barton *et al.* 2009; Zhang *et al.* 2010). Beiliu (北刘) is an Early Holocene Laoguantai Culture occupation site. Through the systematic floatation and analysis of plant remains from Beiliu, we are gaining greater insights into Laoguantai plant use exploitation. Given its proximity to Banpo (the type site for the earlier stage of the Yangshao culture), Beiliu therefore has the potential to reveal much about both the origins of agriculture in this region and the development of agricultural societies towards later Yangshao Culture. With this article, we therefore contribute to understanding of the development of early agricultural societies in northern China.

The middle-lower Yangzi River is widely considered to be the birthplace of rice agriculture in China and the initial stage of the origin of rice can be traced back to at least 10 000 years ago (Higham & Lu 1998; Crawford 2006). With Early Holocene climatic change and expansive Neolithic cultures, rice farming gradually extended beyond this centre of domestication, though our understanding of the timing and routes by which it spread north and west remains incomplete. For example, the date at which rice was first cultivated in the dry-farming region of the middle Yellow River and on the Weihe Plain is an open question not least because the recovery of rice grains in this part of north-west China could indicate the presence of wild rice, the importation of rice from more southerly regions, or the adoption and local cultivation of rice.

Here, we document charred plant remains from Beiliu, which include three grains of rice. We evaluate the role of this rice and other plant foods at the Early Neolithic Beiliu. Archaeological plant remains result from a variety of subsistence and taphonomic processes (Fuller *et al.* 2014b); by understanding the formation of the deposits containing these charred plant remains, it is possible to connect these archaeobotanical assemblages with specific human activities. In brief, we address the question: where does the subsistence economy of Beiliu sit within the middle ground of early food production in north-west China?

Beiliu and its archaeological context

The Beiliu site (34°22′21.8″N, 109°32′37.7″E) is located south-west of Beiliu village in Weinan, Shaanxi province, at the confluence of the Qingshui and Choushui rivers on a secondary terrace (Figures 1 & 2). From 2019 to 2022, the sixth Shaanxi Archaeology Team of

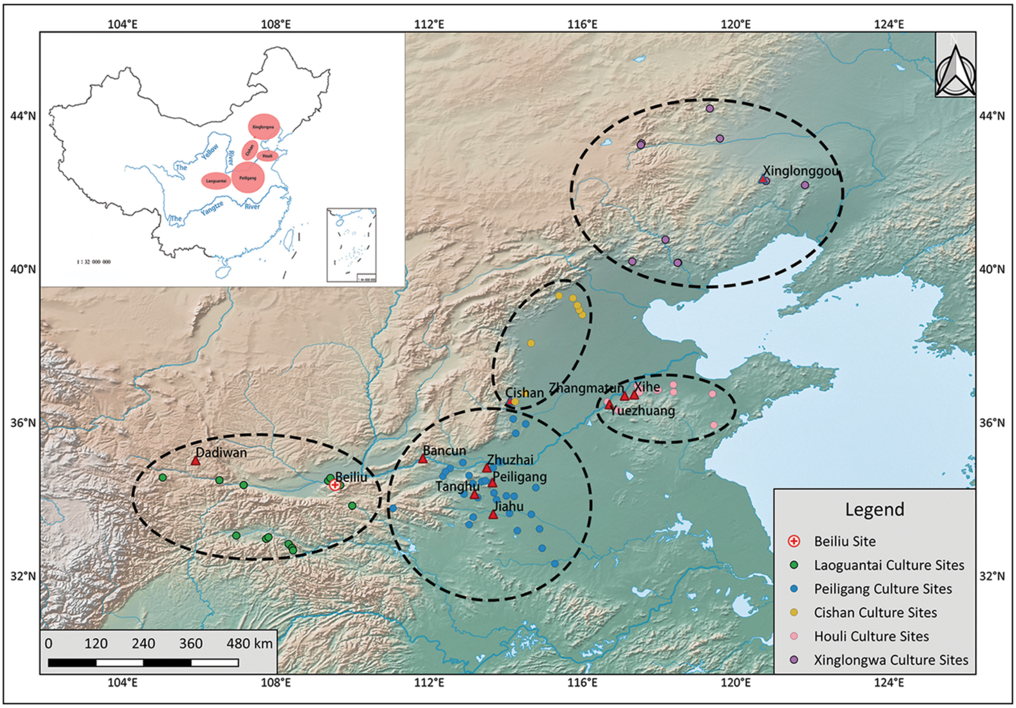


Figure 1. Early cultures and millet complexes of northern China (c. 8000 cal BP) and the location of the Beiliu site; red triangles represent typical archaeological sites of different cultural zones (map by H. Zhou).

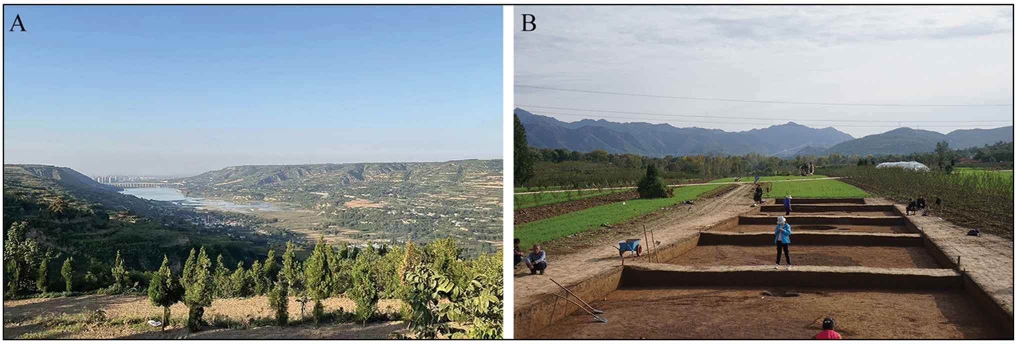


Figure 2. A) overview of the Beiliu site; B) on-site excavation (photographs by H. Zhou).

the Chinese Academy of Social Sciences and the Shaanxi Academy of Archaeology excavated an area of $500 m^2$ at the site, uncovering ash pits, house structures, hearths, kilns and burials. The main phases of the site relate to an earlier Laoguantai occupation (*c.* 8000–7000 cal BP) and a later Miaodigou Culture occupation (*c.* 6000–5500 cal BP). Here, we consider only the earlier of the two phases. The semi-subterranean house structures have square plans with rounded corners (Figure 3). Typical pottery finds include round-bottomed bowls (圜底钵), circle-footed bowls (圈足碗), three-legged bowls (三足钵) and three-legged

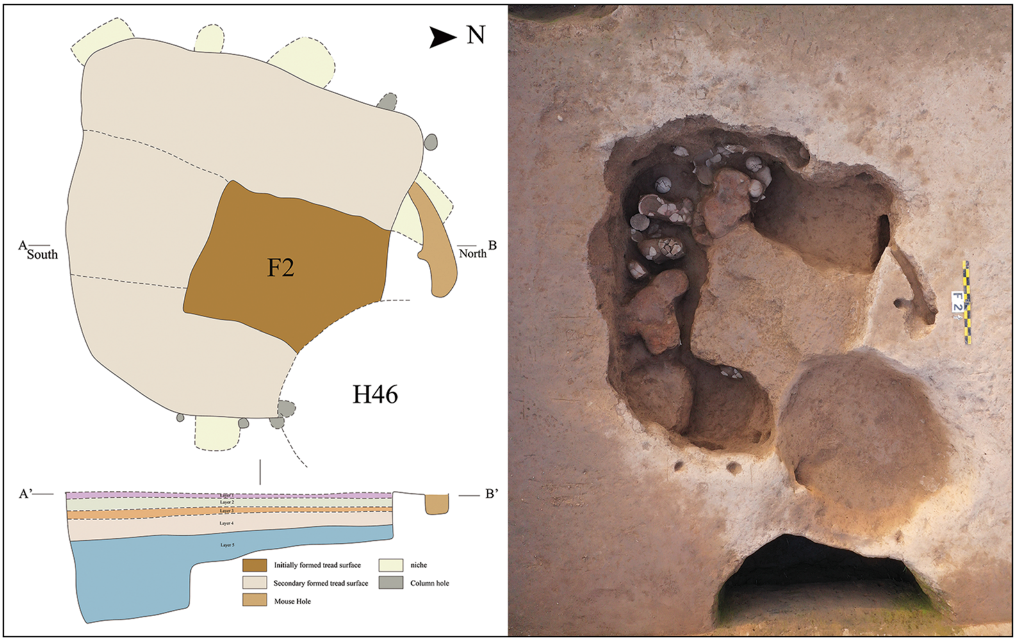


Figure 3. The plan, profile and location of house F2 (drawing by H. Zhou).

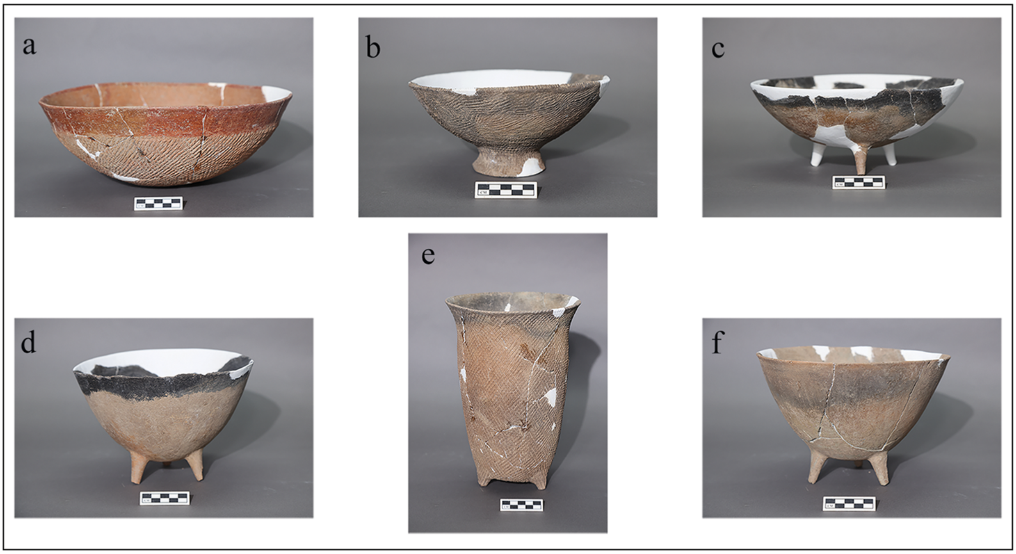


Figure 4. Laoguantai Culture pottery: a) round-bottomed bowl, huandi bo (圜底钵); b) circle foot bowl, quanzu wan (圈足碗); c, d & f) three-legged bowls, sanzu bo (三足钵); e) three-legged jar, sanzu guan (三足罐) (photographs by X.Q. Wang).

jars (三足罐) (Figure 4). Tools include bone spades (骨铲) and bone tilling tools (骨耜) for cultivation, stone (石刀) and shell knives (蚌刀) used for harvesting, and grinding stones (石磨棒) for food processing (Xi'an Banpo Museum *et al.* 1982, 1986). Preliminary on-site

Figure 5. A) sample collection; B) sample floatation (photographs by H. Zhou).

observations of the zooarchaeological finds indicate a diversity of animal remains including fish, shellfish, reptiles, small and large mammals, and birds.

Materials and methods

Plant remains at the Beiliu site were sampled in 2022 using both targeted and grid sampling methods. A total of 81 samples were collected from Laoguantai contexts: 14 from targeted sampling of the ash pits (Figure 5) and 67 from grid sampling of successive layers in house F2 (Figure 6). At least one soil sample of approximately 11 litres in volume was taken from each sampling unit.

Bucket floatation was carried out following Pearsall (2015) and Zhao (2004) using a 0.2mm mesh. After drying, flots were sent to the Archaeobotanical Laboratory at Northwestern University, Xi'an, for identification and analysis. Specimens were measured and photographed with a Nikon SMZ25 stereomicroscope. Plant remains are recorded by absolute number, percentage (the proportion of absolute numbers of different species in all samples) and ubiquity (the proportion of samples of a species unearthed in all samples). We follow the guidelines detailed by Pearsall (2015). In addition, six samples of charred seeds (Figure S1) were sent to the BETA laboratory for accelerator mass spectrometry (AMS) radiocarbon dating. This material includes five samples of broomcorn millet (each composed of 30 seeds) from house F2 and ash pit H57, and one sample of rice (containing two grains) from ash pit H52. All dates are calibrated by BetaCal4.20, high-probability density method, using the IntCal20 calibration curve (Reimer *et al.* 2020).

Results

The charred plant remains from Laoguantai contexts at Beiliu comprise three main categories, charcoal, charred seeds/fruit stones and fragments of nuts and acorns; seeds/fruit stones dominate the assemblage (Figure 7).

Charcoal

Charcoal analysis is an important part of archaeobotany, but in this paper we have only selected charcoal larger than 1 mm for weighing and have not yet done further research.

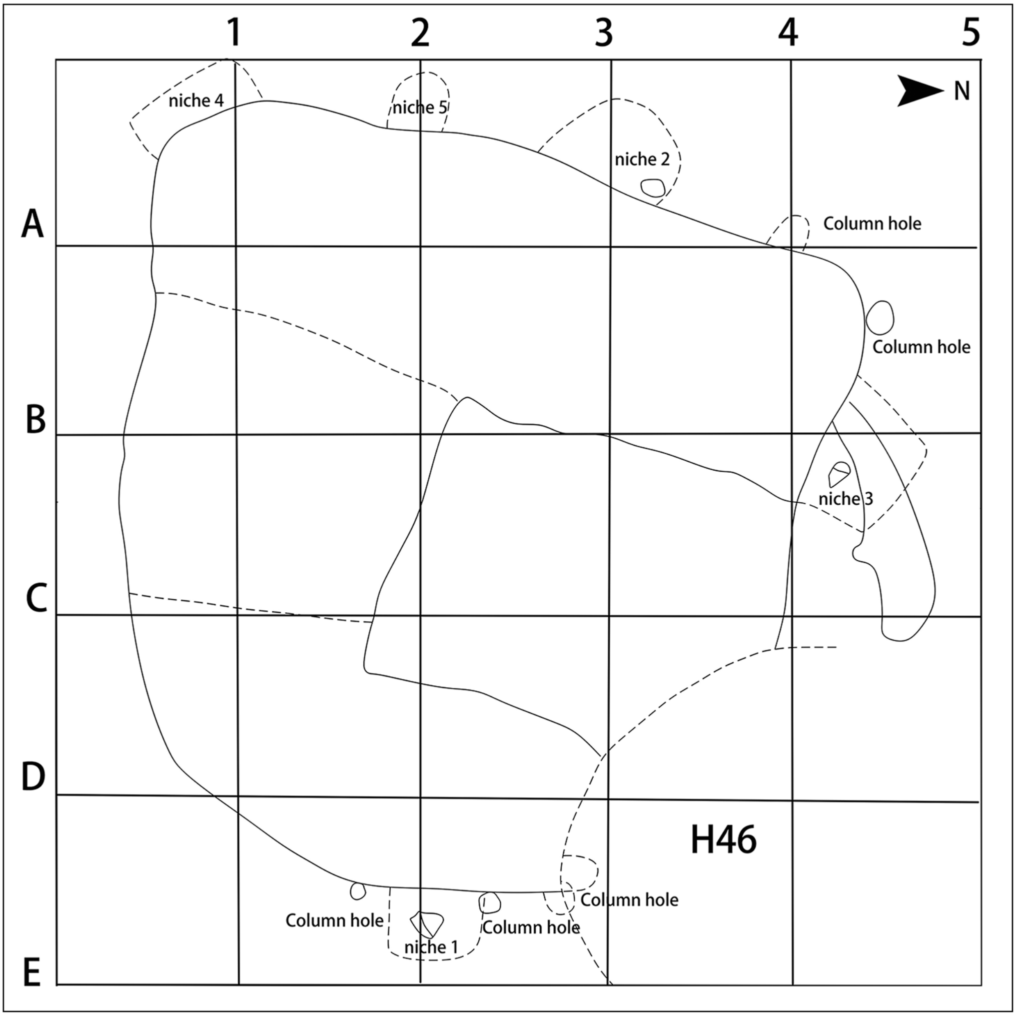


Figure 6. Grid plan of house F2 (drawing by H. Zhou).

Nuts and acorns

Fragments of the kernels from nuts and acorns (*Quercus* sp.) are present in large numbers. There are 44 acorn fragments, with a ubiquity of 28.6 per cent. In addition, there are 203 pieces of varying size that are too fragmented for identification.

Charred seeds/fruit stones

The plant seeds are divided into crop and non-crop categories (Table S2). The former include foxtail millet (*Setaria italica*, n = 24), broomcorn millet (*Panicum miliaceum*, n = 1805) and rice (*Oryza sativa*, n = 3) with a total of 1832 seeds, accounting for 93.3 per cent of the total

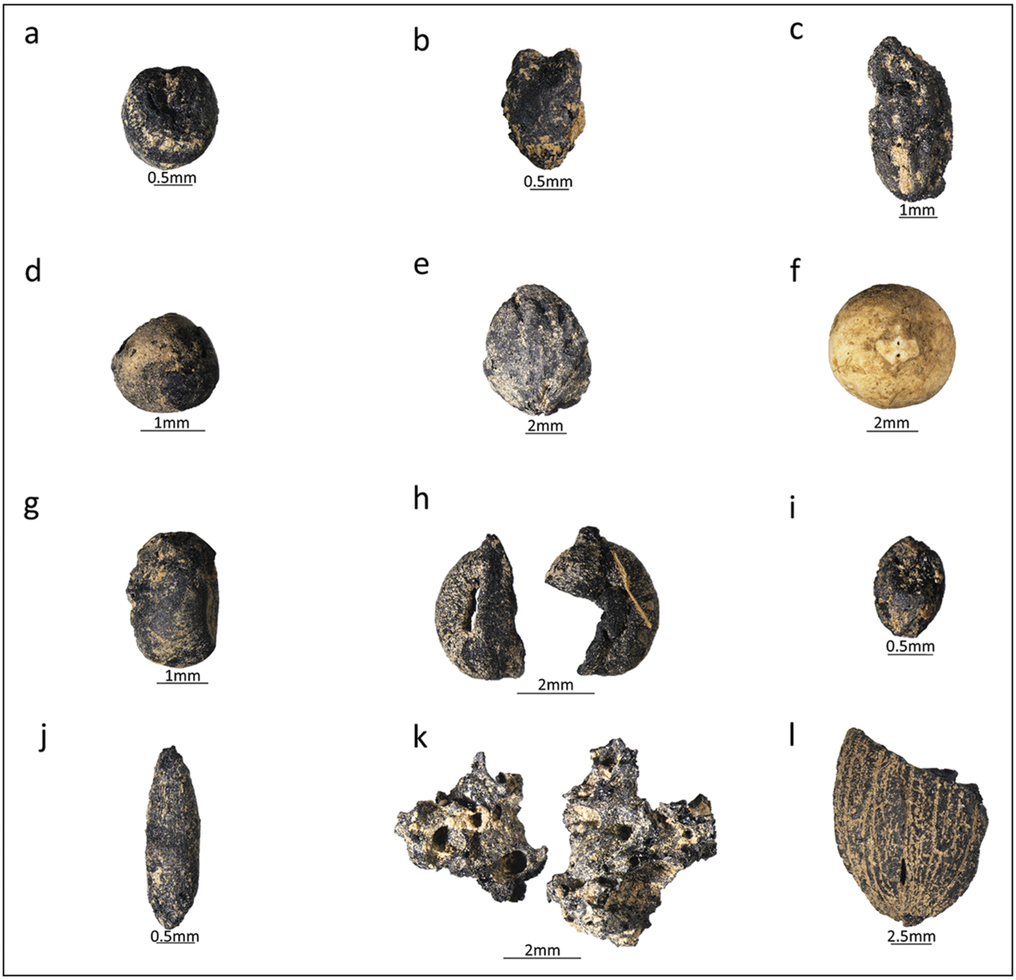


Figure 7. A selection of seeds, grains and plant remains from Beiliu: a) Setaria italica*; b)* Panicum miliaceum*; c)* Oryza sativa*; d)* Perilla frutescens*; e)* Ziziphus jujuba *var.* spinosa*; f)* Celtis sinensis*; g)* Glycine soja*; h)* Vitis vinifera*; i)* Setaria viridis*; j)* Poa annua*; k) clumps of broomcorn seeds; l)* Quercus *sp. (photographs by H. Zhou).*

seed assemblage. The three grains of charred rice (0.2% of the crop seeds, with a ubiquity of 2.5%) were concentrated in ash pit H52. One grain is complete and the other two damaged; measurements are shown in Table 1. Despite their small number, the presence of these grains is potentially significant.

Millets dominate the crop seeds, with broomcorn (98.5% of crops, ubiquity = 86.4%) substantially outnumbering foxtail (1.3% of crops, ubiquity = 21%) (Figure 8, Table S3). Both the foxtail and broomcorn seeds are relatively small; measurements from 40 complete charred broomcorn seeds give an average length, width and thickness of 1.52mm, 1.13mm and 0.99mm, respectively; this equates with an average length/width of 1.36 and an average length/thickness of 1.58 (see Table S4). In addition to the loose grains, 89 variously sized

Table 1. Measurement data of charred rice (mm).

Excavation units	Length	Width
H52①	4.35	1.99
H52②	4.70	2.36
H52②	4.24	2.11

compressed lumps of multiple broomcorn seeds, and 12 lumps of foxtail or broomcorn seeds were found in the soil samples (Figure 6k).

The non-crop species demonstrate a diverse range of species but the overall number of seeds is low, with 132 specimens, accounting for 6.7 per cent of the total seed assemblage. The non-crops can be divided into three broad categories: edible wild plants, weeds and other plant remains. Most seeds are from the edible wild plants, while weeds and other plant remains are relatively limited. Among the edible wild plants are 56 seeds of perilla (*Perilla frutescens*, 42.4% of non-crops, ubiquity = 15%), 24 seeds of Chinese date (*Ziziphus jujuba* var. *spinosa*, 18.2% of non-crops, ubiquity = 6.2%), 5 seeds of wild soybean (*Glycine soja*, 3.8% of non-crops, ubiquity = 4.9%), 4 seeds of Chinese hackberry (*Celtis sinensis*, 3.0% of non-crops, ubiquity = 1.2%) and 2 grape seeds (*Vitis vinifera*, 1.5% of non-crops, ubiquity = 1.2%). The weed species include hairy crabgrass (*Digitaria sanguinalis*), green foxtail (*Setaria viridis*) and annual meadow grass (*Poa annua*). Additionally, there are other identifiable plant seeds, such as grass-leaved saltwort (*Suaeda glauca*), summer cypress (*Bassia scoparia*), shrubby bushclover (*Lespedeza bicolor*) and yellow sweet clover (*Melilotus officinalis*). These seeds are not included in our analysis due to the small numbers of seeds and the wide geographical distribution of the plants that produce them.

Chronology

The AMS dates all calibrate to *c*. 7500 cal BP, consistent with their archaeological context. The five dates on broomcorn millet are statistically contemporaneous, falling between 7619 and 7427 cal BP (at 95.4% probability). The date of the rice sample, at 7570–7431 cal BP (95.4% probability), is contemporaneous with the millet dates (Table 2).

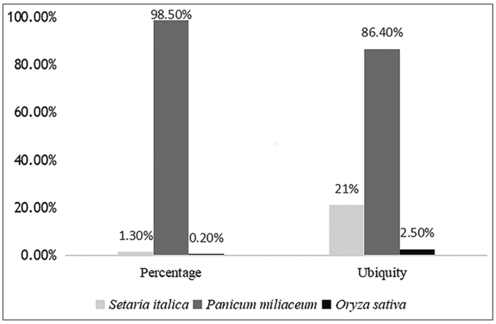


Figure 8. The relative percentage and ubiquity of crop seeds from Laoguantai Culture contexts at Beiliu (figure by H. Zhou).

Discussion

Subsistence strategies at Beiliu

Analysis of the plant remains demonstrates the importance of both cultivated and gathered plants at Beiliu. Acorns, Chinese date, Chinese hackberry, wild soybean and grape are particularly significant as collected wild foods, which provide valuable information for exploring subsistence patterns and agricultural development. Macrobotanical studies have identified *Quercus* sp. acorns

Table 2. AMS radiocarbon dates processed on samples from Beiliu.

Lab no.	Sample (charred seeds)	Excavation units	Relative age	Conventional age (BP)	Calibrated age (BP) (95.4%)
Beta-658071	Broomcorn millet (30)	H57	Laoguantai Culture	6630+/-30	7573–7432
Beta-658072	Rice (2)	H52②	Laoguantai Culture	6620+/-30	7570–7431
Beta-658073	Broomcorn millet (30)	F2②	Laoguantai Culture	6580+/-30	7562–7427
Beta-658074	Broomcorn millet (30)	F2③	Laoguantai Culture	6640+/-30	7576–7432
Beta-658075	Broomcorn millet (30)	F2⑤	Laoguantai Culture	6620+/-30	7570–7431
Beta-658076	Broomcorn millet (30)	F2⑤ braised clay	Laoguantai Culture	6700+/-30	7619–7505

at many sites in China *c*. 8000 years ago (Zhao & Zhang 2009; Deng & Gao 2012; Wang *et al*. 2018), and starch grain studies also suggest that these were an important dietary staple in the early and mid-Holocene (Liu *et al*. 2010, 2011). Acorns of *Quercus* sp. are often bitter, requiring processing before they can be consumed. As a result, they are generally not consumed in large quantities. With the emergence of farming practices, the role of acorns in subsistence gradually decreased (Zhao & Zhang 2009).

One ash pit (H52) contained a large number of perilla seeds and millet grains, suggesting that both plants were probably important dietary resources for the site's inhabitants. Further fruits, including Chinese date (likely of the wild variety), Chinese hackberry and grape, also probably served as essential wild food resources.

The numbers of weed species identified in Laoguantai contexts at Beiliu are much lower than those recorded at sites in the middle Yellow River of the subsequent Yangshao period (*c*. 7000–5000 cal BP) (Zhao 2017; Zhong *et al*. 2020). This potentially reflects the relatively low level of agricultural development at Beiliu at the time. Cultivation appears to have focused on broomcorn millet with some evidence for the cultivation of foxtail millet, consistent with archaeobotanical evidence from other sites of this date (see below). The inhabitants of Beiliu also appear to have collected edible wild plants to supplement cultivated crops. This subsistence strategy reflects a low level of agricultural production that fits within the protracted and complex transition from hunting and gathering to farming (Bestel *et al*. 2018; Stevens *et al*. 2021). The location of Beiliu, set between mountains and river valleys, provided an amenable environment for the transition from fishing, hunting and gathering to agriculture.

Character and development of Laoguantai agricultural production

Broomcorn and foxtail millets belong to the typical dry-land agricultural tradition associated with historical northern China. A similar dominance of broomcorn millet over foxtail millet is observed at sites contemporaneous with Beiliu elsewhere in northern China during the Peiligang period (*c.* 9000–7000 cal BP) (Stevens *et al.* 2021; He *et al.* 2022). These include Xinglonggou, in Inner Mongolia, associated with the Xinglongwa Culture (Zhao 2011); Yuezhuang, a Houli Cultural site in Shandong Province (Crawford *et al.* 2013); Zhuzhai, a Peiligang Culture site in Henan Province (Bestel *et al.* 2018), Dadiwan of the Laoguantai Culture in Gansu Province (Liu *et al.* 2004; Barton *et al.* 2009; Bettinger *et al.* 2010); and Cishan, associated with the Cishan Culture in Hebei Province (Lu *et al.* 2009). Systematic floatation has been carried out at Xinglonggou, Yuezhuang, Zhuzhai and Dadiwan (Barton 2009), as well as at other contemporaneous sites (Shelach-Lavi *et al.* 2019). At Cishan, phytoliths of broomcorn millet are more common in early cultural layers, but no charred grains have yet been found (Lu *et al.* 2009). The number of millet grains recovered from these broadly contemporaneous sites is very low, however, and only Zhuzhai, with 358 grains recovered from across multiple contexts, approaches the size of the archaeobotanical assemblage at Beiliu.

The archaeobotanical assemblage from Beiliu is in keeping with a general trend observed in contemporaneous cultures in northern China: broomcorn millet appears to have been relatively more important than foxtail millet in the early stages of food production between *c.* 8000 and 7000 years ago. The results from Beiliu fill the gap in our understanding of food production in the Laoguantai Culture of the middle Yellow River and confirm that dryland agriculture in northern China was characterised by an early predominance of broomcorn millet and a later rise in foxtail millet (He *et al.* 2022). Thus, Beiliu demonstrates that the development of agriculture at various sites in northern China *c.* 8000 years ago was generally synchronous, with distinct early dry farming economies at similar levels of development.

The broomcorn grains found at Beiliu are shorter and narrower than those from later Neolithic sites, and their overall size is generally consistent with that of the Xinglonggou and Yuezhuang samples (Figure 9). This change in the size and shape of broomcorn millet grains through the Neolithic has been noted previously and attributed to developments in domestication and cultivation practices (Bestel *et al.* 2018; Stevens *et al.* 2021). Direct AMS dating of the seeds shows that the broomcorn millet unearthed at Beiliu are among the oldest dated broomcorn remains in China. Therefore, we suggest that the broomcorn at Beiliu is representative of an early form of cultivated/domesticated broomcorn, with the seeds retaining strong wild ancestral characteristics.

Implications of rice finds at Beiliu

Scholarly consensus suggests that domesticated rice originated in the middle and lower Yangzi Valley, but there are still many questions regarding the timing, pathways and modes of its subsequent outward spread (Wu 1998; An 1999; Qin 2012). The discovery of rice in Early Neolithic contexts at sites in the Yellow River basin and Shandong Province are generally considered to indicate the early dispersal of rice (Zhang 2011; Zhang & Hung 2013). Rice is present in the Yangshao period in the Yellow River basin but its contribution to subsistence appears relatively minor (Stevens & Fuller 2017). In subsequent periods rice continued to play a limited role in this region (Deng *et al.* 2020), although it increased in importance in Central China (Li *et al.* 2020).

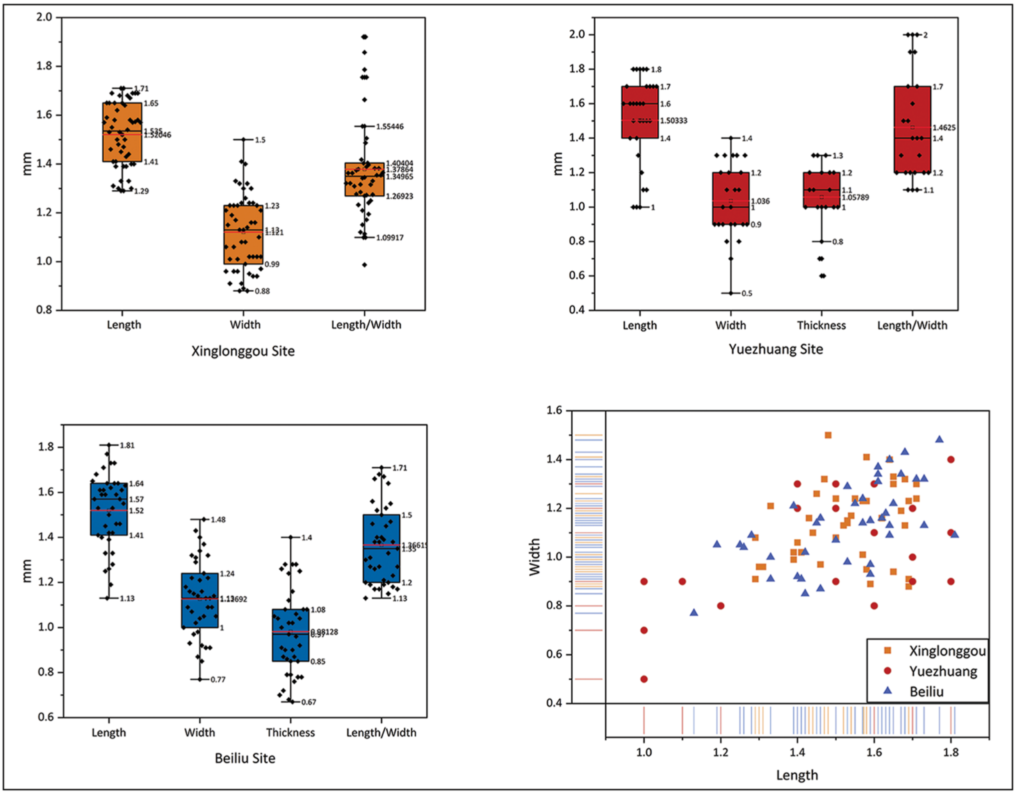


Figure 9. Measurement of broomcorn millet grain size at Xinglonggou, Yuezhuang and Beiliu (mm) (figure by H. Zhou).

The presence of rice at Beiliu is therefore significant, particularly as direct radiocarbon dating provides confirmation that these are the earliest charred rice grains yet found in the middle Yellow River Valley. Previous studies have suggested that rice appeared in the Yellow River basin as early as 9000–7000 years ago, with charred rice grains recovered from both Yuezhuang (Crawford *et al.* 2013) and Xihe (Jin *et al.* 2014) in the lower Yellow River Valley, and from Zhuzhai in the middle valley (Bestel *et al.* 2018), though the Zhuzhai date is based on associated charcoal rather than directly on the rice grains. Prior to the evidence from Beiliu presented here, the earliest charred rice found in the Weihe Plain is from Yuhuazhai, *c.* 7000 to 6000 years ago (Zhao 2017). From the Weihe Plain, rice may have then spread further westward along the Wei River and into the upper Yellow River Valley *c.* 5500–5000 years ago (Zhang & Wang 2000; Li *et al.* 2007).

Based on the direct dating of grains, the sites of Yuezhuang and Xihe show that rice dispersed northwards into the lower Yellow River Valley *c.* 8000–7700 years ago, and Beiliu suggests that it spread to the middle valley *c.* 7500 years ago. Phytoliths and charred grains from Tanghu provide new evidence of mixed broomcorn and rice cultivation in the middle Yellow River Valley, *c.* 7800 cal BP (Zhang *et al.* 2012). Although here, again, dating is based on associated charcoal rather than the charred rice.

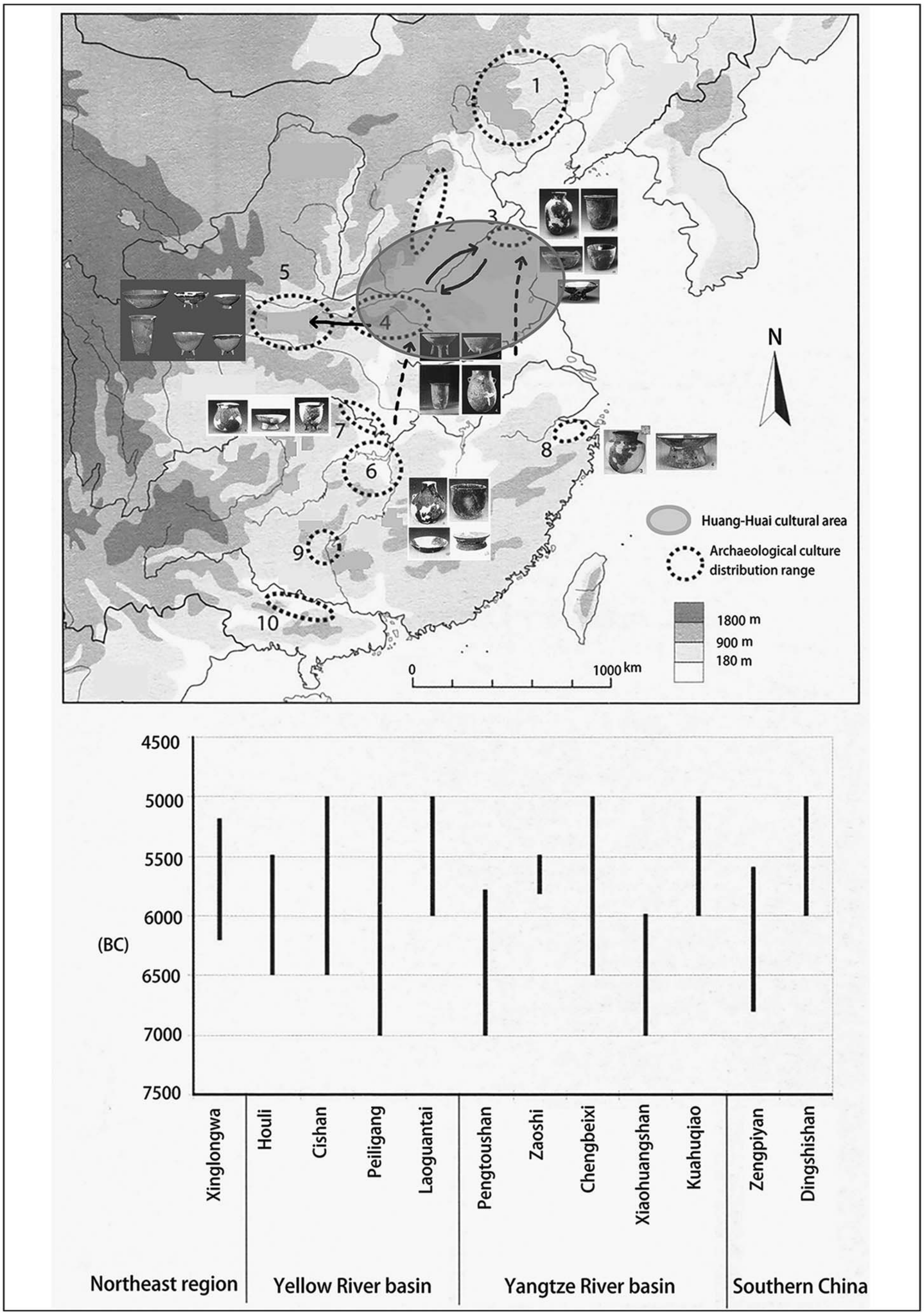


Figure 10. Early Neolithic cultures in China, 7000–5000BC and the expansion of rice agriculture northwards to the middle and lower Yellow River: 1) Xinglongwa Culture; 2) Cishan Culture; 3) Houli Culture; 4) Peiligang Culture; 5) Laoguantai Culture; 6) Pengtoushan-Zaoshi Culture; 7) Chengbeixi Culture; 8) Xiaohuangshan-Kuahuqiao Culture; 9) Zengpiyan Culture; 10) Dingshishan Culture; after Liu and Chen (2012, figs. 5.1, 5.2) (map by H. Zhou).

The period *c.* 9000–7000 BP was the first major expansion of rice resources in China, though the nature of this expansion is unclear. It is possible that changing climatic conditions during this period permitted an expansion of the natural distribution range of wild rice (e.g. into Shandong Province, d'Alpoim Guedes *et al.* 2015) or the extended range might be the result of cultural transmission and human migration (Zhang 2011). In either case, this expansion enabled the utilisation of rice resources in the Huang-Huai cultural area (Qin 2012). No evidence of wild rice has been found on the Weihe Plain so far. Cultural exchanges are, however, apparent between the Houli Culture in the Haidai area and the Xiaohuangshan-Kuahuqiao Culture in the lower Yangzi Valley, as well as between the Laoguantai and Peiligang cultures in the middle Yellow River Valley, and Pengtoushan-Zaoshi and Chengbeixi cultures in the middle Yangzi Valley in the same period. The appearance of rice on Weihe Plain during this period is therefore more likely to represent its introduction from neighbouring regions than local domestication. It is worth reiterating that the process of domestication takes a long time (Fuller *et al.* 2014a). So it represents only the introduction of rice rather than the gathering or domestication of local wild varieties. We therefore consider the rice from Beiliu as a product of cultivation (Figure 10).

The Beiliu rice grains inform understanding of spatial and temporal patterns in the spread of this species in the Yellow River basin, filling a gap in the route of rice transmission moving north and west across China. The limited presence of rice at Beiliu indicates that it was not the dominant crop in cultivation and consumption in the middle Yellow River *c.* 9000–7000 BP. Rice is a wetland crop, that can tolerate a relatively broad temperature range but requires an abundant water source. The Yellow River basin is a traditional millet farming area, with reduced water availability compared to southern China. Yet the discovery of rice at Beiliu may indicate that environmental conditions were different during the Early Holocene, including climate, landform, soils and hydrology.

Palaeoenvironmental analyses indicate that the climate of the Weihe River basin was warm and humid during the Laoguantai period, supporting the growth of a temperate, deciduous broad-leaved forest (Lu & Zhang 2008). The Beiliu site is located on a secondary terrace, where river channels intersect, a place of abundant water and fertile soils ideal for rice cultivation. The alluvial plain may also have afforded higher levels of sedentism, which could have provided an opportunity for farmers to integrate rice cultivation alongside early dry farming. The moist and low-lying microenvironment of the site, and the humid and rainy climate of the Holocene Climate Optimum, provided the conditions necessary for the cultivation of rice by the Laoguantai people. The coincidence of suitable growing conditions raises the strong possibility that rice was cultivated locally at this early date. However, the absence of spikelet bases at Beiliu, which can help distinguish between wild and domesticated rice and which are often discarded during rice processing, means that the exchange of processed grains from cultures further south must also remain a possibility.

Conclusion

Scientific sampling and systematic floatation has resulted in the collection of a relatively rich assemblage of charred plant remains from the early Neolithic site of Beiliu in northern China. Cultivated crops include foxtail and broomcorn millets and rice, while edible wild foods include acorns, Chinese date, Chinese hackberry and grape. The Beiliu dataset provides an insight into the subsistence economy on the Weihe Plain during the 'middle ground' of the transition from hunting and gathering to farming. The results presented here add to growing understanding of Early Holocene subsistence regimes in northern China, situating Beiliu well along the continuum of farming. In common with other early Neolithic occupation sites in northern China, broomcorn millet dominates the Beiliu archaeobotanical assemblage, suggesting broad homogeneity in agricultural trajectories at this time. The direct dating of rice grains from Beiliu has provided one of the earliest known dates for charred rice grains in northern China. These findings therefore shed new light on the timing and routes by which rice cultivation spread from southern China and on the integration of this crop into local subsistence strategies in northern China; not later than 7500 years ago, rice was present on the Weihe Plain in the middle Yellow River Valley. The Beiliu site therefore contributes to our growing understanding of the long transition from hunting and gathering to food production in East Asia and beyond.

Acknowledgements

We thank the sixth Shaanxi Archaeology Team of the Chinese Academy of Social Sciences for collecting samples and Mr Jingang Yang for his help with seed identification. We acknowledge Liya Tang, Ruichen Yang, Kai Han, Wenbin Fu, Jiaqi Liu, Qianyi Lin, Anqi Yang and Xu Liu *et al.* for their help with their suggestions on the drafts. We are also grateful to Xiaowen Chang for assistance in mapping and to Ximan Wang and Jin Su for help in reviewing the details of the article.

Funding statement

This research was funded by the Innovative Project of the Institute of Archaeology, Chinese Academy of Social Sciences Archaeological Research on the Transition from the Paleolithic to the Neolithic Period in the Middle Reach of the Yellow River 2021KGYJ002.

Online supplementary material (OSM)

To view supplementary material for this article, please visit https://doi.org/10.15184/aqy.2024.190 and select the supplementary materials tab.

References

An, Zhimin. 1999. The origin and eastward spread of rice-planting culture of China. *Wenwu* (*Cultural Relics*) 2: 63–70 (in Chinese).

Barton, L.W. 2009. Early food production in China's western loess plateau. Unpublished PhD dissertation, University of California, Davis.

Barton, L.W. *et al.* 2009. Agricultural origins and the isotopic identity of domestication in northern China. *Proceedings of the National Academy of Sciences USA* 106: 5523–28. https://doi.org/10.1073/pnas.0809960106

Bellwood, P. 2005. *First farmers: the origin of agricultural societies*. London: Blackwell.

Bettinger, R.L., L. Barton & C. Morgan. 2010. The origins of food production in north China: a different kind of agricultural revolution. *Evolutionary Anthropology: Issues News and Reviews* 19: 9–21. https://doi.org/10.1002/evan.20236

Bestel, Sheahan, Yingjian Bao, Hua Zhong, Xingcan Chen & Li Liu. 2018. Wild plant use and multi-cropping at the early Neolithic Zhuzhai site in the Middle Yellow River region, China. *The Holocene* 28: 195–207. https://doi.org/10.1177/0959683617721328

CRAWFORD, G.W. 2006. East Asian plant domestication, in M.T. Stark (ed.) *Archaeology of Asia*: 77–95. Oxford: Blackwell. https://doi.org/10.1002/9780470774670.ch5

CRAWFORD, G.W. *et al.* 2013. A preliminary analysis on plant remains of the Yuezhuang site in Changqing District, Jinan City, Shandong Province. *Jianghan Archaeology* 127(2): 107–16 (in Chinese).

D'ALPOIM GUEDES, J., GUIYUN JIN & R. KYLEBOCINSKY. 2015. The impact of climate on the spread of rice to north-eastern China: a new look at the data from Shandong Province. *PLoS ONE* 10. https://doi.org/10.1371/journal.pone.0130430

DENG, ZHENHUA & YU GAO. 2012. Analysis of the plant remains from the Bailigang site in Dengzhou, Henan. *Nanfangwenwu* (*Cultural Relics in Southern China*) 1: 156–63 (in Chinese).

DENG, ZHENHUA *et al.* 2020. Assessing the occurrence and status of wheat in Late Neolithic central China: the importance of direct AMS radiocarbon dates from Xiazhai. *Vegetation History and Archaeobotany* 29: 61–73. https://doi.org/10.1007/s00334-019-00732-7

FENG, SHENGWU. 1985. Origin of Chinese agriculture as viewed from Dadiwan cultural relics. *Acta Geographica Sinica* 40(3): 207–14 (in Chinese).

FULLER, D.Q. 2007. Contrasting patterns in crop domestication and domestication rates: recent archaeobotanical insights from the Old World. *Annals of Botany* 100: 903–924. https://doi.org/10.1093/aob/mcm048

FULLER, D.Q. *et al.* 2014a. Convergent evolution and parallelism in plant domestication revealed by an expanding archaeological record. *Proceedings of the National Academy of Sciences USA* 111: 6147–52. doi:10.1073/pnas.1308937110

FULLER, D.Q., C. STEVENS & M. MCCLATCHIE. 2014b. Routine activities, tertiary refuse and labor organization: social inferences from everyday archaeobotany, in M. Madella, C. Lancelotti & M. Savard (ed.) *Ancient plants and people: contemporary trends in archaeobotany*: 174–217. Tucson: University of Arizona Press.

HIGHAM, C. & TRACEY L.-D. LU. 1998. The origins and dispersal of rice cultivation. *Antiquity* 72: 867–77. https://doi.org/10.1017/S0003598X00087500

HE, KEYANG, HOUYUAN LU, JIANPING ZHANG & CAN WANG. 2022. Holocene spatiotemporal millet agricultural patterns in northern China: a dataset of archaeobotanical macroremains. *Earth System Science Data* 14: 4777–91. https://doi.org/10.5194/essd-14-4777-2022

JIANG, LEPING & LI LIU. 2006. New evidence for the origins of sedentism and rice domestication in the Lower Yangzi River, China. *Antiquity* 80: 355–61. https://doi.org/10.1017/S0003598X00093674

JIN, GUIYUN, WENWAN WU, HESI ZHANG, ZEBING WANG & XIAOHONG WU. 2014. 8000-year-old rice remains from the north edge of the Shandong Highlands, East China. *Journal of Archaeological Science* 51: 34–42. https://doi.org/10.1016/j.jas.2013.01.007

LI, WEI *et al.* 2020. Interdisciplinary study on dietary complexity in Central China during the Longshan period (4.5–3.8 kaBP): new isotopic evidence from Wadian and Haojiatai, Henan Province. *The Holocene* 31: 258–70. https://doi.org/10.1177/0959683620970252

LI, XIAOQIANG, JOHN DODSON, XINJING ZHOU, HONGBIN ZHANG & RYO MASUTOMOTO. 2007. Early cultivated wheat and broadening of agriculture in Neolithic China. *The Holocene* 17: 555–60. https://doi.org/10.1177/0959683607078978

LIU, C.J. 2006. Identification report of botanical remains at Dadiwan site, in Gansu Provincial Institute of Cultural Relics and Archaeology (ed.) *Dadiwan in Qin'an report on excavations at a Neolithic site*: 914–16. Beijing: Cultural Relics (in Chinese).

LIU, CHANGJIANG, ZHAOCHEN KONG & SHUDE LANG. 2004. Exploring the environment of agricultural plant remains and human survival at Dadiwan site. *Zhongyuan wenwu* (*Cultural Relics of Central China*) 4: 26–30 (in Chinese).

LIU, LI *et al.* 2010. The exploitation of acorn and rice in Early Holocene Lower Yangzi River, China. *Acta Anthropologica Sinica* 29(3): 317–36 (in Chinese).

– 2011. Plant exploitation of the last foragers at Shizitan in the Middle Yellow River Valley China: evidence from grinding stones. *Journal of Archaeological Science* 38: 3524–32. https://doi.org/10.1016/j.jas.2011.08.015

LIU, LI & XINGCAN CHEN. 2012. The archaeology of China from the late Paleolithic to the Early Bronze Age. Beijing: SDX Joint Publishing Company.

Lu, Houyuan & Jianping Zhang. 2008. Neolithic cultural evolution and Holocene climate change in the Guanzhong Basin, Shaanxi, China. *Quaternary Sciences* 28(6): 1050–60.

Lu, Houyuan *et al.* 2009. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. *Proceedings of the National Academy of Sciences USA* 106: 7367–72. https://doi.org/10.1073/pnas.0900158106

Pearsall, D.M. 2015. *Paleoethnobotany: a handbook of procedures*. Third edition. Walnut Creek (CA): Left Coast.

Qin, Ling. 2012. Phytoarchaeological research and perspectives on the origin of Chinese agriculture. *A Collection of Studies on Archaeology*: 260–315 (in Chinese).

Reimer, P.J. *et al.* 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62: 725–57. https://doi.org/10.1017/RDC.2020.41

Ren, Shinan. 1995. Important results regarding Neolithic cultures in China earlier than 5000 B.C. *Kaogu* (*Archaeology*) 1: 37–49 (in Chinese).

Shelach-Lavi, G. *et al.* 2019. Sedentism and plant cultivation in northeast China emerged during affluent conditions. *PLoS ONE* 14. https://doi.org/10.1371/journal.pone.0218751

Smith, B.D. 2001. Low-level food production. *Journal of Archaeological Research* 9: 1–43. https://doi.org/10.1023/A:1009436110049

– 2006. Documenting domesticated plants in the archaeological record, in M.A. Zeder, D.G. Bradley, E. Emshwiller & B.D. Smith (ed.) *Documenting domestication: new genetic and archaeological paradigms*: 15–24. Berkeley: University of California Press.

Stevens, C.J. & D.Q. Fuller. 2017. The spread of agriculture in eastern Asia. *Language Dynamics and Change* 7(2): 152–86. https://doi.org/10.1163/22105832-00702001

Stevens, C.J. *et al.* 2021. A model for the domestication of *Panicum miliaceum* (common, proso or broomcorn millet) in China. *Vegetation History and Archaeobotany* 30: 21–33. https://doi.org/10.1007/s00334-020-00804-z

Wang, Jiajing, Xueye Zhao, Hui Wang & Li Liu. 2018. Plant exploitation of the first farmers in northwest China: microbotanical evidence from Dadiwan. *Quaternary International* 529: 3–9. https://doi.org/10.1016/j.quaint.2018.10.019

Wu, Shichi. 1998. An introduction to the origin and development of primitive rice farming in China. *Agricultural Archaeology* 1: 87–93 (in Chinese).

Xi'an Banpo Museum *et al.* 1982. Brief report on investigation and trial excavation of Early Neolithic sites in Beiliu, Weinan. *Kaogu Yu Wenwu* (*Archaeology and Cultural Relics*) 4: 1–10 (in Chinese).

– 1986. Brief report of the second and third excavations at Beilu site in Weinan. *Prehistory* Z1: 111–28 (in Chinese).

Yang, Xiaoyan *et al.* 2012. Early millet use in northern China. *Proceedings of the National Academy of Sciences USA* 109: 3726–30. https://doi.org/10.1073/pnas.1115430109

Zhang, Chi. 2011. On the remains of the first stage of Jiahu Culture. *Wenwu* (*Cultural Relics*) 3: 46–53 (in Chinese).

Zhang, Chi & Hsiao-chun Hung. 2013. Jiahu 1: earliest farmers beyond the Yangtze River. *Antiquity* 87: 46–63. https://doi.org/10.1017/S0003598X00048614

Zhang, Dongju *et al.* 2010. Archaeological records of Dadiwan in the past 60 ka and the origin of millet agriculture. *Chinese Science Bulletin* 55: 1636–42. https://doi.org/10.1007/s11434-010-3097-4

Zhang, Hongyan. 2007. On the periodization and typology of the Laoguantai culture in the Weishui River valley. *Acta Archaeologica Sinica* 165(2): 153–78 (in Chinese).

Zhang, Jianping *et al.* 2012. Early mixed farming of millet and rice 7800 years ago in the middle Yellow River region, China. *PLoS ONE* 7. https://doi.org/10.1371/journal.pone.0052146

Zhang, Pengchuan & Shude Lang. 1983. The main harvest from 1978 to 1982 excavations at the Dadiwan site in Qin'an, Gansu. *Wenwu* (*Cultural Relics*) 11: 21–30 (in Chinese).

Zhang, Wenxu & Hui Wang. 2000. A study of ancient rice cultivation at the relic site of Qingyang, Gansu Province. *Agricultural Archaeology* 3: 80–85 (in Chinese).

Zhao, Zhijun. 2004. Flotation: a field technique of paleoethnobotany for recovering plant remains. *Kaogu* (*Archaeology*) 438(3): 80–87 (in Chinese).

– 2005. Discussion of the Xinglonggou site flotation results and the origin of dry farming in northern China, in Department of Arts and Letters, Nanjing Normal University (ed.) *Antiquities of* *eastern Asia A*: 188–99. Beijing: Cultural Relics (in Chinese).

– 2010. New data and new issues for the study of origin of rice agriculture in China. *Archaeological and Anthropological Sciences* 2: 99–105. https://doi.org/10.1007/s12520-010-0028-x

– 2011. New archaeobotanic data for the study of the origins of agriculture in China. *Current Anthropology* 52: S295–S306. https://doi.org/10.1086/659308

– 2014. The process of origin of agriculture in China: archaeological evidence from flotation results. *Quaternary Sciences* 34(1): 73–84 (in Chinese). https://doi/10.3969/j.issn.1001-7410.2014.10

– 2017. The development of agriculture in the time of Yangshao Culture and the establishment of agricultural society: an analysis on the flotation result of Yuhuazhai site. *Jianghan Archaeology* 153(6): 98–108 (in Chinese).

ZHAO, ZHIJUN & JUZHONG ZHANG. 2009. Report on the analysis of the results of the 2001 floatation of the Jiahu site. *Kaogu* (*Archaeology*) 8: 84–93 (in Chinese).

ZHAO, ZHIJUN *et al.* 2020. Results of floatation and analysis of floral remains from Donghulin site, Beijing. *Kaogu* (*Archaeology*) 634(7): 99–106 (in Chinese).

ZHONG, HUA, ZINWEI LI, WEILIN WANG, LIPING YANG & ZHIJUN ZHAO. 2020. Preliminary research of the farming production pattern in the Central Plain area during the Miaodigou period. *Quaternary Sciences* 40(2): 472–85 (in Chinese). https://doi.org/10.11928/j.issn.1001-7410.2020.02.17