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Short Communication

The spatial pattern of farming and factors influencing it during the Peiligang culture period in the middle Yellow River valley, China

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The Peiligang culture (ca. 7000–5000 cal BC) is the earliest Neolithic culture in the middle Yellow River valley and represents the emergence of cereal farming in the region [1]. It has long been considered representative of millet farming [2], which requires a dry field, a certain amount of rainfall, and minimal crop management, but new records reveal that mixed farming of millet and rice (*Oryza* sp.) took place during this period [3]. Therefore, it is possible that millet farming coexisted with mixed farming in the Peiligang culture rather than one or the other. The environmental conditions required for mixed farming should be different from those required for millet farming, because rice generally requires more soil moisture and nutrients than millet. Thus, there is a need to know how these agricultural modes were distributed in these sites and what the influencing environmental factors were. However, crop assemblages from the different Peiligang culture sites have rarely been comparatively studied previously; therefore, the spatial distribution patterns of millet and mixed farming are still unknown.

In terms of their geographical locations, Peiligang culture sites are classified into two types: those on the alluvial plains and those on the hilly lands [1]. Sites of the former type are generally large, with thick cultural deposits and rich artifacts, while sites of the latter type are small, with thin deposits and fewer remains. These contrasting traits may reflect different adaptive subsistence strategies [1]. Therefore, the question arises as to whether these two types performed different agricultural modes to adapt to different natural circumstances.

To date, more than 120 Peiligang culture sites have been identified, distributed over a large area of the middle Yellow River valley [4], but fewer than 20 sites have been excavated [5] and only 13 sites had archaeobotanical data [3,4,6–8]. In this paper, in order to answer the above question, on-the-spot investigations were carried out at four sites of both types, and phytolith and plant macroremain analyses were conducted on samples to recover the cultivated crop assemblages. In addition, published archaeobotanical data were integrated to reveal crop remains in different Peiligang culture sites. Our study attempts to find the differences in crop cultivation in the two types of sites and, finally, reconstruct the spatial pattern of agriculture in the middle Yellow River valley during the Peiligang culture period.

Four representative Peiligang culture sites, namely Wuluoxipo (113°0′14″E, 34°38′20″N), Zhuangling (113°8′46″E, 34°49′19″N), Lijiagou (113°31′26″E, 34°33′54″N), and Zhuzhai (113°30′19″E, 34°49′31″N) were investigated in a 2012 survey. Wuluoxipo, Zhuangling, and Lijiagou are located in hilly lands with higher elevation (178–275 m) and smaller area (2–3 ha), while Zhuzhai is located in alluvial plains with lower elevation (105 m) and larger area (10 ha) (Table S1). Archaeobotanical data from the other nine Peiligang culture sites were also collected. Geographic information on all thirteen sites is listed in Table S1. Fig. 1(a) also shows the geographical locations of these sites. The thirteen sites are distributed in the Luoyang, Zhengzhou, and Xuchang cities in the northern Henan Province.

Nine phytolith samples and two floatation samples (15 L) were collected from one ash pit (WLXPH1) at Wuluoxipo, twenty-four samples for phytolith analysis were collected from three ash pits

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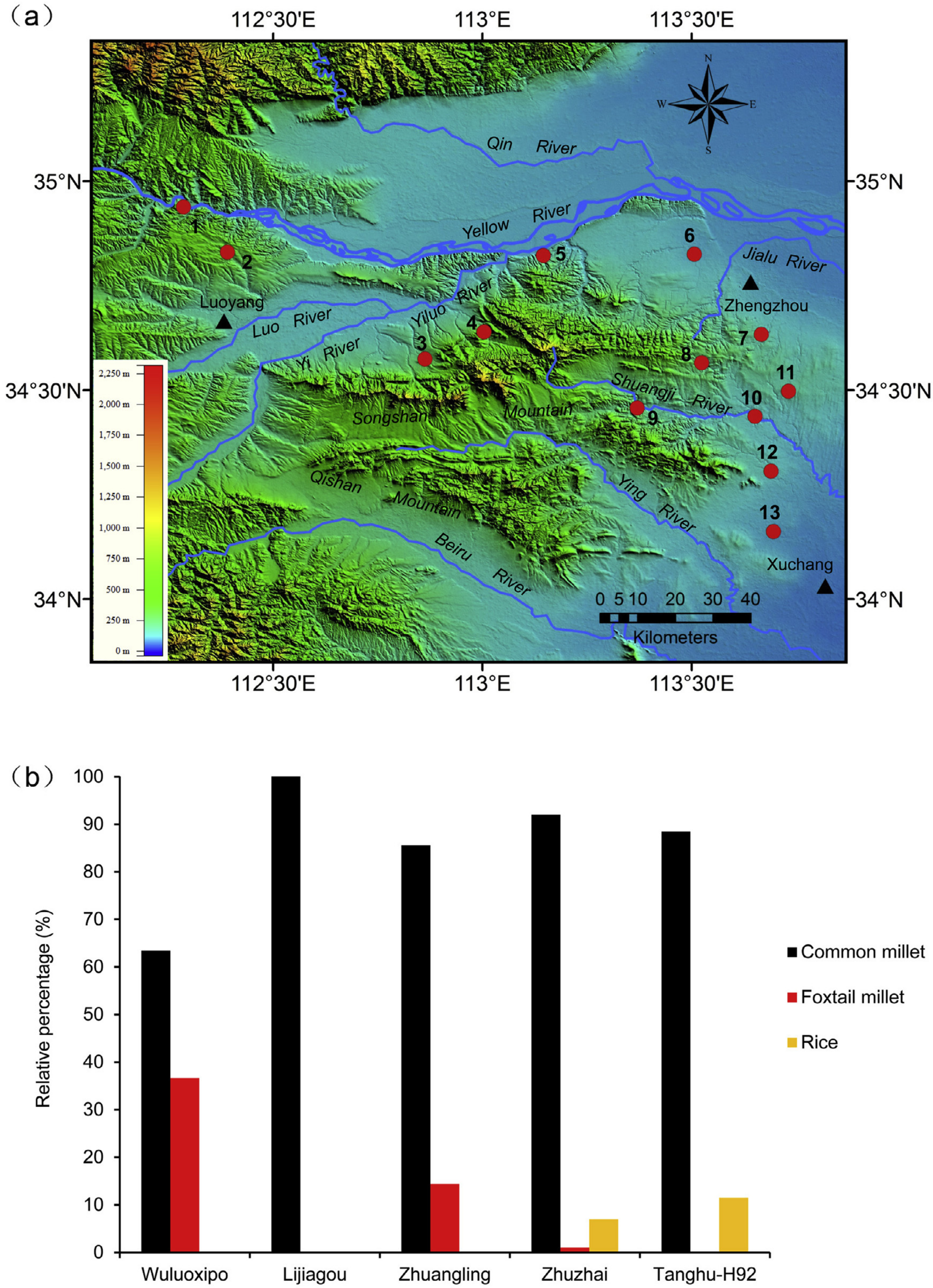

Fig. 1. (a) Locations of the Peiligang culture sites discussed in the text. 1. Zhaigen; 2. Bangou; 3. Fudian; 4. Wuluoxipo; 5. Zhuangling; 6. Zhuzhai; 7. Shawoli; 8. Lijiagou; 9. Egou; 10. Peiligang; 11. Gangshi; 12. Tanghu; 13. Shigu. (b) Relative percentage of phytolith from common millet, foxtail millet, and rice at different sites. The H92 data of the Tanghu site are adapted from Zhang et al. [3].

(ZL-2, ZL-3, and ZL-4) at Zhuangling, one phytolith sample (LJG2) was collected from the Peiligang cultural layer at Lijiagou, and twelve phytolith samples and four floatation samples (30 L) were collected from twelve ash pits at Zhuzhai.

The wet oxidation method was used to extract phytoliths from the soil. The procedure consisted of weighing out 2 g of soil, then treating with 30% hydrogen peroxide (H_2O_2) and 10% cold hydrochloric acid (HCl), separating it with a zinc bromide ($ZnBr_2$, density 2.35 g/cm^3) heavy liquid, and mounting it on a slide with neutral resin and fixing a glass cover over it. Phytolith identification, counting, and photographing was conducted using a Leica DM750 light microscope at 400× magnification. More than 400 phytoliths were counted in each sample. Identification was aided by the use of reference materials and published keys for millet and rice phytoliths [9]. Phytolith abundance was expressed as a percentage of all phytoliths counted.

All the floatation samples were floated by bucket with a 0.2 mm mesh screen. After drying, the light fraction samples were sifted in sample sieves (2, 1, 0.7, and 0.5 mm), and the <0.5 mm fractions were excluded because no charred seeds were found in these tiny remains. The remaining samples were sorted under a Leica L2 binocular stereomicroscope. Charred seeds, fruits, and plant remains were removed from charcoal and stored in plastic tubes. The identification of the charred remains was performed by Changjiang Liu at the State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany CAS.

A total of nine samples were selected for AMS radiocarbon dating. The dating materials were mostly charcoal, except for two samples from Zhuangling and Wuluoxipo respectively, which were phytoliths. The phytoliths were extracted by Xinxin Zuo following an improved method described in Zuo et al. [10] and the purity of the extracted phytoliths has been proven to be reliable for dating [10]. The nine AMS dates obtained from the four analyzed sites are shown in Table S2. The ages cover the time interval 6417–5226 cal BC (95.4% range), which is consistent with the Peiligang cultural period.

At Wuluoxipo, a total of 3868 phytoliths were counted from nine samples in WLXPH1, of which three samples (60–70, 70–80, and 80–90 cm) contained crop phytoliths, including 7 pieces of common millet (*Panicum miliaceum*) husks (η-type: Fig. S1(a)) and 4 pieces of foxtail millet (*Setaria italica*) husks (Ω-type: Fig. S1(e)). The percentage of common millet was 0.24%–0.70%, while the percentage of foxtail millet was 0%–0.69%. In order to determine the relative proportion of common millet versus foxtail millet, their phytoliths were solely counted again in the three samples. The crop phytolith content of sample 60–70 cm was scarce and only 9 pieces of common millet husks were counted in one slide. By comparison, more than 200 crop phytoliths were counted in the other two samples. Finally, 268 phytoliths from common millet husks and 148 phytoliths from foxtail millet husks were found in these samples. The ratio of common and foxtail millet phytoliths was about 2:1. The number of charred seeds in the two samples from WLXPH1 is rather small. Only one seed of common millet was found (Fig. S2(a)), with a density of 0.07 seeds/L.

At Zhuangling, a total of 10,533 phytoliths were encountered in twenty-four samples, all of which contained crop phytoliths. In these samples, 376 phytoliths from common millet husks (η-type: Fig. S1c) and 63 phytoliths from foxtail millet husks (Ω-type: Fig. S1f) were found. The common millet phytoliths were dominant in all the samples, with the highest percentage reaching 13.94%, while that of foxtail millet was 1.60%.

At Lijiagou, a total of 436 phytoliths were identified from the one sample (LJG2) that contained one phytolith from common millet husks (η-type: Fig. S1b). The percentage of common millet phytolith was 0.23%. We observed another slide from this sample and found 3 pieces of common millet husks. Phytoliths of other crops were not found.

At Zhuzhai, a total of 5845 phytoliths were counted from twelve samples, of which nine samples contained crop phytoliths. Present in these samples were 448 pieces of common millet husks (η-type: Fig. S1d), 32 rice phytoliths (including 29 double-peaks and 3 rice bulliforms) (Fig. S1h, i), and 4 pieces of foxtail millet husks (Ω-type: Fig. S1g). The highest percentage of common millet was 40%, while the highest percentages of rice and foxtail millet were 5% and 0.6%, respectively. A total of 64 charred plant remains were found in four samples, with a density of 2.1 grains/L on average. The crops were present in low quantities, including five grains of common millet (Fig. S2b), six grains of foxtail millet (Fig. S2c), and one grain of rice (Fig. S2d), making up a small proportion of all the charred remains (18.75%).

Fig. 1(b) shows the relative percentage of crop phytoliths in the four analyzed sites and the Tanghu site [3]. According to the differences in the crop species found, these sites can be grouped into two sets. The first set contains Wuluoxipo, Zhuangling, and Lijiagou, which have only millets. Common millet was dominant in the three sites (63%–100% ratios). The second set contains Zhuzhai and Tanghu, which have not only millets, but also rice. Common millet dominated the two sites (88%–92% ratios), and the ratio of rice was 7%–12%, exceeding that of foxtail millet. It is also noted that the sites in the first set are located in the hilly lands, while the sites in the second set are located in the alluvial plains (Table S1).

Table 1 summarizes the archaeobotanical information about the crop remains from the thirteen Peiligang culture sites, including our analyzed sites. It can be seen that millet (either common millet or foxtail millet or both) was found in all ten hilly land sites, but rice was absent. Rice only occurred in the alluvial plain sites.

Table 1
Crop remains from the thirteen Peiligang culture sites.

Site	Geomorphic type	Crop	References
Wuluoxipo	Hilly lands	Foxtail millet (*C*; *P*)[a,b] Common millet (*C*; *P*)	This article and [2]
Zhuangling	Hilly lands	Foxtail millet (*P*) Common millet (*P*)	This article
Lijiagou	Hilly lands	Common millet (*P*)	This article
Egou	Hilly lands	Possible millet (*S*)[c]	[6,8]
Peiligang	Hilly lands	Possible millet (*S*)	[8]
Shawoli	Hilly lands	Possible millet (*S*)	[8]
Gangshi	Hilly lands	Possible millet (*S*)	[8]
Zhaigen	Hilly lands	Possible millet (*S*)	[7]
Bangou	Hilly lands	Possible millet (*S*)	[7]
Fudian	Hilly lands	Foxtail millet (*C*)	[2]
Zhuzhai	Alluvial plains	Foxtail millet (*C*; *P*) Common millet (*C*; *P*) Rice (*C*; *P*)	This article
Tanghu	Alluvial plains	Foxtail millet (*S*) Common millet (*P*) Rice (*P*; *S*)	[3,14]
Shigu	Alluvial plains	Possible millet (*S*)	[6,8]

[a] *C* = Charred seed.
[b] *P* = Phytolith.
[c] *S* = Starch grain.

Our research indicates that the sites located in the hilly lands only cultivated millet. Mixed farming of millet and rice may have been confined to the alluvial plains. The result confirms the coexistence relationship between millet farming and mixed farming during the Peiligang culture period in the middle Yellow River valley.

Scholars have suggested that ancient agricultural practices were influenced by various environmental factors such as climate, landform, soil, and hydrology [11]. During the Peiligang culture period (7000–5000 cal BC), all sites in the middle Yellow River valley were under the same climate conditions. According to our research, landform and hydrology were probably the main limiting factors for this spatial pattern of millet and mixed farming. On the other hand, this pattern could also be a result of human adaptation under different environmental settings.

The sites in the hilly lands were distributed on the loess terraces near the river, which was 30–60 m above the riverbed. This upland was not only far away from water sources but also had little flat land suitable for farming, which did not meet the needs of rice cultivation. Millet, especially common millet, has a low water requirement and could grow well in the loess with mean annual rainfall of 350–550 mm [12,13], thus making it more adaptable to environmental conditions in the hilly areas. Moreover, the sites in the hilly lands are likely to have been small villages or even to have been seasonal camp sites witnessing high levels of mobility [4]. Therefore, it was impossible for people there to devote time and energy to labor-intensive rice cultivation, which is why millet, a relatively short-season crop (usually mature in 80–120 days) requiring low-intensity dry cultivation [13], was preferred.

The sites in the alluvial plains usually occupied the tableland at the confluence of two rivers with a flat terrain 10–20 m above the riverbed. This lowland was vast and had abundant water and fertile soil, making it ideal for rice cultivation. In addition, the sites in the alluvial plains may have had higher levels of sedentism [4], which could have provided an opportunity for farmers to participate in continuous maintenance of rice along with dry farming, contributing to the formation of mixed agriculture with millet and rice at this site.

In contrast, the Jiahu site, a Peiligang culture site in the alluvial plain of Huai River valley, resulted in many rice remains but no millets [15]. The Jiahu site was bounded by a lake and two rivers, and a large amount of wild water food resources such as lotus (*Nelumbo nucifera*), water chestnut (*Trapa* sp.), fish bones, and shells were recovered along with rice [4,15], suggesting a wetland environment near the site. This environment was not suitable for millet cultivation, which needed a well-drained soil. Our results, together with findings from the Jiahu site, suggest that the local hydrological habitat had a significant influence on the proportion of millet to rice in the alluvial plains of different river valleys.

In conclusion, it is confirmed that millet farming and mixed millet and rice farming were concomitant in the Peiligang culture rather than one or the other. The spatial pattern of farming in the middle Yellow River valley during the Peiligang period was millet farming in the hilly lands, while mixed farming was conducted in the alluvial plains. In all Peiligang culture sites, regardless of whether millet farming or mixed farming was conducted, common millet was the most important crop in the records. In the same climate background, the agricultural mode selection in different sites was mainly influenced by landform and hydrology. This spatial pattern of farming also reflected human adaptive subsistence practices, which responded to different natural circumstances.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.scib.2017.10.003.

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