



Agriculture, the Environment, and Social Complexity From the Early to Late Yangshao Periods (5000–3000 BC): Insights From Macro-Botanical Remains in North-Central China

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In northern China, the Yangshao cultural period (5000–3000 BC) was a critical timespan in the establishment of agricultural economies and the emergence of social complexity. We present the results of archeobotanical analysis from 58 soil samples collected from 12 recently investigated sites located in the Luoyang Basin, and recovered 5290 carbonized plant remains from 9 sites dating to the Late Yangshao period. We compared our novel dataset with previous archeobotanical data, compiling a total of 196 samples from 58 sites in central and western Henan Province. During the Early Yangshao period (5000–4200 BC), a nascent, extensive agricultural economy based primarily on broomcorn millet, with lesser foxtail millet and rice, was developing in small settlements (<0.2 km²) in the loess tablelands and valleys of western Henan province. However, the population pressure—rather than environmental degradation—drove the “foxtail millet-broomcorn millet substitution” during the Middle Yangshao period (4200–3500BC). The intensive agriculture based mainly on foxtail millet facilitated the development of social complexity in the region, as demonstrated by the emergence of size-graded agricultural settlements of medium (0.2–0.6 km²) and large (> 0.6 km²) scale. Notably, millets tend to be less ubiquitous in these larger settlements compared to smaller ones, with differences in millet ubiquity between sites increasing over time. The local surface hydrology influenced by paleoclimatic changes prompted the spread of agriculture from higher loess tablelands and valleys during the early Yangshao period into more marginal loess tablelands and plains by the Middle and Late Yangshao periods. Rice cultivation is concentrated in valley areas and appears to have been closely tied to environments with better hydrothermal conditions. Our research shows that climatic conditions during the Holocene fostered the development of agriculture during the Yangshao Culture period and that the distribution of settlements throughout this time was influenced by highly localized geomorphologic environments delimiting the distribution of crops. The

rise of agriculture promoted the formation of complex and stratified economies in the Yangshao Culture period and it was the intensification and elaboration of these new economic and social systems that led to later transformation in agricultural structures and settlement sizes.

Keywords: central and western Henan Province, Yangshao Culture, foxtail millet-broomcorn millet substitution, Valley-Rice Planting, paleoenvironment, social complexity

INTRODUCTION

The emergence of social complexity—or the process by which a society transitions from relatively simple to more complex forms of economic and social organization—has long been a subject of considerable interest and debate among archaeologists. Socially complex societies are generally associated with large and dense populations, urbanism, socio-economic specialization, and the appearance of social hierarchies and inequality (Adams, 2001; Smith, 2009; Feinman, 2011). Almost simultaneously, around 3500 BC dramatic changes to social and economic organization were occurring in many regions of the world (Sandweiss et al., 1999; Brooks, 2006; Liu and Chen, 2012; Luan, 2012) and archeological evidence of pronounced cultural differentiation as well as enhanced inter-community communication and exchange (Han, 2015) attest to similar transformations underway in China, with indications of increasing social complexity becoming more and more obvious through time (Zhao, 2001; Chen et al., 2003; Liu, 2005; Liu and Chen, 2012; Dai, 2012).

Characterized by a significant increase in settlements and the advent of mature millet cultivation practices in the Loess Plateau (Barton et al., 2009), the Yangshao Culture period (5000–3000 BC) is recognized as a critical timespan for understanding the rise of complex and socially stratified agricultural societies in Neolithic northern China (Zhao, 2001; Chen et al., 2003; Liu, 2005; Dai, 2012; Luan, 2012; Wagner et al., 2013). The critical interval of rapid cultural development and population growth that marks the initial rise and expansion of the Yangshao Culture in the Neolithic is often attributed to the warm and humid climatic conditions of the mid-Holocene Megathermal period—also termed the “Yangshao Warm Period” (Shi et al., 1992; Xia et al., 2001)—which is hypothesized to have facilitated the emergence of agricultural economies at this time (Wang J. H., 2005; Wang X. G., 2005; Gao, 2009; Zhao, 2014; Han, 2015).

In Henan province, social development has been characterized as a transition from initially egalitarian organization during the Early period (5000–4200 BC) that gradually becomes more complex, eventually transforming into a stratified society by the Middle and Late Yangshao periods (4200–3000 BC) (Zhao, 2001; Dai, 2012). Concurrent with these striking social changes was a transition away from hunting and gathering and the establishment of a subsistence economy based on the cultivation of domestic crops. This transition is demonstrated by a growing number of archeobotanical studies using both macro and micro-botanical plant remains that provide evidence for increasing dependence on foxtail (*Setaria italica*) and broomcorn (*Panicum miliaceum*) millets throughout the Yangshao cultural period, culminating with these small domesticated grains becoming

the foundation for Yangshao food production systems and representing the early formation of a mature agricultural system based on domestic millets (Lee et al., 2007; Zhao, 2014, 2017; Zhang et al., 2014; Wang, 2016; Zhong et al., 2020; Yang et al., 2020).

Social complexity has long been considered to be directly related to economic production systems (Tylor, 1958; Service, 1962; Mogan, 1963; Fried, 1967). For example, case studies from Southern Levant (Kuijt and Goring-Morris, 2002), Northern Negev of Israel (Winter-Livneh et al., 2010), and southwestern Asia (Algaze, 2001) have demonstrated the intimate connection between agriculture and social complexity. While the development of agriculture has been recognized as having a profound impact on complexification processes during the Yangshao Culture period (Yan, 1989; Gao, 2009; Cao, 2013; Han, 2015; Dai, 2016), discussions of how this is evinced in archeobotanical evidence from this period have been lacking in detail.

Additionally, factors constraining or facilitating the development of the agricultural practices associated with these social transformations are complex, which have been proposed by scholars as climatic changes (Dong et al., 2012; Yang et al., 2018), social complexification (Wang J. H., 2005; Gao, 2009; Zhong et al., 2020), or developments in agricultural technology (Fan, 1988; Gao, 2009; Zhao, 2018). Climate change is supposed to have a greater impact on agriculture at large spatial scales, but geomorphologic condition will be more influential at smaller, more local scales (Robert et al., 1989). Restricted by geomorphologic conditions, the distribution of prehistoric agriculture often changes with time. Studies in the Near East, for example, have shown that agriculture originates from marginal piedmont grasslands and transfers to valleys and lowlands (Binford, 1968; Flannery, 1973); Liu et al. (2009) and Ren et al. (2016) provided evidence that the distribution of both early millet in northern China and rice in southern China shifted from the foothills to the valleys. Despite a great deal of discussion surrounding the relationship between ancient agricultural developments and climate change (Jia et al., 2013; Yang et al., 2018; Zhang et al., 2018), there have been fewer studies of the relationship between agriculture and geomorphologic environments at different stages in prehistoric China (Zhang et al., 2014; Li and Zhang, 2020).

Furthermore, we know relatively little about changes regarding the agricultural economic structure or planting patterns as they occurred throughout the Yangshao period—ultimately hindering our understanding of economic conditions at this time and their relationship to cultural changes and the paleoenvironment. Situated within this gap in our understanding

is ongoing debate about whether or not foxtail millet substituted broomcorn millet as the dominant staple crop across the Yangshao Culture area, and the role such a substitution would have played in the establishment of an agricultural economy (Liu et al., 2008; Han, 2015; Wang et al., 2015; Wang, 2016; Lu, 2017; Zhong et al., 2020). Foxtail millet and broomcorn millet constitute the earliest domesticated crops in northern China, dating back to more than 8,000 years ago (Zhao, 2014). Archeobotanical research has shown that initially, during the early stages of millet domestication prior to 5000 BC, broomcorn millet was the prevailing crop (Liu et al., 2008; Lu et al., 2009; Zhao, 2011, 2014). Recent evidence from charred plant remains suggests that after 5000 BC—at the onset of the Yangshao culture—foxtail millet came to replace broomcorn millet as the primary domesticated crop (Wei, 2014; Zhao, 2014, 2017; Zhong et al., 2020). This shift, however, research on phytoliths has provided evidence for the continued dominance of broomcorn millet over foxtail millet throughout the Yangshao period in northern China, complicating interpretations (Wang et al., 2015, 2019a,b; Xia et al., 2016). Why Yangshao peoples would have shifted away from broomcorn millet and focused instead on foxtail millet is a complicated question that merits further discussion and investigation. One starting point toward comprehensively addressing this question is the implementation of systematic archeobotanical research on carbonized plant macro-fossils from multiple sites representing as many temporal phases belonging to the Yangshao Culture as possible.

Based on new archeobotanical analysis of 12 sites in the Luoyang Basin, in combination with a comprehensive dataset of macro-fossil remains from central and western of Henan Province compiled from previous research, we present a comprehensive picture of agricultural development as it occurred throughout the Yangshao culture period in northern China. Using these data, we discuss structural and geographical changes in the distribution of foxtail millet, broomcorn millet, and rice as they relate to (1) paleoclimatic changes, (2) geomorphologic conditions, (3) settlement sizes, and (4) social complexity.

STUDY AREA

Environmental Settings

Our research area consists of central and western Henan Province (110°21' 114°39' E, 33°31' 35°05') and is located at the transition between warm-temperate and subtropical ecozones, exhibiting a continental monsoon climate. The research area includes the Sanmenxia area, the Luoyang and Yiluo River basins, and Ying River basin (Figure 1).

The Sanmenxia area is located in western Henan Province, and has complex terrain consisting of mountains, loess plateaus, hills, rivers, and valleys. In addition to the Yellow River, the Luo, Hongnongjian, Qinglongjian, and Canglongjian rivers also have large tributary systems in this region. Average annual temperature is 13.9°C with annual precipitation around 550–800 mm. Soils of the Sanmenxia area are typified by obvious

vertical and horizontal stratification. Fluvo-aquic soil, cinnamon soil, yellow-brown soil, and brown soil are vertically distributed sequentially from the banks of the Yellow River down to the southern mountains (LCCSC, 1997; HPICRA, 2009).

The Luoyang Basin is located in the central part of Henan Province. In terms of geomorphology, moving from north to south the Luoyang Basin consists of the loessic Mangshan Mountains and the alluvial plain of the Yiluo River Valley to the north and eroded shallow loess piedmonts to the south. The hydrological system of the Luoyang Basin is the Yi, Luo, Jian and Chan rivers. Average annual temperatures is between 12.7 and 14.6°C, with annual precipitation of about 500–650 mm (IACASS and SAACATYRV, 2019). The soils here mainly include yellow-brown soil, brown soil, cinnamon soil, carbonate cinnamon soil, fluvio-aquic soil, and mountain meadow soil (Wang, 1999).

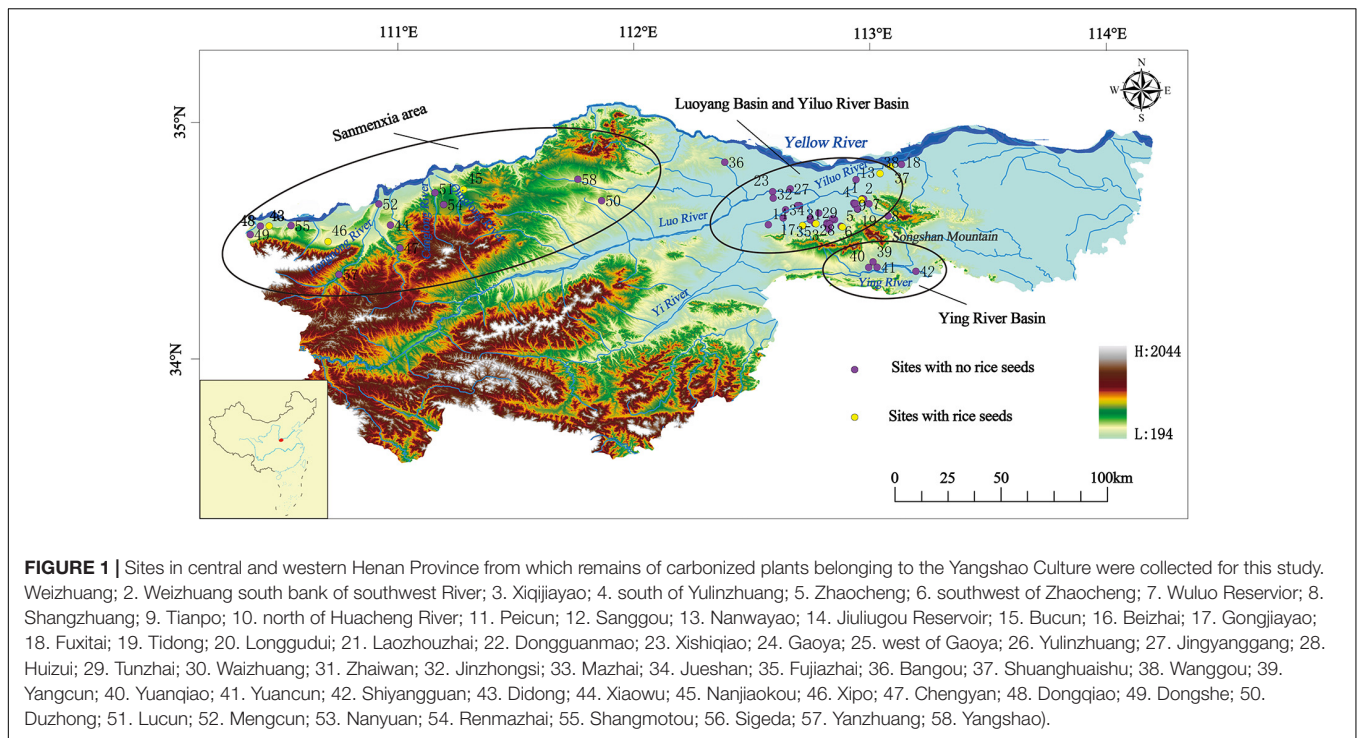
The Ying River Basin belongs to the central part of Henan Province, which consists of mountains, hills, basins, valleys and plains. The Ying River is the largest river in this region and has a highly developed tributary system. Average annual temperature is 14°C, with average annual precipitation about 600–700 mm (HPICRA et al., 2008). The soils in this area include brown loam, leaching cinnamon, carbonate cinnamon, cinnamon, aquic cinnamon and fluvio-aquic soil (Li, 1995).

Overall, the central and western Henan Province consist of a diverse array of landforms and soil types. The climate, topography, and geomorphology of the area make it suitable for the cultivation of a variety of thermophilic crops. River terraces in this area are generally flat with abundant water resources and abundant yellow fluvio-aquic soil that is rich in organic matter, allowing for the cultivation of wheat, rice, and maize. The gently sloping loess plateau area provides for sufficient water resources and adequate drainage and consists of a porous cinnamon-colored soil that facilitates modern wheat and corn-based agriculture. In contrast, the hilly piedmont areas have limited access to water and are characterized by cinnamon-colored and carbonate soils that are nutrient poor. Modern crop production in this area consists of mainly wheat, maize, and millet (Wang, 1999).

Archeological Settings

Chinese archeology began with excavations taking place in Yangshao, Mianchi County, Henan Province in 1921 (Andersson, 2011), making this region one of the earliest centers for archeological excavations and research on Neolithic China. After several generations of archeological inquiry, the Neolithic chronology for central and western Henan province was established, beginning with the Peiligang culture, followed by the Yangshao culture, and then the second phase of the Miaodigou culture—all of which made active contributions to the Neolithic archeological cultural system of Central China (Wei, 2014).

This article is concerned with agricultural developments during the Yangshao cultural period which lasted from approximately 5000 BC until 3000 BC. This can be further divided into three stages: Early Yangshao (5000–4200 BC) (Yan, 1989; Han, 2015), Middle Yangshao (4200–3500 BC) (Gao, 2009), and Late Yangshao (3500–3000 BC) (Yan, 1989; Gao, 2009; Han, 2015).



MATERIALS AND METHODS

Materials

In 2016, we carried out our field survey of carbonized archeobotanical remains belonging to the Yangshao period and collected samples from sites located around the Yiluo River Valley within the Luoyang Basin, including from localities near the Liujian River, Majian River, Gangou River, and other tributaries within the basin. From the exposed sections of each site, a trowel was used in the field to search for ash pits and cultural layers with a thickness of greater than 50 cm. Samples for flotation were then collected from bulk soil samples taken from these central part of ash pit deposits. On the basis of the established typology for this region, pottery recovered from these ash pits allowed us to make preliminary determinations of the cultural period that these deposits belonged to.

Our field sampling followed three principles: First, we selected as many sites as possible from different geomorphologic locations and different cultural ages. Second, in order to accurately determine where in the chronology of the Yangshao culture our samples derived from we only sampled ash pits with clear stratigraphic boundaries. Thirdly, we sampled only those pits without mixed assemblages containing material cultural remains from older or more recent periods (Zhang et al., 2014). Soil samples were taken from a total of 12 different sites: Peicun, Gaoya, Fujiazhai, Sanggou, Mazhai, Jueshan, Huizui, Zhaiwan, Jinzhongsi (Figure 1), Miaowan, Wutun, and Zhangcun. Altogether we sampled 28 ash pits from these sites, collecting 2–3 bags of soil samples (6–13 L/one bag) from each individual pit for a total of 58 bags of soil samples, and all used for flotation.

In addition to this original data, we also compiled the results of previous systematic archeobotanical research programs in this area (Supplementary Table 1), including the results of flotation studies from the Yiluo River Valley and on the regional plant remains of the Luoyang Basin (Zhang et al., 2014; IACASS and SAACATYRV, 2019). Archeological data was also extracted from previously published reports of plant remains from Yangshao sites located in Sanmenxia City (Zhao, 2011; Wei, 2014; Yang et al., 2020) as well as in the Yinghe River Basin in the Songshan region (AMPU and HPICRA, 2007; Zhong, 2016, 2018). The archeological sites discussed in this article are shown in Figure 1.

Methods

Flotation was performed on the collected soil samples with the use of a flotation station. Carbonized materials were collected using a 0.2 mm mesh sieve and were then set aside to dry. Once the materials were dry, they were sorted on the basis of size in the laboratory using 0.45, 0.75, 1, and 2 mm standard mesh sieves. Samples with particle sizes greater than 0.45 mm were selected and then sorted into preliminary categories with the aid of an optical stereo microscope. Carbonized samples and seeds were separated and put into sealed bags for analysis. Final taxonomic identification to the level of species of the archeobotanical samples separated at the previous step was carried out in the Archeobotany Laboratory at the Institute of Archeology, Chinese Academy of Social Sciences in Beijing. Each sample was then photographed and counted at this stage. Finally, we weighed and counted any charcoal, snail shell, and bone present in the samples.

As discussed previously, for each sample collected the relative age and archeological culture were assigned during field sampling on the basis of stratigraphic and typological material cultural

evidence present in the ash pit from which the individual sample was collected. To confirm these chronological assignments nine individual charred plant seeds of foxtail millet and rice were selected and sent to Beta Analytic for direct AMS ^{14}C dating.

$$R(w) = \frac{N(bm)}{N(fm) \div 2.26} \quad R(n) = \frac{N(bm)}{N(fm)}$$

To analyze the carbonized archeobotanical samples we calculated (1) ubiquity, (2) the ratio of broomcorn to foxtail millet, according to abundance, denoted as $R(n)$; and (3) the ratio of broomcorn to foxtail millet in terms of weight, denoted as $R(w)$.

Ubiquity refers to the probability that an individual plant species will be recovered from an archeological site and reflects the distribution of plant remains (Zhao and He, 2006). The ubiquity index is calculated as a percentage of the number of samples containing specimens of a given plant species relative to the total number of samples collected. In order to compare with other sites of systematic excavation, this paper separately calculated the three regional surveys in Luoyang Basin (Zhang et al., 2014; IACASS and SAACATYRV, 2019; this study) and the regional survey in Sanmenxia (Yang et al., 2020).

The second measure, $R(n)$, refers to the ratio of the absolute number of broomcorn millet specimens to the number of foxtail millet specimens. The third and final measure, $R(w)$, similarly refers to the ratio of broomcorn to foxtail millet but uses the relative weight of carbonized seeds for each species rather than the absolute number.

The average weight of 1,000 grains of broomcorn millet is 2.26 times the weight of 1000 grains of foxtail millet, meaning that the average number of individual grains in 1 g of foxtail millet is 2.26 times that of the average number of grains in 1 g of broomcorn millet (Zhang et al., 2010). The formulas for calculating both the ratio of broomcorn to foxtail millet by abundance— $R(n)$ —as well as the ratio of broomcorn to foxtail millet by weight— $R(w)$ —are presented below, where $N(bm)$ stands for the number of broomcorn millet specimens and $N(fm)$ stands for the number of foxtail millet specimens.

RESULTS

Radiocarbon Ages

The radiocarbon ages obtained are listed in **Table 1**. Huizui, Sanggou, Jinzhongsi, Mazhai, and Zhaiwan yielded corrected dates of between 3314 and 2891 cal BC, corresponding to the Late Yangshao period (3500–3000 BC). These radiocarbon dates are consistent with relative dates for the archeological cultures as determined by ceramic typologies and can thus be considered reliable. The radiocarbon ages of the Miaowan, Wutun, and Zhangcun sites are not dated to the Yangshao period. In addition, based on analysis of texture and stylistic traits of pottery sherds recovered from each site, Peicun, Gaoya, Fujiazhai, and Jueshan can also be attributed to the Late Yangshao period. So our study provides new evidence for the remains of carbonized plants from nine late Yangshao Culture sites in the Luoyang Basin.

Crop Assemblages in This Survey

We obtained a total of 40 soil samples, collected from 9 sites belonging to the Yangshao culture, which included approximately 5290 carbonized seeds (**Table 2**). In total, 4,484 foxtail millet seeds (*S. italica*), 90 broomcorn millet seeds (*P. miliaceum*), 704 rice (*O. sativa*) seeds, and a single soybean (*Glycine max*) were identified (**Figure 2**). Remains of weedy species recovered include milkvetch (*Astragalus membranaceus*), Manchu tubergourd (*Thladiantha dubia*), and green bristlegrass (also called green or wild foxtail millet) (*Setaria viridis*).

Regarding the archeobotanical remains of domestic crop species, foxtail millet comprises the largest part of the assemblages with 84.96% and is followed by rice at 13.33%. Broomcorn millet made up only 1.7% of the domestic crop assemblage and soybeans accounted for a meager 0.01%. Furthermore, foxtail millet had the greatest ubiquity rate at 54.76%, followed by 31.25% for broomcorn millet, and 4.17% for rice.

The large number of macrobotanical remains of foxtail millet (4,424) and rice (704) from the Zhaiwan site is especially notable. Zhaiwan is the only site where rice was recovered and at all other sites where the remains of crop plants were collected totals are relatively small, never exceeding 100 grains.

Crop Assemblages From Previous Studies

The results of previous analyses on carbonized archeobotanical species from other sites in central and western Henan province are summarized in **Supplementary Table 1**. These have been included in our analysis below.

DATA ANALYSIS

Due to the very small quantity of other seeds recovered, this article focuses on changes in the quantities of foxtail millet, broomcorn millet, and rice.

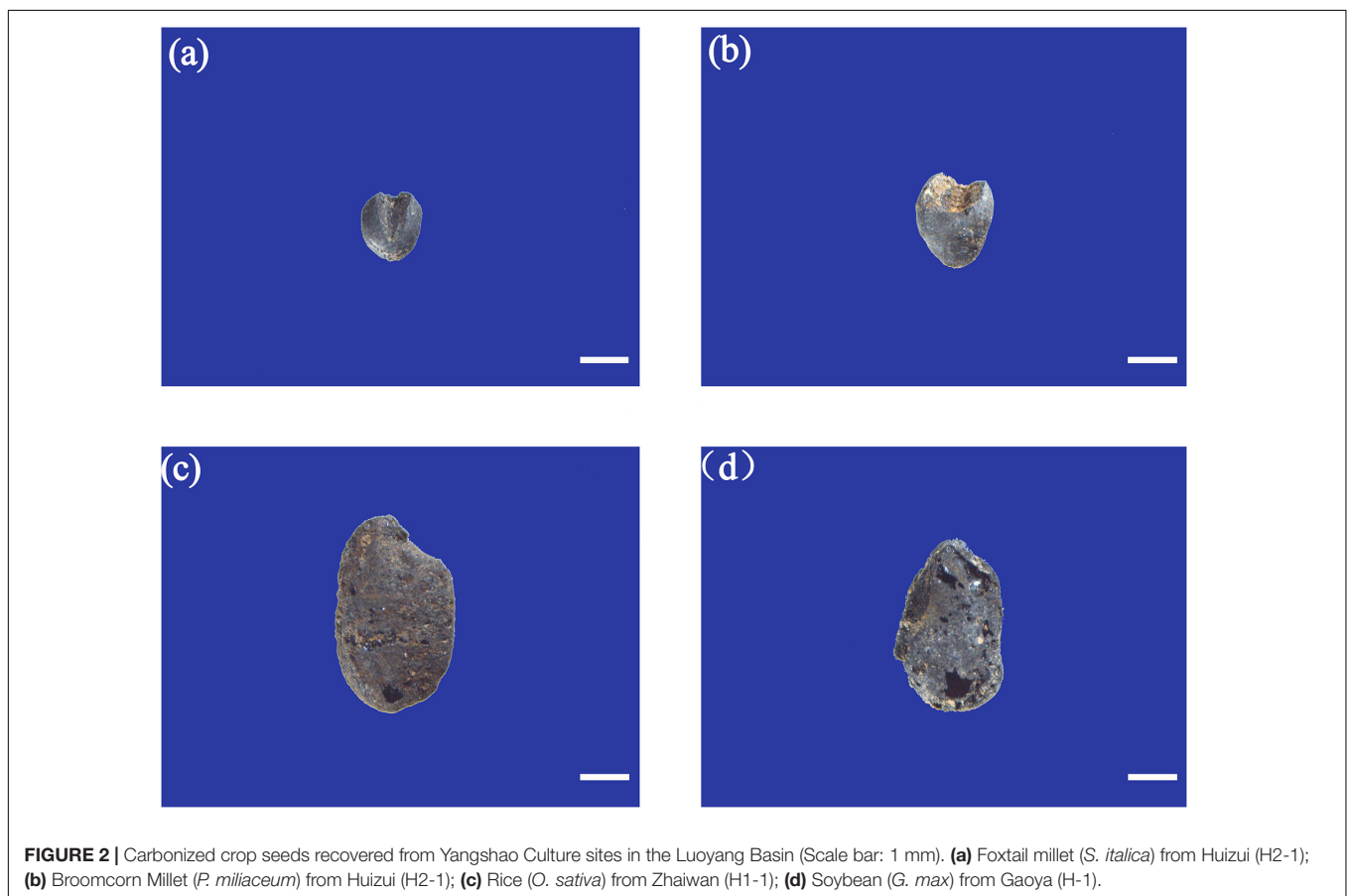
Overall Characteristics and Trends in the Development of Agricultural Practices During the Yangshao Period

According to the results of this paper in combination with those from previous studies (**Table 2** and **Supplementary Table 1**), for each individual site we calculated: (1) the ubiquity of millet and rice, (2) the ratio of broomcorn to foxtail millet (in terms of ubiquity, abundance and weight) (**Supplementary Table 2**). Results of analysis are available in **Supplementary Table 2** and are shown in **Figures 3, 4**.

In general, archeological sites with archeobotanical remains of domestic crops attributed to the Early Yangshao period (5000–4200 BC) are distributed within the Sanmenxia area (**Supplementary Table 2** and **Figure 3**). In terms of ubiquity, these Early period sites yield the highest ubiquity for broomcorn millet—ranging from 37.5 to 75%, with an overall average of 54.9%. At the Didong and North Didong sites—which belong to

TABLE 1 | Calibrated radiocarbon dates from sites investigated in Luoyang Basin (this study).

Radiocarbon Lab no.	Site	Sample	Cultural period	Conventional 14C age BC ($\pm 1\sigma$)	Calibrated age (cal. BC)	
					1 σ (68.2%)	2 σ (95.4%)
Beta-480949	Huizui East, H2-1	Foxtail millet	The late Yangshao	2371 \pm 30	(54.2%) 2934–2893 (14%) 3008–2987	(95.4%) 3014–2891
Beta-480951	Sanggou southeast, H1-2	Foxtail millet	The late Yangshao	2381 \pm 30	(45.9%) 2940–2899 (22.3%) 3010–2980	(95.4%) 3019–2894
Beta-480952	Jinzhongsi, H1-2	Foxtail millet	The late Yangshao	2430 \pm 30	(68.2%) 3020–2926	(80.3%) 3036–2913 (15.1%) 3090–3045
Beta-480953	Mazhai, H2-2	Foxtail millet	The late Yangshao	2441 \pm 30	(61.1%) 3026–2928 (7.1%) 3081–3069	(95.4%) 3092–2918
Beta-480954	Zhaiwan Southeast, H1-1	Foxtail millet	The late Yangshao	2531 \pm 30	(48.2%) 3329–3216 (10.9%) 3124–3097 (9.1%) 3181–3158	(90.8%) 3341–3087 (4.6%) 3059–3030
Beta-565106	Zhaiwan Southeast, H1-1	Rice	The late Yangshao	2391 \pm 30	(36%) 2493–2905 (26.1%) 3011–2978 (6.1%) 2961–2951	(95.4%) 3024–2896



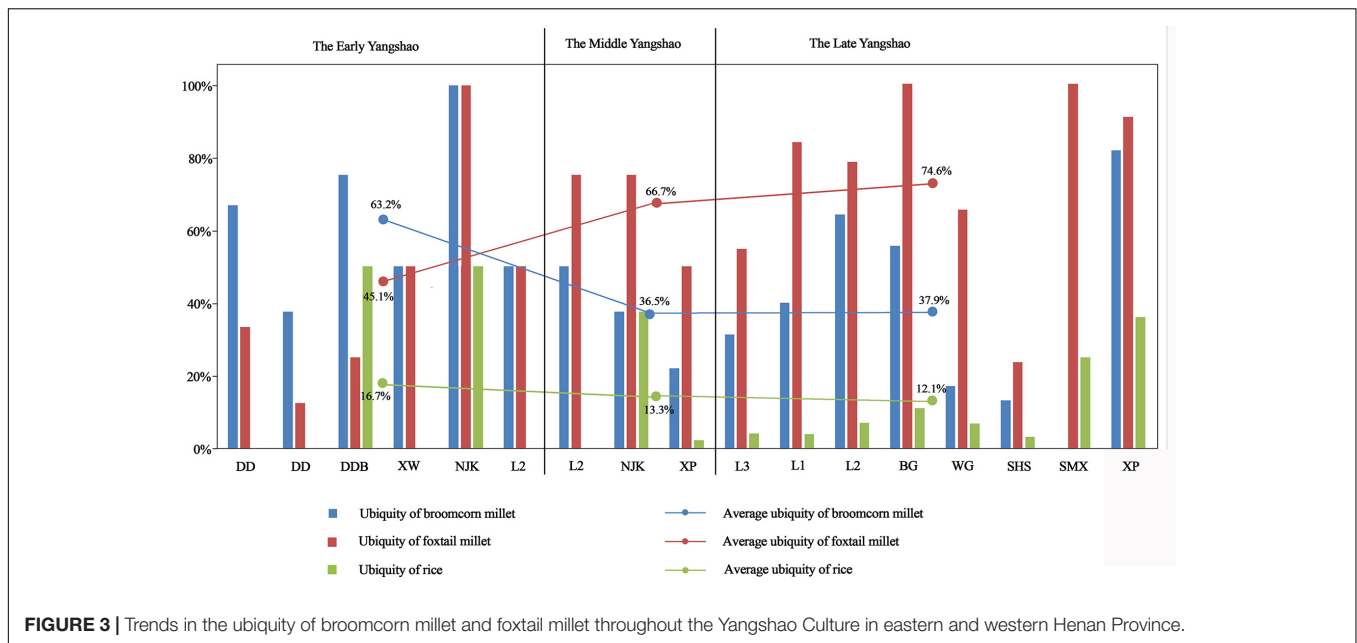
the first phase of the Early Yangshao period (5000–4500 BC)—the ubiquity of broomcorn millet is especially high with more than 60%. Foxtail millet is less ubiquitous at Early Yangshao sites, with an average of 36.8%. The probability of recovering foxtail, however, is never below 12.5% at any site from this period. Rice was recovered at rather high rates (ubiquity indices of around

50%) at the North Didong and Nanjiaokou sites, but was not found at any other sites at present, yielding an overall average ubiquity index of 16.7% for the Early Yangshao.

From 4200 to 3500 BC, during the Middle Yangshao period, sites with archeobotanical remains of crop species are found both in the area of Sanmenxia as well as within in Luoyang

TABLE 2 | Counts of crop seeds remains in the flotation samples from the Late Yangshao period archaeological sites in Luoyang basin (our study).

Site	Sample code	Landscape area	Volume of soil sample (L)	Foxtail millet			Broomcorn millet		Rice		Soybean	Milkvetch	Manchu tubergourd	Green bristlegrass	Unknown
				Whole	broken	agglomerate	Whole	broken	Whole	broken					
Huizui east	H1-1	Valley	10	4			3								
	H1-2		13												
	H2-1		13	22	4		9	4			1				
	H2-2		13	14	1		12	1							
	H3-1		13	3	2		3								
	H3-2		13	3	1		1								
Peicun	A southeast H1-1	Valley	6												
	A southeast H1-2		10												
	A southeast H2-1		6				2								
	A southeast H2-2		10	1			1								1
	C southeast H-1		8												
	C southeast H-2		10	1	1										
Gaoya	Northwest H-1	Plain	6												5
	Northwest H-2		6												
	Northeast H-1		6	11			1			1				1	
	Northeast H-2		6	1			1								
	East H-1		6	3			1								
Fujiashai	North H-1	Valley	6												
	Northeast H1-1		6	4	2										
	Northeast H1-2		6												
	Northeast H2-1		10												
	Northeast H2-2		12	1											
Sanggou southeast	H1-1	Valley	8	21	5		4								
	H1-2		8	22	11		13	6							
	H2-1		10	9	4										
	H2-2		8	4	2										
Jinzhongsi	H1-1	Plain	8												
	H1-2		8	13	7	1									
	H2-1		10	1											
	H2-2		6				4	3							
Mazhai west	H1-1	Valley	8	6	1										
	H1-2		8												1
	H2-1		6	13	4										
	H2-2		8	56	2										
Zhaiwan	Southeast H1-1	Valley	8	1530	700		20		3	350+				3	
	Southeast H1-2		8	1210	784				1	350+		1		2	
	Northeast H2-1		10												
	Northeast H2-2		8												
Jueshan northeast	H-1	Valley	10												
	H-2		12												
Amount				2953	1531	1	75	15	4	700+	1	1	1	1	7



Basin (Supplementary Table 2 and Figure 3). At these sites, the likelihood of recovering foxtail millet was the highest of among all crop species in our analysis, having an overall average ubiquity index of 66.7% and a range of between 50 and 70%. The rate of recovery for broomcorn millet comes second with an average of 36.5% and a range of between 22 and 50%. Rice was recovered only from Middle Yangshao contexts at Nanjiaokou and Xipo, with a range of 2.3–37.5%. Overall ubiquity for rice also decreases slightly through time, going from an overall average of 16.7% in the Early Yangshao to only 13.3% in the Middle period.

By the Late Yangshao period from 3500 to 3000BC, most sites with archeobotanical remains are located in the Luoyang Basin and Songshan area (Supplementary Table 2 and Figure 3). As was the case in the Middle Yangshao, foxtail millet had the highest ubiquity indices, with the site of Shuanghuaishu yielding the lowest index at 23.7% and all other sites having rates above 50% and as high 100%. Overall ubiquity indices for foxtail during the Late Yangshao are higher than they were in previous periods as well, reaching an average of 74.6%. Broomcorn millet once again occupies a secondary position with 37.9% on average and a range of 13.2–81.8%. Except for the L2 (64.2%) and BG (55.6%) sites, broomcorn millet ubiquity indices consistently fall below 40% in this period. In this period we also observe an increase in the number of sites with rice, although the average ubiquity index remains low at 12.1% and the range was between 3.2 and 36%, with only Xipo and sites from the Sanmenxia survey producing indices higher than 12%.

Analysis of Changes of Foxtail and Broomcorn Millet

In the early Yangshao ubiquity ratios are in almost all cases above 1.0, with an average of 1.83—indicating a consistently greater likelihood of recovering broomcorn over foxtail at this time (Figure 4E). Except for at the sites of North Didong and

Nanjiaokou—where foxtail millet cultivation was emphasized over broomcorn millet—this trends is echoed in the other two ratios for abundance and weight with averages of 1.67 and 3.7, respectively (Figures 4C,D).

Ratios of broomcorn millet to foxtail millet in terms of ubiquity, abundance, and weight for sites from the Middle and Late periods are roughly equivalent in terms of both ranges (Middle: 0.54–0.17; Late: 0.56–0.17) and averages (Middle: 0.36; Late: 0.40) (Figures 4C–E). Notably, all of these ratios drop to below 1.0, decreasing significantly from those calculated for the Early Yangshao and indicating the prevalence of foxtail over broomcorn millet in these later periods.

A Comparison of Crop Remains From Sites With Different Surface Areas

We also analyzed the composition of the agricultural structure—on the basis of ubiquity and abundance indices—apparent at sites of different sizes (Figure 5). Information was available about the size of 34 of the archeological sites examined in this study. For each period of the Yangshao Culture we divided these into (1) small sites with an area of less than 0.2 km², (2) medium sites with areas of between 0.2 and 0.6 km², and (3) large sites of over 0.6 km².

For sites from the Early Yangshao period with available data (Figure 5A), all four sites with carbonized crop seeds are classified as small. Across these four sites, broomcorn millet, foxtail millet, and rice had average ubiquity ratios of 69.45, 49.6, and 15.5%, respectively. In terms of relative abundance, broomcorn millet comprised 51.35% of assemblages on average, followed by foxtail millet (45.03%) and rice (3.62%).

For the Middle Yangshao (Figure 5B), the six sites with archeobotanical assemblages containing domestic crops are evenly distributed between small ($n = 3$) and medium ($n = 3$) sized sites. Average ubiquity indices and relative abundances,

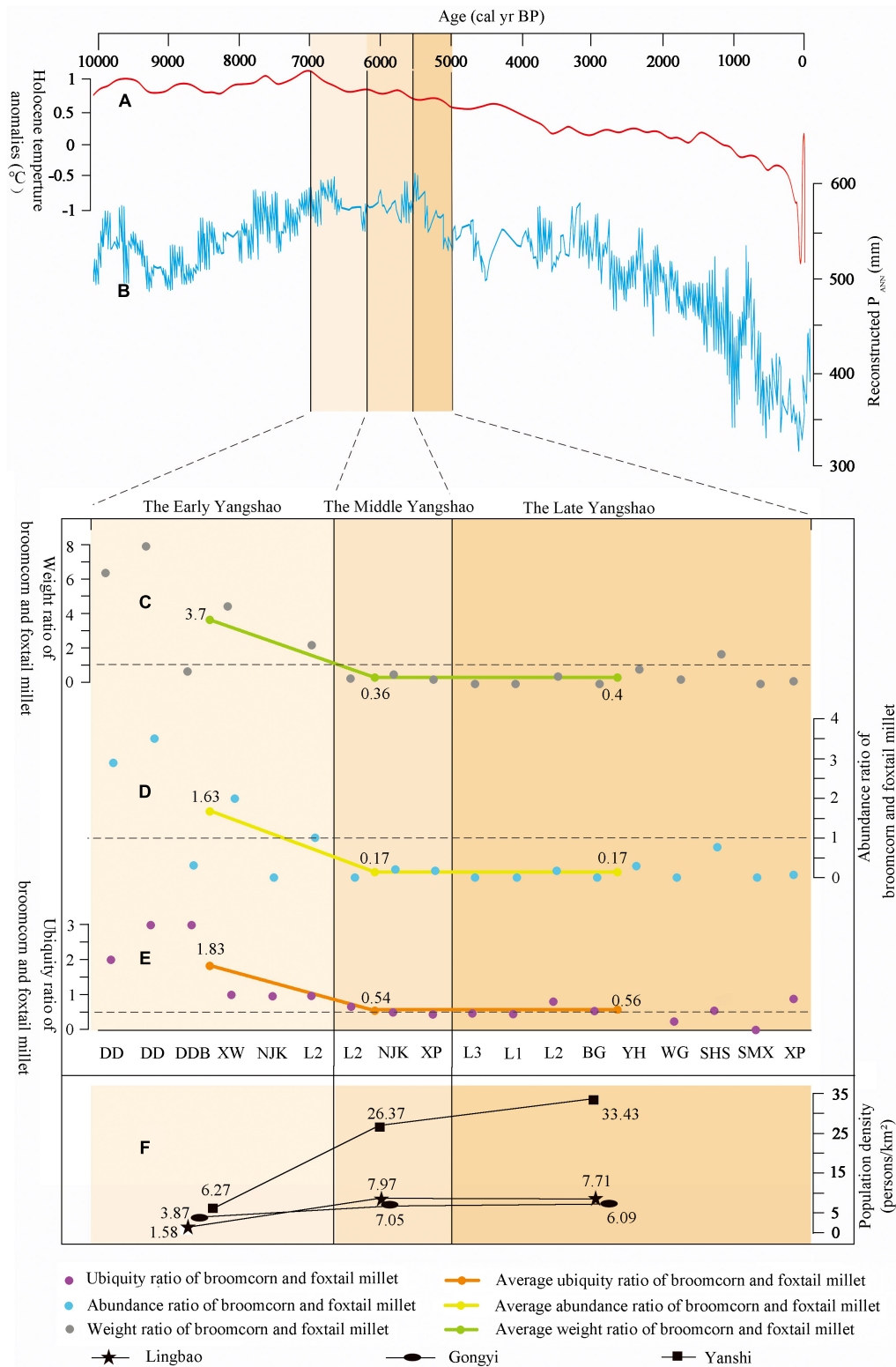
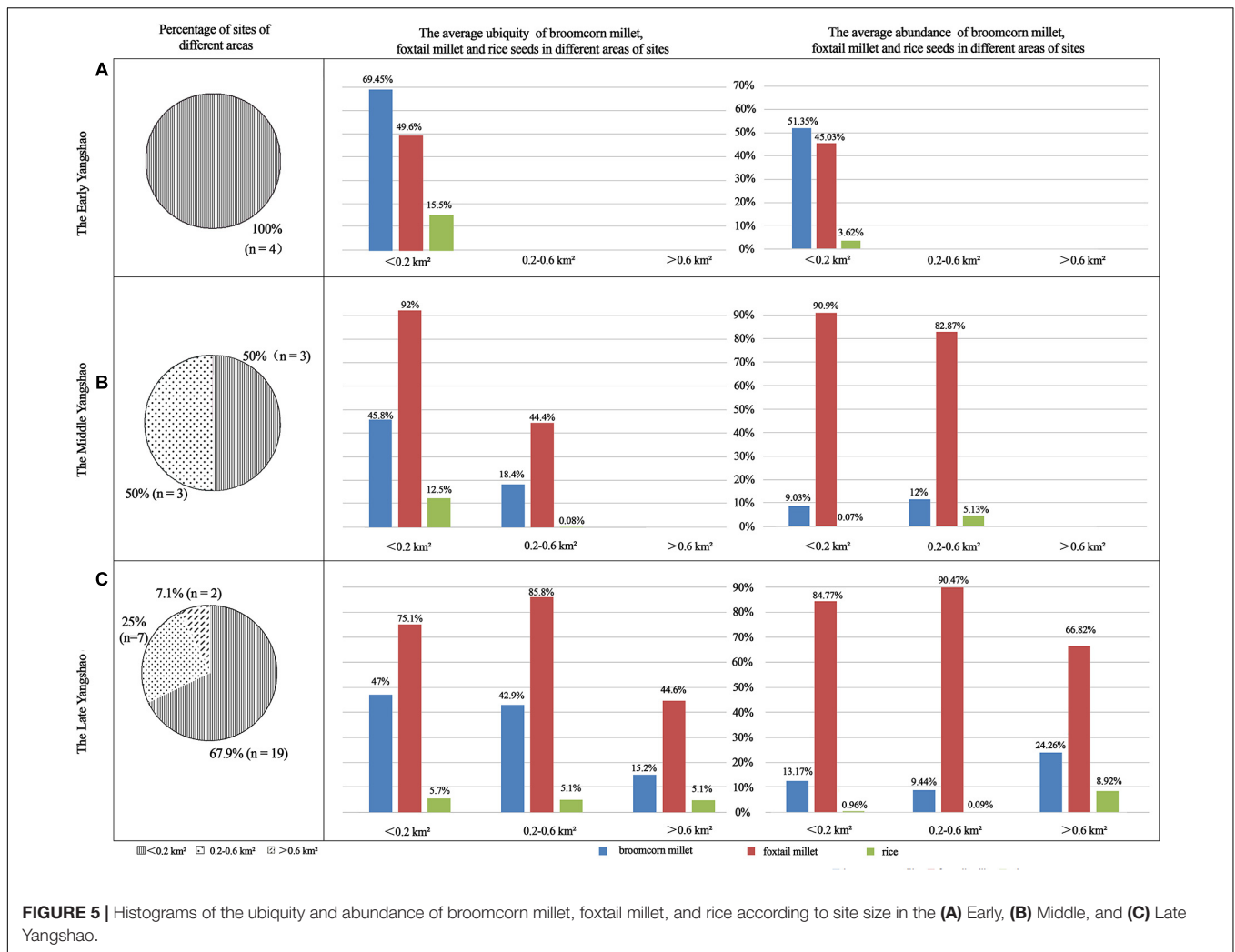


FIGURE 4 | Climate, three ratios of broomcorn millet to foxtail millet, population density curve. **(A)** Synthesized Northern Hemisphere (30°–90°N) temperature record during the Holocene55 (Shakun et al., 2012; Marcott et al., 2013). **(B)** Pollen-based annual precipitation (PANN) reconstructed from Gonghai Lake (Chen et al., 2015). **(C)** Weight ratio of broomcorn millet to foxtail millet from sites examined in this study. **(D)** Abundance ratio of broomcorn millet to foxtail millet from sites examined in this study. **(E)** Ubiquity ratio of broomcorn millet to foxtail millet from sites examined in this study. **(F)** Population density in central and western Henan Province (Wang J. H., 2005).



respectively in small sites for this period were: 45.8 and 9.03% for broomcorn millet, 92 and 90.9% for foxtail millet, and 12.5 and 0.07% for rice. Average ubiquity indices and relative abundances in medium sites for this period were: 18.4 and 12% for broomcorn millet, 44.4 and 82.87% for foxtail millet, and 0.08 and 5.13% for rice.

The Late Yangshao provided the largest number of sites ($n = 28$) with macro-botanical remains of crops (Figure 5C). The majority of these (67.8%) are small sites, where broomcorn millet, foxtail millet, and rice, respectively yielded average ubiquity ratios of 47, 75.1, and 5.7%, and comprised 13.17, 84.77, and 0.96% of these assemblages, respectively, on average abundance ratios. Medium sized sites are the next most abundant making up 25% of the Late Yangshao sites for which we have data. Both ubiquity and relative abundances are fairly similar to those for small sites (average ubiquity and abundance: broomcorn: 42.9 and 9.44%, foxtail: 85.8 and 90.47%, and rice: 5.1 and 0.09%). Large sites are less abundant than either small or medium sized sites during the Late Yangshao, comprising only 7.1%. Ubiquity is similar to contemporary medium and small sized sites for rice (Large: 5.1%), but the average ubiquity as well as abundance of both

broomcorn (15.2, 24.06%) and foxtail (44.6, 66.82%) millets is much smaller at the Large sized sites.

DISCUSSION

Foxtail Millet-Broomcorn Millet Substitution

Results from our analysis of archeobotanical remains from Yangshao sites in Henan demonstrate that throughout the Early Yangshao period broomcorn millet represented the primary crop within the Yangshao agricultural system, while foxtail millet made up a smaller, although not insignificant, part of Yangshao foodways at this time. In the Middle and Late Yangshao periods ubiquity, relative abundance, and relative weight measurements present an opposing trend, with foxtail millet superseding broomcorn millet for dominance in Yangshao food production systems. Our results are in line with evidence from a number of previous archeobotanical studies of Yangshao sites in the Henan province and surrounding areas where systematic flotation was conducted—including Yangguanzhai, Xipo, Didong, and

Nanjiaokou (Wei, 2014; Zhong et al., 2020)—which demonstrate a shift from broomcorn millet toward foxtail millet during these latter two periods of the Yangshao culture.

Climate change played a critical role in the selection of millet species for domestication during different periods in North China (Lu, 2017; Yang et al., 2018). However, geological records, including eolian deposits, lake sediments and soils, have shown that during the Yangshao Warm Period climatic conditions in Henan Province were much more favorable for cultivation than those seen today (Shakun et al., 2012; Marcott et al., 2013; Chen et al., 2015; **Figures 4A,B**). Environmental records from the Sihenan site in Luoyang Basin show that the lakes and marshes present during the Early and Middle Yangshao—between 5000 and 3500 BC—were less saline and supported a greater number of flora and fauna preferring warm and humid environments (Sun and Xia, 2005). Furthermore, zooarcheological studies from Xishan in Zhengzhou reporting the presence of an abundance of heat-loving terrestrial and aquatic animal species strongly suggests that a warm and wet climate continued into the Late Yangshao (Chen, 2006). Therefore, we think that climate change during the Yangshao period would not have been severe enough to result in the changes we see to agricultural systems during this time—especially because agricultural production was centered around highly adaptable, heat and drought-tolerant millets.

The Early Yangshao period represents an early stage of agricultural development in Northern China, characterized by underdeveloped crop cultivation practices and predominantly extensive production (Zhao, 2017). In this context, the dominance of broomcorn millet in the agricultural structure of the Early Yangshao was driven by a preference for this species, owing to its adaptability to various (and poor) environments, ease of cultivation, and low requirements in terms of land management and inputs (SCGR, 1994; Dong and Zheng, 2006; Zhao, 2018).

Archeological studies have shown that the Dongzhuang-Miaodigou culture type emerged in western Henan and rapidly expanded into surrounding areas during the Middle Yangshao period (Han, 2015) and the population density in the study area increased sharply during this period (Wang J. H., 2005; **Figure 4F**). In this stage, agricultural economy establishes principal position (Zhao, 2014; Li, 2018; Zhong et al., 2020). Agricultural modes of production at this time changed from “extensive” to “intensive” strategies in order to cope with ensuing resource depression brought on by population increases (Fan, 1988; Gao, 2009; Zhao, 2014, 2018; Han, 2015). Broomcorn millet can have unstable yields because its grains fall off easily after the plant reaches maturity and are difficult to harvest (Dong and Zheng, 2006; Zhang, 2016). Foxtail millet has the advantage of a short growth period along with high yields (e.g., 1950's production of foxtail millet: 750 kg/hm² vs. broomcorn millet 670 kg/hm²), and the grains also provide for better flavor and superior storage stability (SCGR, 1994; Dong and Zheng, 2006; Liu et al., 2008). Therefore, with investments in soil and land management strategies—including nutrient inputs, weeding, and pest controls (SCGR, 1994; Dong and Zheng, 2006; Liu et al., 2008)—Yangshao farmers would have preferred to plant foxtail millet over broomcorn, leading to the

shift from broomcorn to foxtail millet evident in the Middle Yangshao period.

As such, we assert that the substitution of broomcorn millet for foxtail millet in Henan Province during the Middle Yangshao was propelled by social development and demographic expansion, rather than by environmental factors. This conclusion is also supported by research conducted at the wider regional level. Comparing the agricultural characteristics of areas surrounding Henan province, Zhong et al. (2020) proposed that foxtail millet was far more important in the agricultural systems of Henan Province than it was within other traditional dry-land farming areas in neighboring regions such as Haidai and Shanxi. He further speculates that higher numbers of sites, sites of larger size, and other evidence for higher population density within the core Miaodigou Culture area resulted in a greater demand for the higher-yielding foxtail millet (Zhong et al., 2020).

It should be noted that evidence from phytoliths is suggestive of broomcorn millet, and not foxtail, serving as the main agricultural crop in the Zhengzhou region of central Henan throughout the Yangshao Culture, with no evidence of replacement in either the Middle or Late periods (Wang et al., 2015, 2019a,b; Wang, 2016). However, remains from sites such as Lajia (Zhao, 2003; Wang et al., 2015), as well as others in the Guanzhong Basin (Zhang et al., 2010; Liu et al., 2013; Zhong et al., 2015) have shown that the results of analysis of phytoliths vs. carbonized macro-botanical remains can present conflicting results—owing to the fact that phytoliths and carbonized macrobotanical remains are studied in different ways. And the variety of preservation conditions (Renfrew, 1973) and carbonization temperature (Yang et al., 2011; Wang and Lu, 2020) both affect the carbonization rate of millet. So it is difficult to compare results based on phytoliths and carbonized remains in practice, and our study depends on examination of the latter, the discussion in this paper is mainly based on evidence from carbonized remains.

Valley-Rice Planting and Palaeogeomorphologic Evolution

Domesticated rice originated in China's Yangtze River basin (Jones and Liu, 2009; Zhao, 2014), and spread northwards into the Central Plains region to the middle reaches of the Yellow River around 8000–7000 a B.P. (Zhang et al., 2012; Wang, 2016; Lu, 2017; Wang et al., 2017), becoming an important dietary supplement to prehistoric people. The warm and humid climate of the Yangshao period was crucial for the development of rice cultivation in this region (Shi et al., 1992; Xia et al., 2001). However, the cultivation of rice in northern China relies on particular geomorphologic and environmental conditions, especially in terms of water availability (Li and Zhang, 2020). Sites where rice has been observed are located near rivers and lakes, where aquatic resources were conveniently available (Zhong et al., 2020). Thus, in northern China the potential for rice cultivation at a given site was not determined by climate or latitude, but rather by proximity to an abundant water source.

Of the archeobotanical assemblages in our analysis that yielded remains of rice (**Figure 6D**), 10 sites are located in river

valleys, and none were found in plains. In the Early Yangshao period, the North Didong and Nanjiaokou sites are situated on platforms along the valleys of the Xiyu and Qinglong rivers in western Henan Province. Middle Yangshao sites with rice, such as Nanjiaokou and Xipo, are similarly located within the river valleys of the Qinglong and Sha Rivers in western Henan. This trend continues into the late Yangshao period, with sites in both western and central Henan province once again found in river valleys of the Sha, Hongnong, Yihe, Luo, Yiluo, and Ying rivers.

The valley area refers to the relatively high altitude, complex and topographically variable terrain found to either side of the valley formed by the loess plateau and river terraces of the upper reaches of the Ying River (Zhang et al., 2014). For example, in the Songshan area, the western loess area experienced several fluvial deposition-erosional cycles since the terminal Late Pleistocene. A large-scale alluvial aggradation took place in the Middle Holocene, resulting in the formation of lakes, marshes and wetlands (Lu et al., 2020). And in the Luoyang Basin, during the late-middle Holocene (5300/5010~2130/1870 BC), the loess tablelands and gullies experienced erosion of mountain slopes, resulting in increased accumulation in valleys and the formation of clay-rich and water-filled depressions. A fine sand and gravel layer from the Huizui site penetrates a layer of clay sediments, suggesting the formation of seasonal marshes and waterlogging (Rosen, 2008). This evidence indicates that during the Yangshao period, conditions in the valley areas were humid, creating an abundance of moist depressions suitable for paddy fields and providing optimal conditions for rice cultivation.

The alluvial plains area refers to the flood plain on both sides of the Yiluo River (Zhang et al., 2014) and the eastern Songshan Mountain plains, where the terrain is low and flat with less landform diversity and fertile soils. The floodplain on both sides of the Yiluo River in the central Luoyang Basin was cut down around 7,000 years ago, forming a vast area of dry and stable T1 terraces (Zhang et al., 2019). In the low-lying area the eastern Songshan plains, some of these lakes converged into large water areas and lasted throughout the Late Pleistocene and Early- Middle Holocene period (Lu et al., 2020). In short, the plain terraces of Luoyang Basin are generally dry, and the eastern Songshan plain was full of lakes and marshes, with both areas lacking stable, lowland environments allowing for rice cultivation. Therefore, we propose that the absence of rice remains from sites located in alluvial plains in central and western Henan Province dated to the Yangshao period is best explained by differences in local geomorphologic environments.

Agricultural Distribution, Paleoenvironment, and Social Complexity

A diachronic shift is evident in the distribution of sites associated with agricultural practices between the Early and Late Yangshao periods. Early period sites are primarily in the western part of Henan Province, but by the Late Yangshao sites primarily in Central Henan resulting in a more balanced representation of geomorphologic regions in site locations (Figure 6).

The Early Yangshao Culture Period (5000–4200 BC)

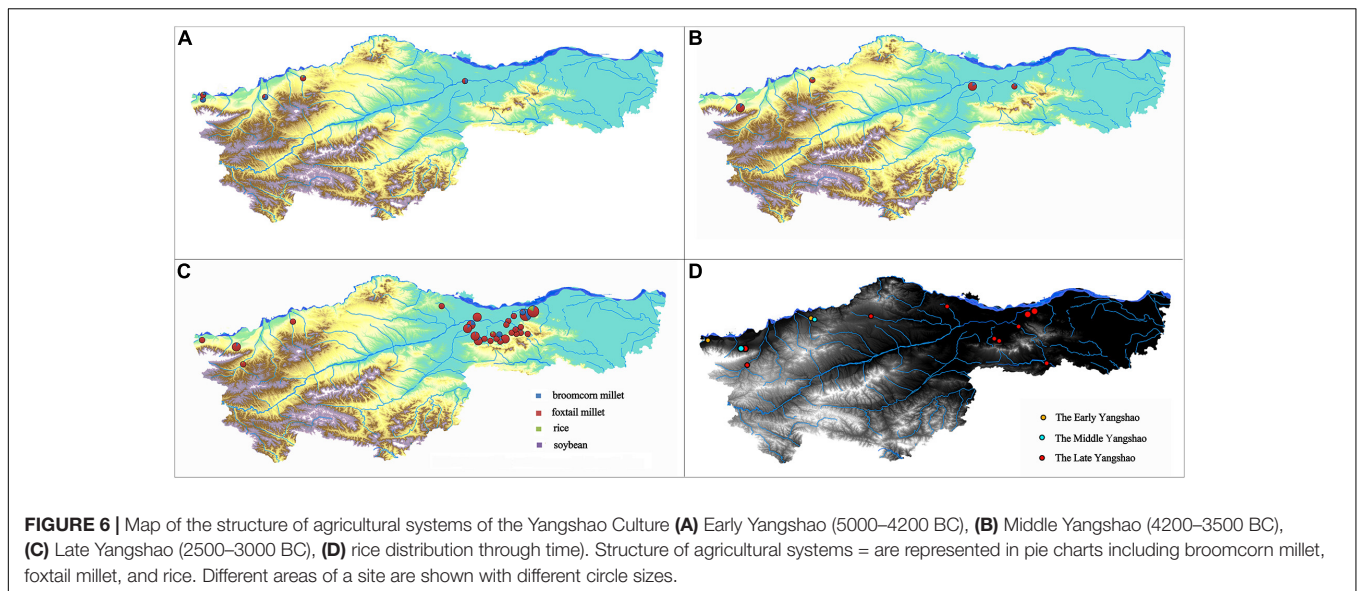
During the Early Yangshao Culture period, the Mid-Holocene Megathermal Period established a climate that was warm and humid in this region (Sun and Xia, 2005). Numerous lakes developed in the central and western areas of Henan Province (Dong et al., 2006; Zhai et al., 2011; Li et al., 2014), and in central Henan, the area around Zhengzhou especially experienced vast lake development (Li et al., 2014; Lu et al., 2020). Archeological evidence shows that settlements from this time period are mainly distributed in the areas of higher elevation, such as loess tablelands and river terraces (Zhao, 2001; HPI-CRA, 2009; Liao et al., 2019; Lu et al., 2020). In comparison, western Henan is generally higher in elevation than central regions, with a more diverse array of geomorphologic features. Here, ancient people similarly established settlements on the loess tablelands and terraces (HPI-CRA, 2009). During this period, hunting and gathering constituted a large proportion of economic and food procuring activities (Kong et al., 1998, 1999; Zhao, 2014, 2017; Li, 2018), which were facilitated in western Henan by the abundant mountainous areas rich with animal and plant resources. This situation helps to explain why sites with carbonized remains from the early Yangshao period are primarily found in western Henan Province (Figure 6A).

Social stratification was low or absent during the Early Yangshao period and society was likely organized around simple kin-based networks (HPI-CRA, 2009; Dai, 2012). Settlements from this period are small and there is no evidence for any kind of settlement hierarchy (Zhao, 2001). The lithic industry included stone spades, blades, saddle-querns, and rollers and was predominantly based on groundstone tools (ZMIA, 2001), and population densities were low (Wang J. H., 2005; Figure 4F). Our study provides evidence of the presence of mixed cropping systems (based on both types of millet and, in some cases, also rice) from Early Yangshao sites (Figures 5, 6A), reflecting relatively undeveloped and extensive agricultural activities adapted to simple forms of social organization.

The Middle Yangshao Culture Period (4200–3500 BC)

A stable warm and wet climate during the Middle Yangshao period (Shakun et al., 2012; Marcott et al., 2013; Chen et al., 2015; Hou et al., 2019), and the presence of loess soils suitable for rain-fed dry-land farming practices in the central and western Henan Province (HPI-CRA, 2009), provided improved conditions for early agricultural reclamation and crop sowing. In this period, settlements increase in size and scale and can now be found at the edge of tableland areas. For example, the Nanjiaokou site is located along secondary terraces and along the slope of the middle and lower part of the southern loess tableland (HPI-CRA, 2009). At this time, the Dongzhuang-Miaodigou type of the Yangshao Culture emerged rapidly in western Henan and expanded vigorously into surrounding areas (Han, 2015). This expansion is also confirmed by the distribution of crop remains, which display a wider and more balanced area of distribution from sites located on terraces, in tableland areas, and along tableland edges during the Middle Yangshao (Figure 6B).

Although the number of carbonized seeds recovered from Middle Yangshao sites is relatively small, the dominance of



foxtail millet in these agricultural assemblages is obvious, with broomcorn millet and rice as secondary crops in small and medium sites in the central and western Henan Province (**Figure 5B**). We speculate that these differences between settlements of different sizes can be explained by the establishment of stratified social organization during this period. As mentioned above, the substitution of broomcorn millet for foxtail millet that occurred during the Middle Yangshao period created a new agricultural system that was now dominated by the higher yielding millet species, which in turn promoted dramatic agricultural developments. Subsequently, differentiation within and between settlements (HPICRA, 2009; Dai, 2012; Luan, 2012; Zhao, 2014; Han, 2015), distinctions between tombs and grave goods (IACASS and HPICRA, 2010) and other phenomena suggesting intensified social stratification were becoming increasingly obvious, marking a period of novel social tensions and relationships between people (Liu, 2005; Wang J. H., 2005; Dai, 2012; Han, 2015).

In this context, economic specialization resulted in the emergence of handicraft activities separate from agricultural production, including specialized lithic, ceramic, and jade working industries, as well as an increase in trade between settlements in commodities and other economic goods (Dai, 2004, 2012, 2016; Jin, 2005; Gao, 2009; Han, 2010). The small size and populations of small settlements meant they functioned primarily as agricultural settlements, whereas the larger populations and more complex economic structures of medium-sized settlements allowed for the emergence of specialized industries with a lesser emphasis on agriculture, explaining the lower probability of recovering crop remains at these sites.

The Late Yangshao Culture Period (3500–3000 BC)

Climatic conditions in these latter periods do appear to fluctuate, including a period of cooling as well as drought from 5.5 to 5 ka BP (Jiang et al., 2006; Chen et al., 2015; Dong et al., 2015; Goldsmith et al., 2017). Climatic fluctuations resulted in changes

to surface hydrology, which included a decrease in surface water levels and the subsidence of lake marshes (Sun and Xia, 2005; Dong et al., 2006; Bi et al., 2016). Archeological investigation shows that settlements were being established at lower elevations in this area, with site locations expanding into the lower-lying areas such as river terraces and plains (Zhao, 2001; HPICRA, 2009; Liao et al., 2019; Lu et al., 2020).

Our data show that Late Yangshao period remains are found both along tableland valleys as well as in plains in the central and western Henan Province, with a more balanced the distribution across the landscape (**Figure 6C**). This was a result of a decline in the level of surface water runoff as well as an increase of arable land in the plains, which provided additional land suitable for agricultural production. During this period, an influx of foreign cultural influences appeared to have caused Yangshao culture in the former western core to decline; Central Henan thus became a place of cultural convergence and a unique cultural system developed in the newly populated region (Luan, 1996; Zhang, 2010; Dai, 2012; Han, 2015). Agricultural activities during this period were therefore more concentrated in central Henan than they were in western regions.

In the late Yangshao period, the average ubiquity of millet and rice, and the average abundance of foxtail millet in large sites was smaller than those in medium and small sites (**Figure 5C**). At this stage, differentiation between settlements of different scales was more obvious, and differences between settlement areas of different levels was more pronounced (Zhao, 2001; Gao, 2009; HPICRA, 2009). Massive rammed-earth wall structures and weapons found at the Xishan site in Zhengzhou (Yang, 1997) reflect a time period of violent conflict and social tension (Dai, 2012). Concentrated and intensive handicraft production at a large scale is apparent at large and central settlements of this period, and the range and amount of products evident at these sites indicates that these materials were produced to fulfill non-local demands beyond the settlement itself (Dai, 2012, 2016). It is thus likely that this resulted in the more diversified economic

structure evident in larger-sized settlements, further evinced by a lower proportion of agricultural remains from these sites compared to smaller settlements.

CONCLUSION

Our study provides new evidence for the remains of carbonized plants from nine late Yangshao sites in the Luoyang Basin. In addition to millet, the hundreds of rice fragments found at the site of Zhaiwan represent the largest assemblage of rice from the Late Yangshao period found in the Luoyang Basin. Combining new data with previous evidence of carbonized plants from the Yangshao period in central and western Henan Province, this paper explores the relationship between agriculture, the environment, and social complexity.

The stable, warm and humid climate in the Mid-Holocene Warm Period provided an optimal environmental background promoting the development of agriculture in the Yangshao Culture, which subsequently became the foundation for further sustainable agricultural developments and the intensification of social complexity throughout this period. Climatic fluctuations affecting surface water levels and runoff distribution and resulting in geomorphologic changes, are associated with the spread of agricultural practices initially located in the loess tableland valley areas at higher elevations during the Early Yangshao and expanding into marginal areas and plains during the Middle and Late Yangshao periods. These low-lying lands—with better hydrothermal conditions in valley areas—meant that these areas were more suitable for rice cultivation than the plains were. Changes in the structure of crop assemblages further affected the distribution of site clusters and changes in cultural areas.

Furthermore, using carbonized macrobotanical remains we obtained key evidence of the substitution of broomcorn millet with foxtail millet by the Late Yangshao, providing a direct contrast to results from this region using phytoliths. We believe that this substitution was primarily driven by population pressure, rather than environmental degradation. The establishment of a highly efficient, foxtail millet-based agricultural system—which had its apex during the Middle Yangshao—promoted population growth, economic and social differentiation, and social stratification, resulting in a period of intensified social complexity.

Finally, our study provides an example of how processes of social complexity can affect the structure and scale of agricultural practices at different types of archeological settlements. In the Middle and Late periods, the average ubiquity and abundance of agricultural crops is lower at larger settlements than in smaller ones—Middle Yangshao period: medium < small; Later Yangshao period: large < medium and small—and this appears to be

related to a reduced emphasis on agricultural production at larger settlements, due in part to their more complex economic structures and specialized handicraft production systems.

It should be noted that the imbalance of the number of sites found in western Henan and central Henan during the Yangshao period may have an effect on the distribution of foxtail millet, broomcorn millet and rice, which needs to be verified by systematic analysis of assemblages from more and newly excavated sites in this region.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

JZ designed the research. YL and JZ performed the research and completed writing. YL, JZ, and XZ analyzed the data. HZ and YL completed sampling in the field. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feart.2021.662391/full#supplementary-material>

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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