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Distinct water and field management by first wheat and barley cultivators in north China

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Abstract

Studies of 'food globalisation' have traced the disper- sal of cereals across prehistoric Eurasia. The degree to which these crops were accompanied by knowledge of soil and water preparation is less well known, how- ever. The authors use stable isotope and archaeobota- nical analyses to trace long-term trends in cultivation practices on the Loess Plateau (6000 BC–AD 1900). The results indicate that ancient farmers cultivated grains originating in South-west Asia and used dis- tinct strategies for different species. Barley was inte- grated into pre-existing practices, while wheat was grown using novel soil and water management strat- egies. These distinct approaches suggest that the spread of prehistoric crops and knowledge about them varied by local context.

Keywords: Loess Plateau, stable isotope analysis, archaeobotany, crop management, wheat and barley, millet

Introduction

This paper explores whether the eastern dispersal of wheat and barley into ancient China was accompanied by water management and planting systems that originated in the Fertile Crescent. The study employs stable isotope analysis to measure archaeobotanical remains recovered from 50 sites in order to ascertain the growing conditions—in particular, the water and soil status—of major crops cultivated between 6000 BCE and the 19th century CE in the western Loess Plateau in China.

Prehistoric farming dispersals across the Eurasian continent had profound social and ecological impacts on distant parts of the region, transforming the ancient societies that lived there (e.g. Jones et al. 2011, Liu et al. 2019). Between the 6th and the 2nd millennium BCE, wheat and barley spread from their center of origin in southwestern Asia into ancient China, while broomcorn and foxtail millet dispersed in the opposite direction: from northern China to southwestern Asia and Europe (e.g., Zhao 2012; Liu et al. 2017; Lightfoot et al. 2013). One of the major distinctions between eastern and western Eurasian agricultural systems is the variable seasonal demand for water. For example, broomcorn and foxtail millet are mostly sown in the spring and harvested in the autumn. These crops require a steady amount of water during the summer growing seasons but can tolerate water stress and poor soil conditions. Wheat and barley, on the other hand, are predominantly autumn-sown and grow in the winter. They can tolerate frosty conditions better, but require much higher amounts of water and soil nutrients compared to millets.

How early wheat and barley cultivators in ancient China managed their fields—whether using strategies employed by southwestern Asian farmers or strategies more familiar to local millet cultivators—remains unknown. To address this gap in knowledge, we engage with recent archaeological discoveries at Zhuanglang, a county in the Gansu Province situated in the western Loess Plateau and investigate the long-term farming strategies through macrofossil and stable isotope analyses. These approaches enable direct assessment of past crop watering regimes and growing conditions and shed light on the manner in which cultivation was configured at the crossroad of eastern and western farming systems.

Stable isotope analysis of plant remains

Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope values of charred plant remains enable the investigation of the plants' growing conditions. In particular, $\delta^{13}C$ values can be used to infer crop water status, where increasingly lower $\delta^{13}C$ values signal higher water availability during the grain filling period (e.g., Farquhar et al. 1982, Araus et al. 1999, Wallace et al. 2013; Flohr et al. 2011), while $\delta^{15}N$ values allow the assessment of soil ^{15}N enrichment caused by natural factors (e.g. salinity, denitrification) or anthropogenic factors (e.g. application of farmyard manure, organic waste or other decomposing organic matter) (Bogaard et al. 2007; Fraser et al. 2011). Bulk analyses of archaeological plant $\delta^{13}C$ and $\delta^{15}N$ values have shed light on early crop management in Europe and the Middle East, illuminating insight into the antiquity of manuring practice and systematic water management as far back as the 6th millennium BCE (Bogaard et al. 2013; Wallace et al. 2015).

Interpretation of charred crop $\delta^{13}C$ and $\delta^{15}N$ values relies on principles that have been established through measurement of crops grown in controlled experiments and traditional non-mechanized farming settings in Europe and the eastern Mediterranean (Bogaard et al. 2007; Fraser et al. 2011), North Africa (Styring 2016) and South Asia (Jones et al. 2021). These studies provide comparative estimates of the degree of ^{13}C and ^{15}N enrichment caused by varying crop water and soil fertility status.

Zhuanglang county

Zhuanglang county is located in the western part of the Loess Plateau. It lies on the western foothills of the Liupan Mountains, covering an area of approximately 1500 km^2 (Figure 1). The environment is characterized by a continental monsoon climate, with a mean annual temperatures of around 7.9 °C and mean annual precipitation of about 550 mm/year, peaking between July and September. Within Zhuanglang, altitudes gradually decline from the northeast to the southwest, with the highest elevation reaching 2857 masl (meters above sea level) at Peach Hill and the lowest elevation reaching 1405 masl at Zhangjiawan. Two main inland rivers, the Hulu and Shuiluo, flow through this region.

Paleoenvironmental reconstruction of the region suggests that the western Loess Plateau became increasingly arid over the course of the mid to late Holocene due to the weakening of the East Asian Summer Monsoon and the effect of 4.2 ka event (Wang et al. 2005, Dykoski et al. 2005). At a local level, analysis of sediment cores from the nearby Tianchi Lake—a unique high-altitude freshwater lake situated at Zhuanglang in the Liupan Mountains—show a highly complex climate history with a relatively wet environment between 6200 and 2900 cal. BP, followed by increased aridification that peaked around 1100 cal. BP in Zhuanglang (Zhou et al. 2010).

The prehistoric cultural phase groups in this area, reconstructed using archaeological remains (e.g., Bureau of National Cultural Relics 2011; Wang 2012), include Dadiwan phase I (6000–5300 BCE), Early (4300–4000 BCE) and Middle–Late Yangshao (4000–2300 BCE), Qijia (2300–1500 BCE), Siwa (1500–300 BCE) periods (Wang 2012). The historical era can be divided into several sequential dynastic episodes, including the Han–Tang (202 BCE–907 CE), Song–Yuan (960–1368 CE), Ming–Qing (1368–1911 CE). We use a six-phase sequence (from Middle–Late Yangshao to Ming–Qing), which has been examined using 35 radiocarbon measurements (detailed below) as a general chronological framework in this study. See Figure 4 for details of the prehistoric and historic chronological sequences, including the results of radiocarbon measurements.

Material and methods

50 archaeological sites were excavated in Zhuanglang in 2013 (see Figure 1 for locations and Supplementary Table S1 for site information). 124 soil samples were collected for flotation, which was carried out in the field using a 'Flote-Tech' machine described by Rossen (1999) (see Supplementary File 1&2). Collected light fractions were subsequently analyzed at the Institute of Archaeology, Chinese Academy of Social Sciences. 35 selected charred cereal remains (including wheat, barley, broomcorn and foxtail millet) were directly dated using AMS radiocarbon dating at the MOE Key Laboratory of Western China's Environmental Systems, Lanzhou University (n=12) and Radiocarbon Accelerator Laboratory, Peking University (n=23). Additional three specimens were radiocarbon dated by Beta Analytic (Supplementary 3 and Table S2). Sample pretreatment for isotopic measurement was carried out at the McDonald Institute for Archeological Research, Cambridge, using a gentle acid protocol described in Vaiglova et al. (2014). Stable isotope measurements were carried out at Godwin Laboratory, Cambridge, using an automated Costech elemental analyzer coupled with a continuous flow mode to a Thermo Finnigan MAT253 mass spectrometer (see Supplementary File 4 for complete method details).

Archaeobotanical assemblages

Over 35,000 charred seed remains were identified from 124 flotation samples collected from 50 archaeological sites in Zhuanglang. The most identifiable grains were cereals: foxtail millet (*Setaria italica*), broomcorn millet (*Panicum miliaceum*), free-threshing wheat (*Triticum* cf. *aestivum*), barley (*Hordeum vulgare*) (Figure 3), oat (*Avena sativa*), buckwheat (*Fagopyrum esculentum*) and sorghum (*Sorghum bicolor*). Pulses include pea (*Pisum sativum*), lentil (*Lens culinaris*), mung bean (*Vigna radiata*) and cowpea (*Vigna unguiculata*). Other economically important plants include flax (*Linum* *usitatissimum*), sesame (*Sesamum indicum*), hemp (*Cannabis sativa*), rapeseed (*Brassica napus*), and Sichuan pepper (*Zanthoxylum bungeanum*) (Figure S1).

Chronological changes in the taxonomic structure of the flotation samples reflect long-term transitions in cropping systems that took place over the six millennia (Figure 4). The complete assessment of the composition of the archaeobotanical assemblage is ongoing (Li *et al. in prep*.). In brief, two indigenous millet crops dominate the assemblages dated to the Yangshao (4300–2300 BCE) and the Qijia (2300–1500 BCE) period. Southwestern Asian crops (wheat and barley) started to appear in the Qijia culture and become more visible in the Siwa (1500–300 BCE, with a higher incidence of barley than wheat at this time). The crop assemblages became increasingly diversified during the historical times since the Han-Tang dynasties (220 BCE–907 CE) until wheat and barley become the dominant cereals during the Song-Yuan (960–1368 CE) and the Ming-Qing (1368–1911 CE) periods.

53 species of weedy/herbal plants have also been identified, including milkvetch root (*Astragalus membranaceus*), foxtail grass (*Setaria viridis*), patelliform tickseed (*Corispermum hyssopifolium*), sweet clover (*Melilotus suaveolens*), mallow (*Malva sinensis*), sea-buckthorn (*Hippophae rhamnoides*), three-horned bedstraw (*Galium tricorne*), goosefoot (*Chenopodium album*), bush vetch (*Vicia sepium*), wild soybean (*Glycine soja*), rough fruit corn bedstraw (*Galium tricorne*), basil (*Erilla frutescen*), and licorice (*Glycyrrhiza uralensis*), to name the main ones (See Figure S1 and Table S1 for a complete list).

Stable isotope results

This study applies the interpretative framework established by Wallace et al. (2013) that uses plant $\Delta^{13}C$ values (converted from $\delta^{13}C$ values to account for the fluctuations in atmospheric $\delta^{13}C_{CO2}$ as detailed in Supplementary File 4) to assess crop water status.

The framework takes into account the physiologically-mediated difference in carbon isotope assimilation between wheat and barley, such that barley tends to have $\Delta^{13}C$ values 1–2 ‰ higher compared to wheat when grown under the same watering conditions (Wallace et al. 2013, Voltas et al. 1999). Here, the original Wallace et al.'s (2013) divisions between 'poorly watered' and 'moderately watered plants' are referred to as 'Optimal Watering Threshold' (OWT; 16.0 ‰ for wheat and 17.0 ‰ for barley) while the division between 'moderately watered' and 'well watered plants' is referred to as the 'Superfluous Watering Threshold' (SWT; 17.0 ‰ for wheat and 18.5 ‰ for barley), reflecting whether or not the water status was limiting to the plants growth (e.g. Vaiglova et al. 2021). For millet crops, a positive relationship between $\delta^{13}C$ and water availability has been previously documented (e.g., Reid et al. 2018; An et al. 2015a). However, due to the relatively small differences (< 2.0 ‰) between millets grown under varying watering regimes, as well as large intra-plant variation in stable carbon isotope values, millet $\delta^{13}C$ values are more challenging to employ in interpretations of past water management practices (Lightfoot et al. 2016, Sanborn et al. 2021).

Stable isotope results of the plant samples analyzed in this study are reported in Table S1 and summarized in Table 1. Over half of the wheat samples (n=26) yielded $\Delta^{13}C$ values above the OWT, with six samples above the SWT (Figure 5a), suggesting that water availability did not pose a limitation to this plant's growth. Nearly all samples (n=21) except for one barley are situated below the SWT with two thirds (n=13) yielding $\Delta^{13}C$ below the OWT, suggesting that this crop was cultivated under water-limiting conditions. The results do not appear to show significant changes in wheat and barley $\Delta^{13}C$ values through time, however, large intra-group variabilities preclude a meaningful assessment of chronological shifts. Both wheat and barley have indistinguishable $\Delta^{13}C$ values in the time periods under study (analysis of variance, wheat: $F(4, 21) = 1.924$, $p = 0.144$; barley: $F(4, 16) = 0.686$, $p = 0.612$). Similarly, no significant difference appears in the $\delta^{13}C$ values of the foxtail and broomcorn millet (foxtail millet: $F(5,72) = 1.122$, $p = 0.356$; broomcorn millet: $F(5, 72) = 0.442$, $p = 0.818$) among different time groups.

To assess the relative amounts of manure applied to the cultivation of the crops taking into account variations in precipitation, this study employs the framework established by Styring et al. (2016), which takes into account variable precipitation. Given that the current mean annual precipitation in Zhuanglang is c. 550 mm, the estimated threshold of plant $\delta^{15}N$ values for low, medium and high manuring levels is about 2.5 ‰, 3.5 ‰, and 8.5 ‰, respectively. A local vegetation baseline is estimated to be c. 1.9 ‰ based on average $\delta^{15}N$ values of herbivore from prehistoric western Loess Plateau using a diet to tissue offset of 4.5 ‰ (Ma et al. 2014; Barton et al. 2009; Ma et al. 2016).

All crop samples (apart from one outlier) yield $\delta^{15}N$ values above the estimated medium manuring and significantly higher than the local vegetation baseline. No meaningful differences were identified using analysis of variance between the time groups represented in the analyzed species (wheat: $F(4, 20) = 0.429$, $p = 0.786$; barley: $F(4, 16) = 0.845$, $p = 0.517$; foxtail millet: $F(5, 67) = 1.339$, $p = 0.259$; broomcorn millet: $F(5, 69) = 2.165$, $p = 0.068$). The lack of meaningful differences between the $\delta^{15}N$ values of wheat and barley suggests that those crops were cultivated in similar soil conditions throughout the time period under investigation.

Discussion

The results suggest that past farmers across the Zhuanglang county employed water management systems to cultivate domestic crops. Most of the wheat samples from all time periods are located above the OWT (Figure 5), indicating that their growth was not limited by water availability. Given the arid local environment and the water-demanding nature of wheat, this could not be achieved without some form of artificial water manipulation. However, these efforts do not necessarily imply irrigation or deliberate hand watering (such evidence is currently lacking in the archaeological records). The wheat crops may have been strategically sown in areas with better water availability, either close to local springs or in soils with high water retention. It should be noted that this practice is herein evidenced as far back as the Qijia and Siwa cultures dating to the 2^{nd} millennium BCE, suggesting that strategic cultivation was already in use by the first cultivators of this crop in the study region.

In contrast, barley $\Delta^{13}C$ values show pronounced water stress, as most barley samples fall below the OWT, indicating that plant growth was constrained by water availability. This suggests that wheat and barley were likely cultivated under different water regimes or planted at different locations. Figure 6 shows the locations of sites where wheat grains outnumbered barley in the archaeobotanical assemblages or *vice versa*. The map indicates that most of the sites are located close to local springs and rivers. However, the sites with more barley grains are more frequently situated at higher altitudes in the hilly areas close to the Liupan Mountains, while sites where wheat dominates are located at lower altitudes, such as Hulu and Shuiluo river valleys (see Figure 7a and 7b for examples of typical landscapes of river sites and hill sites). Ecologically, barley can tolerate drier growing conditions better than wheat, and this strategy would have maximized the overall crop yields and optimized the land use in a region where water availability is a major limitation.

The differential strategies in planting wheat and barley are reflected in the carbon isotope values of the two cereals, which indicate the water stress of barley regardless of the location (Figure 7d). As far as wheat is concerned, however, grains from hill sites have been found to have higher $\Delta^{13}C$ values compared to those from lower locations (Figure 7c). This suggests the wheat crops at hill sites received special water treatment in order to buffer the otherwise naturally dry conditions. This further supports that grain types held differential status in human cuisines and diets, as has been discussed elsewhere (Liu and Reid 2020). Such differential strategies have also been evidenced in northern Mesopotamia, where barley was cultivated in drier locations compared to wheat and pulses, which were sown near the local wadis (Styring et al. 2017).

The archaeobotanical record shows that millets were present (often in large quantities) at almost every site regardless of topography, signifying their importance in the local subsistence systems through time. As mentioned above, $\delta^{13}C$ values are more challenging to use for inferring the water status of C_4 plants. However, it has been postulated that the early Neolithic farmers in the Loess Plateau initially cultivated broomcorn and foxtail millet at slow slopes near mountain foothills, in order to take advantage of seasonal fluctuation in soil moisture in the summer monsoonal conditions (Liu et al. 2009). Hill sites surrounding the Liupan Mountains are classical examples of that type of farming system (Figure 7b, Shangping exemplifies a typical 'millet' landscape where barley grains became abundant since c. 4000 BP). Thus, if barley was cultivated in similar conditions in which millet has been cultivated in the region for thousands of years prior to introduction of barley crops, the new insight suggests that barley (but not wheat), was incorporated directly into the locally developed farming systems. Wheat, on the other hand, was introduced to this region along with knowledge on its optimal cultivation (i.e. in soils with human-mediated water availabilities), which allowed farmers to explore landscapes that were previously untenable during the Neolithic with millet alone.

Arable weeds are often used to infer crop growing conditions and can provide complimentary evidence to stable carbon isotope indicators of water status (e.g. Bogaard et al. 2016). However, in the study assemblages, water-demanding taxa are virtually absent (Table S1). *Carex* (which is sometimes used as an indicator of field irrigation due to its adaptation to open and well-watered soils; Rühl et al. 2015, Motuzaite Matuzeviciute et al. 2020), *Malva*, *Polygonum*, and *Cyperaceae* appear in very low numbers, while *Stellaria* is absent. This mismatch between the isotopic and archaeobotanical evidence may indicate intensive weeding activities or removal of weeds during crop processing, which would support the idea of the labor-intensive nature of wheat cultivation (with irrigation, weeding, intensive processing, all at high labor costs). A more detailed analysis of the weed ecology and crop processing activities represented at the study sites will help further illuminate this issue (Li et al. in prep.).

The wide range of crop $\delta^{15}N$ values indicates that all four cereals (wheat, barley, broomcorn and foxtail millet) were cultivated in variable soil conditions throughout the six phases. This variability might be the result of several natural and anthropogenic causes of soil ^{15}N enrichment, including aridity, soil denitrification and manuring. Aridity would be expected to influence both cultivated crops and herbivore forage. In the current dataset, however, the $\delta^{15}N$ values of all four cereals are higher compared to the local vegetation baseline, suggesting that aridity is unlikely to be the main cause of crop ^{15}N-enrichment. Denitrification may cause ^{15}N-enrichment of soils affected by seasonal high-volume floods (Finlay et al. 2008). This could explain the high $\delta^{15}N$ values of wheat, which may have been cultivated on seasonally flooded riverbeds. However, barley—which retains equally high $\delta^{15}N$ values—was likely cultivated on dry soils and at higher elevations, so seasonal flooding is unlikely to explain the elevated $\delta^{15}N$ values of both crops.

Soil can be enriched in ^{15}N as a result of the application of animal manure or organic waste, and this practice has been suggested for wheat and barley cultivation in Southwest Asia and Europe since at least the 6th millennium BCE (Bogaard et al., 2013; Styring et al., 2017; Vaiglova et al., 2020). Data from this study seem to suggest that similar practices employing manuring/middening of wheat and barley fields formed an integral part of the agricultural strategy since the introduction of those crops in prehistoric China.

As far as millet is concerned, it is worth noting that controlled experiments have shown no direct correlation in millet (*Setaria* and *Pennisetum*) $\delta^{15}N$ values with water availability (Lightfoot et al. 2019, Sanborn et al. 2021). This is consistent with the observation that the global trends are consequences of environmental parameters affecting soil $\delta^{15}N$ values, rather than results of plant physiology (Reid et al. 2018, Sanborn et al. 2021). Additionally, one experiment using foxtail millet showed large (up to 6 ‰) variability in $\delta^{15}N$ values between millet grown under varying water regimes (Lightfoot et al. 2018). Another experiment using pearl millet showed a comparatively low overall isotopic variability (c. 2 ‰ in seed; Sanborn et al. 2012). In other words, water availability does not lead to either high or low millet $\delta^{15}N$ values, but could potentially enlarge the isotopic variability. Therefore, the observed distinct high nitrogen isotope values in millet crops need an explanation beyond water availability. The results from this study show significant high millet $\delta^{15}N$ values compared to not only the local vegetation baseline but also the $\delta^{15}N$ values of modern foxtail grass—a feral/ancestral relative to foxtail millet—in this region (An et al. 2015b). Although modern manuring experimental data for broomcorn and foxtail millet is currently lacking, our results do hint at manuring as a likely possibility.

Overall , the results suggest that anthropogenic activities such as manuring were the likely cause of ^{15}N enrichment in wheat and barley, and possibly in broomcorn and foxtail millet as well. The current isotopic evidence is unambiguous in supporting the first scenario, less clear but likely in the second. The lack of significant variation in crop $\delta^{15}N$ values through time implies that the cultivation strategies remained relatively stable in terms of soil conditions over the eight millennia represented in the dataset. This contrasts with the situation in the Near East, where a general trend of decreasing cereal grain $\delta^{15}N$ values has been observed through time, which has been attributed to a decrease in soil fertility caused by changing labour organization (Strying et al. 2017).

Conclusion

The data presented in this study enable three main inferences. Firstly, pioneering wheat cultivators in the ancient Loess Plateau manipulated water resources to meet the demand of this non-native crop. This may have been achieved by either deliberate watering or strategic planting in soils with high water retention capacity. Secondly, the results indicate that different strategies were employed to cultivate barley in drier locations at higher elevations compared to wheat near the local rivers in lower environments. This may have been carried out in order to optimize land use and crop yield by taking advantage of different water demands of wheat and barley. Thirdly, the observed high $\delta^{15}N$ values of cereal crops indicate that the crops were cultivated using farmyard manure, which has a positive effect on soil and plant $\delta^{15}N$ values. These observations resonate with the recent discussion of the novel relationship between non-local domesticates and indigenous customs (e.g. Vaiglova et al. 2021b). In the western Loess Plateau, people adopted the traditional rain-fed strategy to grow barley in dry hills and cultivate wheat under novel water regimes. The former represents continuity and the latter a departure from the long-standing rain-fed farming practices at slow hills in the Loess Plateau since 8000 BP.

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References

AN, C. B., DONG, W., LI, H., ZHANG, P., ZHAO, Y., ZHAO, X., & YU, S. Y. 2015a. Variability of the stable carbon isotope ratio in modern and archaeological millets: evidence from northern China. *Journal of Archaeological Science* 53: 316-322. https://doi.org/10.1016/j.jas.2014.11.001

AN, C. B. *et al*. 2015b. Stable isotopic investigations of modern and charred foxtail millet and the implications for environmental archaeological reconstruction in the western Chinese Loess Plateau. Quaternary Research 84(1): 144-149. https://doi.org/10.1016/j.yqres.2015.04.004

ARAUS, J. L., FEBRERO, A., CATALA, M., MOLIST, M., VOLTAS, J., & ROMAGOSA, I. 1999. Crop water availability in early agriculture: evidence from carbon isotope discrimination of seeds from a tenth millennium BP site on the Euphrates. *Global change biology* 5(2): 201-212. https://doi.org/10.1046/j.1365-2486.1999.00213.x

BARTON, L. W. 2009. Early food production in China's western Loess Plateau. Unpublished PhD Dissertation. *University of California, Davis*.

BOGAARD, A. *et al*. 2013. Crop manuring and intensive land management by Europe's first farmers. *Proceedings of the National Academy of Sciences* 110(31): 12589-12594. https://doi.org/10.1073/pnas.1305918110

BOGAARD, A., HEATON, T. H., POULTON, P., & MERBACH, I. 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34(3):335-343. https://doi.org/10.1016/j.jas.2006.04.009

BOGAARD, A. *et al*. 2016. Combining functional weed ecology and crop stable isotope ratios to identify cultivation intensity: a comparison of cereal production regimes in Haute Provence, France and Asturias, Spain. *Vegetation History and Archaeobotany* 25: 57-73.

Bureau of National Cultural Relics. 2011. *Atlas of Chinese Cultural Relics—Fascicule of Gansu Province*. Beijing, Surveying and Mapping Press. (in Chinese).

DONG, G., YANG, Y., ZHAO, Y., ZHOU, A., ZHANG, X., LI, X., & CHEN, F. 2012. Human settlement and human–environment interactions during the historical period in Zhuanglang County, western Loess Plateau, China. *Quaternary International* 281: 78-83. https://doi.org/10.1016/j.quaint.2012.05.006

DYKOSKI, C. A., EDWARDS, R. L., CHENG, H., ET AL. 2005. A high-resolution, absolute-dated Holocene and deglacial Asian Monsoon record from Dongge Cave, China. *Earth and Planetary Science Letters* 233 (1-2): 71-86.

FARQUHAR, G. D., & SHARKEY, T. D. 1982. Stomatal conductance and photosynthesis. *Annual Review of Plant Physiology* 33(1): 317-345.

FINLAY, J. C., KENDALL, C., MICHENER, R., & LAJTHA, K. 2008. Stable isotopes in ecology and environmental science. *Stable Isotope tracing of temporal and spatial variability in organic matter sources to freshwater ecosystems* 283-324.

FLOHR, P., MÜLDNER, G., & JENKINS, E. 2011. Carbon stable isotope analysis of cereal remains as a way to reconstruct water availability: preliminary results. *Water History* 3(2): 121. https://doi.org/10.1007/s12685-011-0036-5

FRASER, R. A. *et al*. 2011. Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. *Journal of Archaeological Science* 38(10): 2790-2804. https://doi.org/10.1016/j.jas.2011.06.024

JONES, M., HUNT, H., LIGHTFOOT, E., LISTER, D., LIU, X., & MOTUZAITE-MATUZEVICIUTE, G. 2011. Food globalization in prehistory. *World Archaeology* 43(4): 665-675. https://doi.org/10.1080/00438243.2011.624764

JONES, P. J., O'CONNELL, T. C., JONES, M. K., SINGH, R. N., & PETRIE, C. A. 2021. Crop water status from plant stable carbon isotope values: A test case for monsoonal climates. *The Holocene* 31(6): 993-1004. https://doi.org/10.1177/0959683621994649

LI, H. et al. *in prep*. Archaeobotanical remains reflected the long-term transition in agriculture of Western China Loess Plateau from 4th millennium BC to AD 19th Century.

LIGHTFOOT, E., PRZELOMSKA, N., CRAVEN, M., O′ CONNELL, T. C., HE, L., HUNT, H. V., & JONES, M. K. 2016. Intraspecific carbon and nitrogen isotopic variability in foxtail millet (*Setaria italica*). *Rapid Communications in Mass Spectrometry* 30(13):1475-1487. https://doi.org/10.1002/rcm.7583

LIGHTFOOT, E., CEMRE USTUNKAYA, M., PRZELOMSKA, N., O′ CONNELL, T. C., HUNT, H. V., JONES, M. K., & PETRIE, C. A. 2016. Carbon and nitrogen isotopic variability in foxtail millet (*Setaria italica*) with watering regime. *Rapid Communications in Mass Spectrometry* 34(6):e8615.

LIGHTFOOT, E., LIU, X., & JONES, M. K. 2013. Why move starchy cereals? A review of the isotopic evidence for prehistoric millet consumption across Eurasia. *World Archaeology* 45(4): 574-623. https://doi.org/10.1080/00438243.2013.852070

LIU, X. *et al*. 2019. From ecological opportunism to multi-cropping: Mapping food globalisation in prehistory. *Quaternary Science Reviews* 206: 21-28. https://doi.org/10.1016/j.quascirev.2018.12.017

LIU, X. *et al.* 2017. Journey to the east: Diverse routes and variable flowering times for wheat and barley *en route* to prehistoric China. *PLoS One* 12(11): e0187405. https://doi.org/10.1371/journal.pone.0187405

LIU, X., HUNT, H. V., & JONES, M. K. 2009. River valleys and foothills: changing archaeological perceptions of North China's earliest farms. *Antiquity* 83(319): 82-95. https://doi.org/10.1017/S0003598X00098100

LIU, X., & REID, R. E. B. 2020. The prehistoric roots of Chinese cuisines: Mapping staple food systems of Chin, 6000 BC – 220 CE. *PLoS ONE* 15(11): e0240930. https://doi.org/10.1371/journal.pone.0240930

MA, M., DONG, G., JIA, X., WANG, H., CUI, Y., & CHEN, F. 2016. Dietary shift after 3600 cal yr BP and its influencing factors in northwestern China: Evidence from stable isotopes. *Quaternary Science Reviews* 145: 57-70. https://doi.org/10.1016/j.quascirev.2016.05.041

MA, M. M. *et al*. 2014. Stable Isotope Analysis of Human and Faunal Remains in the Western Loess Plateau, Approximately 2000 cal. BCE. *Archaeometry* 56: 237-255. https://doi.org/10.1111/arcm.12071

MOTUZAITE MATUZEVICIUTE, G., MIR-MAKHAMAD, B., & TABALDIEV, K. R. 2021. The first comprehensive archaeobotanical analysis of prehistoric agriculture in Kyrgyzstan. *Vegetation History and Archaeobotany* 30: 743-758.

REID, R. E., LALK, E., MARSHALL, F., & LIU, X. 2018. Carbon and nitrogen isotope variability in the seeds of two African millet species: *Pennisetum glaucum* and *Eleusine coracana*. *Rapid Communications in Mass Spectrometry* 32(19): 1693-1702. https://doi.org/10.1002/rcm.8217

ROSSEN, J. 1999. The Flote-Tech flotation machine: messiah or mixed blessing? *American Antiquity* 64(2): 370-373. https://doi.org/10.2307/2694286

RÜHL, L., HERBIG, C., & STOBBE, A. 2015. Archaeobotanical analysis of plant use at Kamennyi Ambar, a Bronze Age fortified settlement of the Sintashta culture in the southern Trans-Urals steppe, Russia. *Vegetation History and Archaeobotany* 24: 413-426.

SANBORN, L. H., REID, R. E., BRADLEY, A. S., & LIU, X. 2021. The effect of water availability on the carbon and nitrogen isotope composition of a C4 plant (pearl millet, *Pennisetum glaucum*). *Journal of Archaeological Science: Reports 38*: 103047. https://doi.org/10.1016/j.jasrep.2021.103047

STYRING, A. K. *et al.* 2017. Isotope evidence for agricultural extensification reveals how the world's first cities were fed. *Nature Plants* 3(6): 17076. https://doi.org/10.1038/nplants.2017.76

STYRING, A. K. *et al.* 2016. Disentangling the effect of farming practice from aridity on crop stable isotope values: A present-day model from Morocco and its application to early farming sites in the eastern Mediterranean. *The Anthropocene Review*, 3(1), 2-22. https://doi.org/10.1177/2053019616630762

VAIGLOVA, P., REID, R.E.B., LIGHTFOOT, E. *et al.* 2021. Localized management of non-indigenous animal domesticates in Northwestern China during the Bronze Age. *Scientific Reports* 11**:**15764. https://doi.org/10.1038/s41598-021-95233-x

VAIGLOVA, P., GARDEISEN, A., BUCKLEY, M., CAVANAGH, W., RENARD, J., LEE-THORP, J., & BOGAARD, A. 2020. Further insight into Neolithic agricultural management at Kouphovouno, southern Greece: expanding the isotopic approach. *Archaeological and Anthropological Sciences* 12(2): 1-17. https://doi.org/10.1007/s12520-019-00960-y

VAIGLOVA, P., SNOECK, C., NITSCH, E., BOGAARD, A., & LEE-THORP, J. 2014. Impact of contamination and pretreatment on stable carbon and nitrogen isotopic composition of charred plant remains. *Rapid Communications in Mass Spectrometry* 28(23): 2497-2510. https://doi.org/10.1002/rcm.7044

VOLTAS, J., ROMAGOSA, I., LAFARGA, A., ARMESTO, A. P., SOMBRERO, A., & ARAUS, J. L. 1999. Genotype by environment interaction for grain yield and carbon isotope discrimination of barley in Mediterranean Spain. *Australian Journal of Agricultural Research* 50(7): 1263-1271. https://doi.org/10.1071/AR98137

WALLACE, M. P., JONES, G., CHARLES, M., FRASER, R., HEATON, T. H., & BOGAARD, A. 2015. Stable carbon isotope evidence for Neolithic and Bronze Age crop water management in the eastern Mediterranean and southwest Asia. *PlOS ONE 10*(6): e0127085. https://doi.org/10.1371/journal.pone.0127085

WALLACE, M., JONES, G., CHARLES, M., FRASER, R., HALSTEAD, P., HEATON, T. H., & BOGAARD, A. 2013. Stable carbon isotope analysis as a direct means of inferring crop water status and water management practices. *World Archaeology* 45(3): 388-409.

https://doi.org/10.1080/00438243.2013.821671

WANG, H. 2012. Ganqing diqu xinshiqi-qingtong shidai kaoguxue wenhua de puxi yu geju (Geography and chronology of archaeological cultures in Gansu and Qinghai during the Neolithic and Bronze Age). *Kaoguxue yanjiu (Archaeological Research)* 9: 210-243 (in Chinese).

WANG, Y. J. *et al*. 2005. The Holocene Asian monsoon: Links to solar changes and North Atlantic climate. *Science* 308: 854-857.

ZHAO, Z. 2011. New archaeobotanical data for the study of the origins of agriculture in China. *Current Anthropology* 52(S4), S295-S306. https://doi.org/10.1086/659308

ZHOU, A., SUN, H., CHEN, F., ZHAO, Y., AN, C., DONG, G., WANG, Z., CHEN, J. 2010. High-resolution record at Tianchi Lake in the Liupan Mountains reveals climate changes in the Loess Plateau during the middle and late Holocene. Chinese Science Bulletin 55 (22): 2263-2266.

Figures

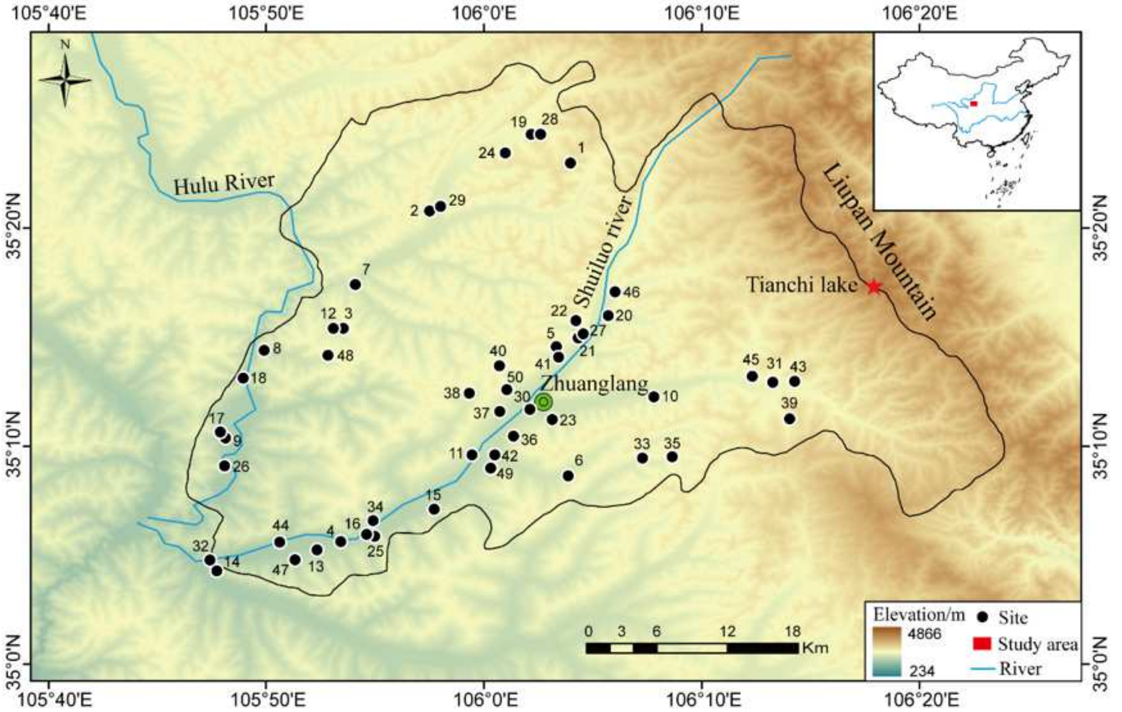

Figure 1. Locations of sites under investigation at Zhuanglang. (1) Nanhugucheng; (2) Wowoping (3) Dujiagoumen; (4) Tijiaping; (5) Buziping; (6) Yujiawan; (7) Shangping; (8) Dongshanzui; (9) Taijiazui; (10) Caojiayuan; (11) Yuliaobuzi; (12) Gaozhuang; (13) Shaojiaping; (14)Xiaodunshan; (15) Jiajiaping; (16) Jiuyuan; (17) Shidongmen; (18) Sumiaoyuantou; (19) Dazuiliang; (20) Duanshanping; (21) Wanerwa; (22) Daping; (23) Taijiguan; (24) Xuanmaoding; (25) Wanjiayuan; (26) Yaping; (27) Yejiabuzi; (28) Hexianzui; (29) Dadichuan; (30) Guanqianmen; (31) Yujiayuan; (32) Chuankouliujia; (33) Guajiazhuang; (34) Liubuping; (35) Caiziwa; (36) Guajiazhuang; (37) Siping; (38) Yumushuwan; (39) Lishuwa; (40) Shuiluocheng; (41) Xulinian; (42) Wujiachuan; (43) Jiajiahewan; (44) Zhangjiayuan; (45) Ximianyuan; (46) Xujiacheng; (47) Shimenkou; (48) Yaerzui; (49) Guandi; (50) Xihe.

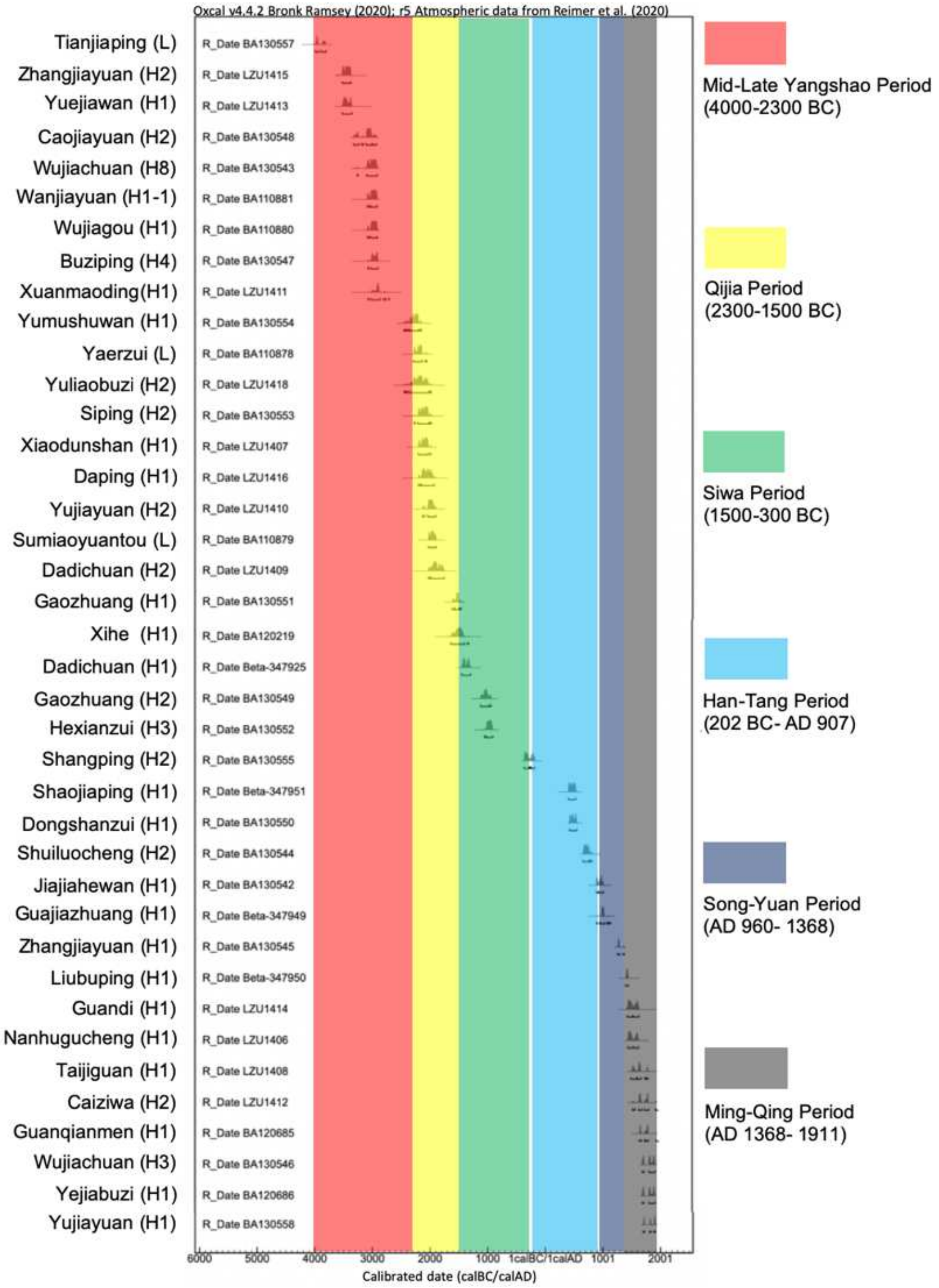

Figure 2. 38 radiocarbon determinations of four cereals (wheat, barley, broomcorn and foxtail millet) from study sites fall into six prehistoric and historic phases spanning six millennia.

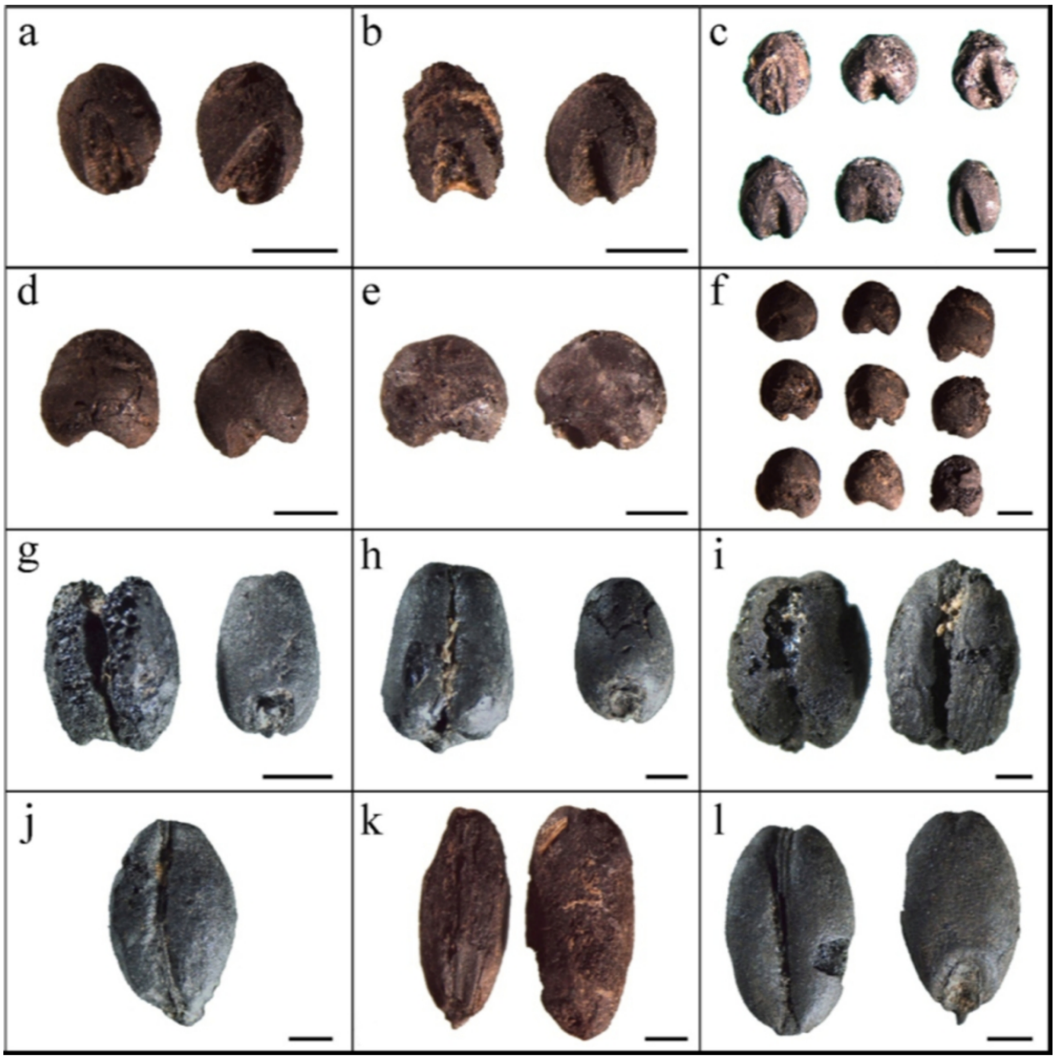

Figure 3. Charred plant remains recovered from sites in Zhuanglang: a) Foxtail millet from Xuanmaoding-H1; b) Foxtail millet from Shaojiaping-H1; c) Foxtail millet from Dongshanzui-H2; d) Broomcorn millet from Shangping-H2-1; e) Broomcorn millet from Dadichuan-H1; f) Broomcorn millet from Caojiayuan-H2; g) Wheat from Hexianzui-H1; h) Wheat from Liubuping-H1; i) Wheat from Dongshanzui-H2; j) Barley from Gaozhuang-H1; k) Barley from Yujiayuan-H1; l) Barley from Shangping-H2-1.

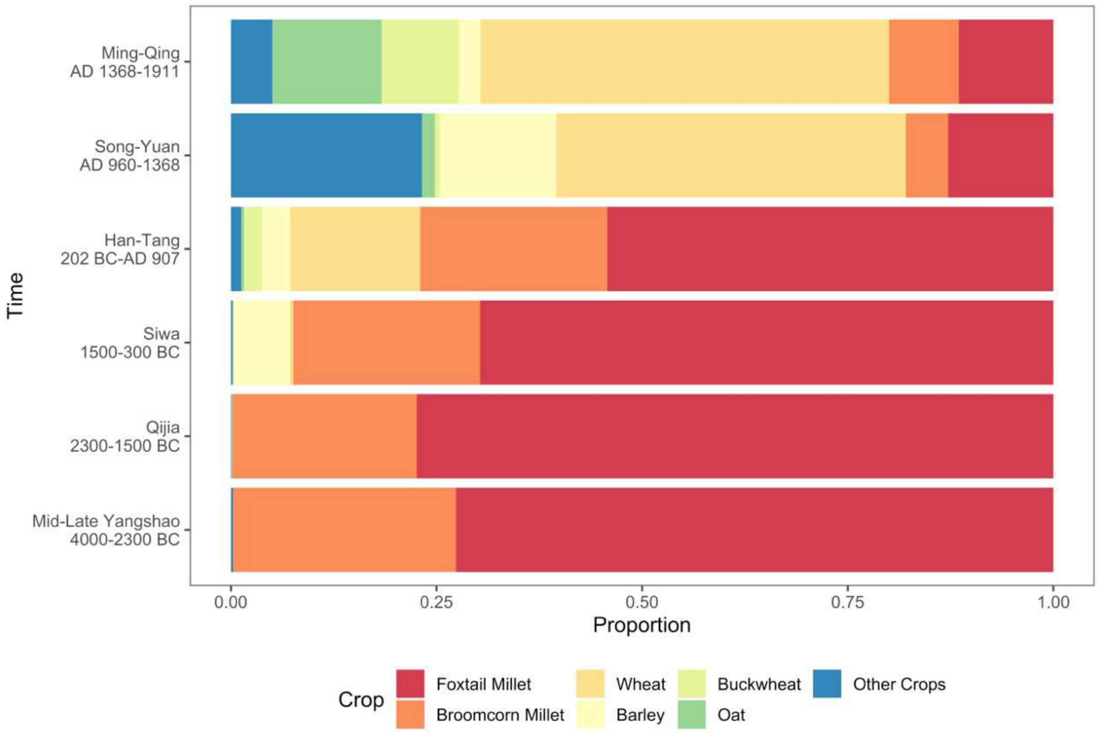

Figure 4. Diachronic changes in the taxonomic combination of major cereals throughout the prehistoric and historical phases.

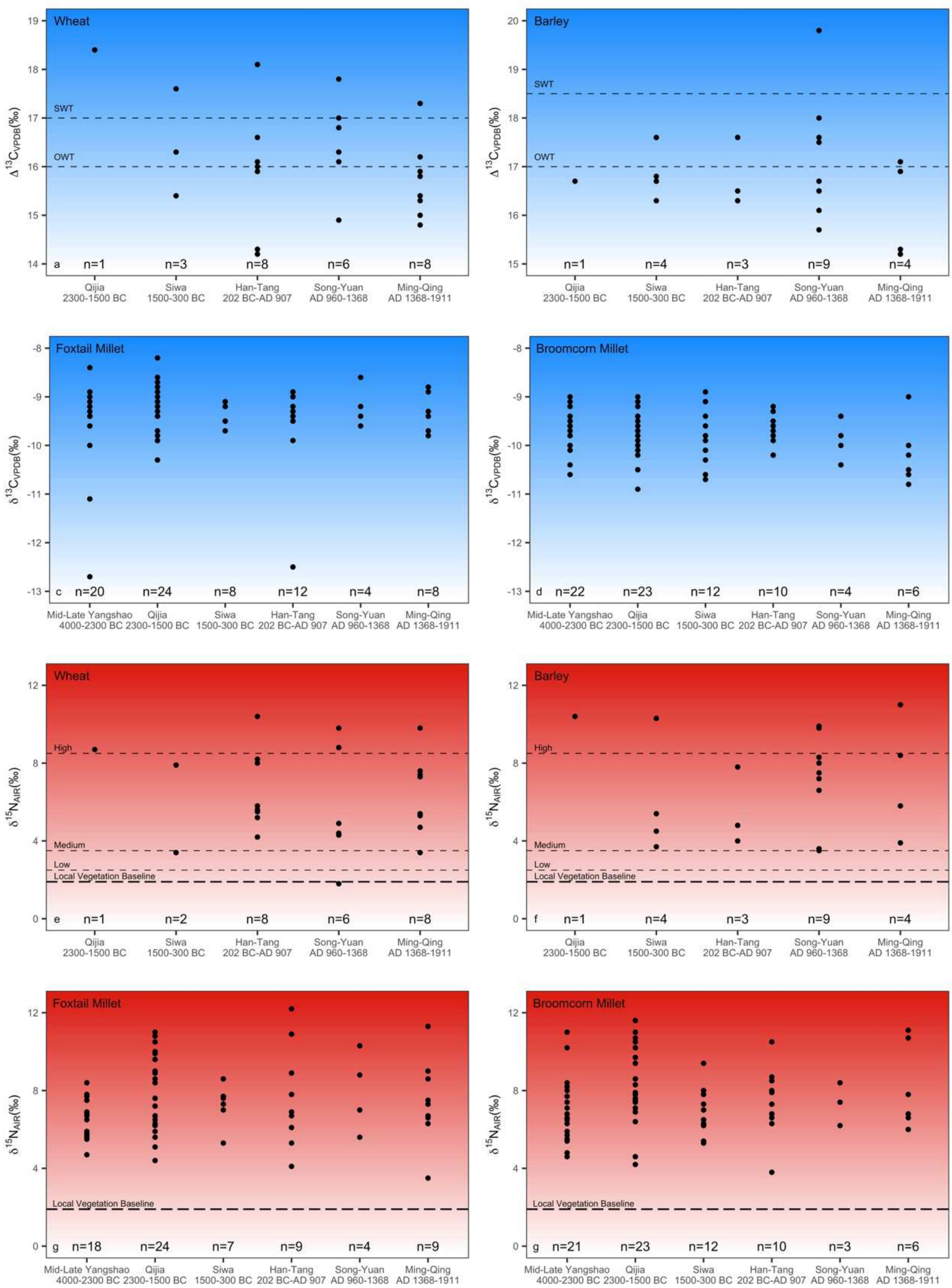

Figure 5. The $\Delta^{13}C$ (a-d) and $\delta^{15}N$ (e-h) values of archaeological wheat, barley, foxtail and broomcorn millet grains from the Zhuanglan. Dashed lines represent Optimal Watering Threshold (OTW) and Superfluous Watering Threshold (SWT) for wheat and barley (a & b), and low, medium and high manuring thresholds as well as local vegetation baseline (e-h).

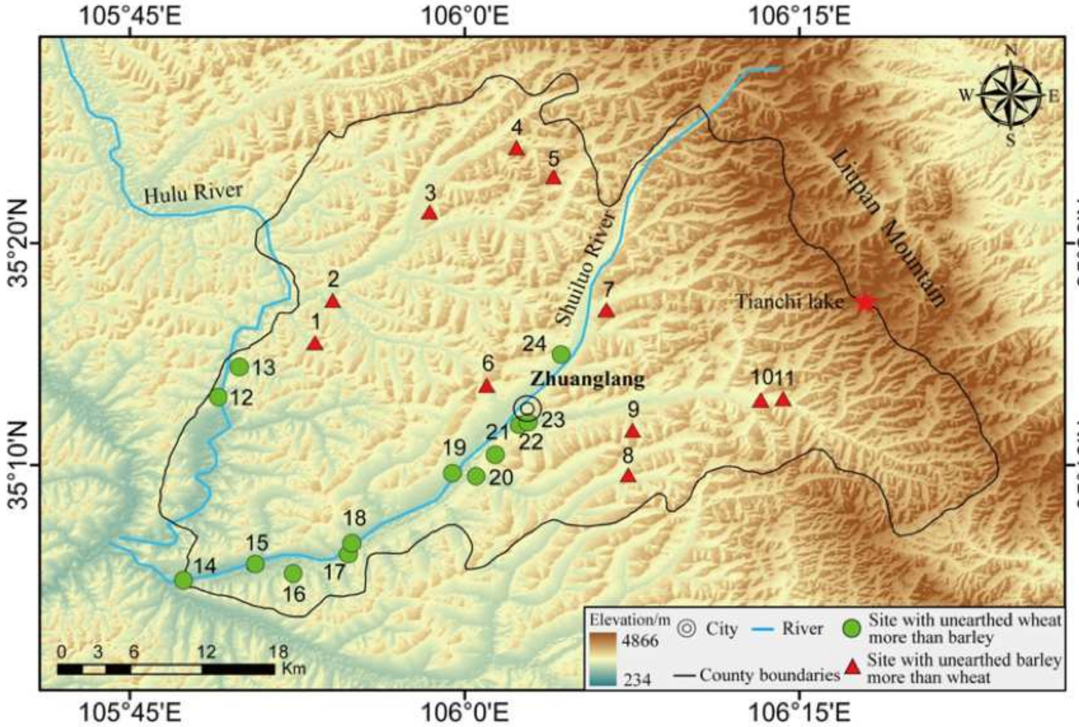

Figure 6. Site locations where wheat grains outnumber barley (○) and barley grains outnumber wheat (△): 1) Gaozhunang; 2) Shangping; 3)Dadichuan; 4) Hexianzui; 5)Nanhugucheng; 6) Shuiluocheng; 7) Xujiacheng; 8)Guajiazhuang; 9) Caiziwa; 10) Yujiayuan; (11) Jiajiahewan; 12) Sumiaoyuantou; 13) Dongshanzui; 14) Chuankouliujia; 15) Zhangjiayuan; 16) Shimenkou; 17) Jiuyuan; 18) Liubuping; 19) Yuliaobuzi; 20) Guandi; 21) Wujiachuan; 22) Guanqianmen; 23) Taijiguan; 24) Yejiabuzi.

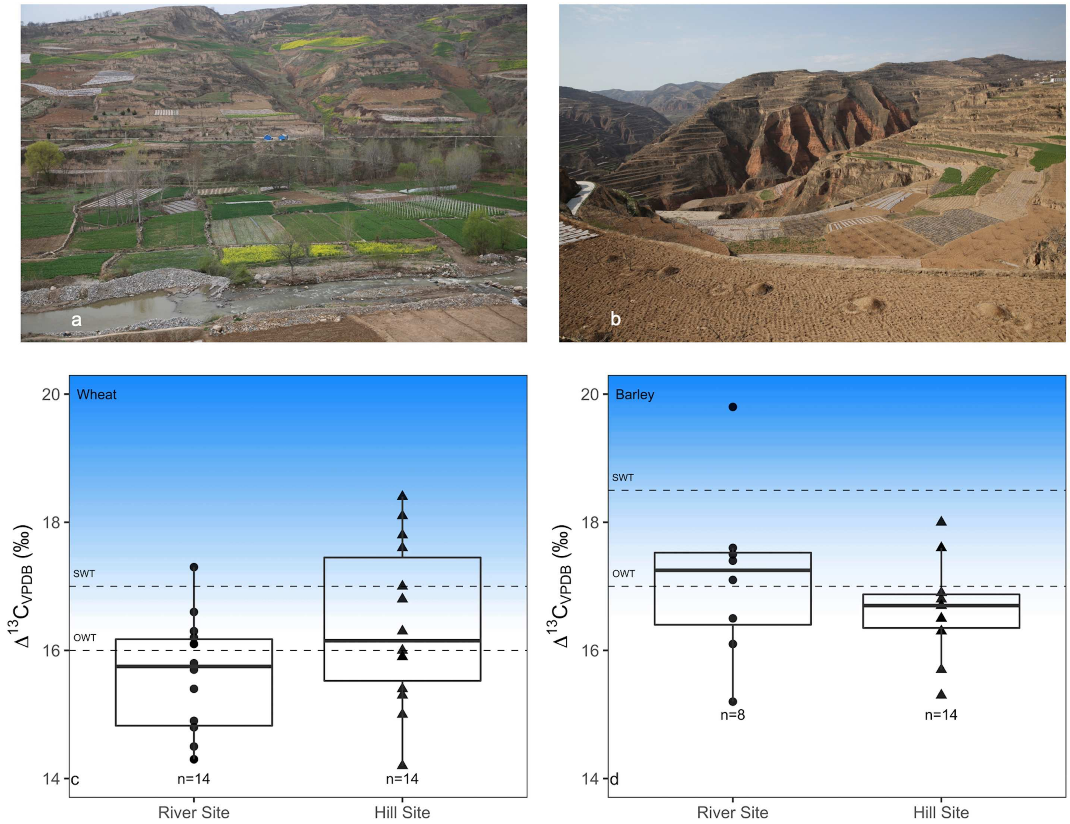

Figure 7. Examples of typical landscapes of "river sites"(sites located along the major rivers where wheat outnumbers barley; a, view near Dongshanzui—13 in Fig. 6) and "hill sites" (sites located at higher elevations where barley outnumbers wheat; b, view near Shangping—2 in Fig. 6); Δ^{13}C values of archaeological wheat and barley from the two types of sites (c & d).

Table 1. A summary of $\Delta^{13}C$ ($\delta^{13}C$) and $\delta^{15}N$ values of foxtail and broomcorn millet, wheat and barley unearthed from studied sites in different periods.

Crops		Mid-Late Yangshao (4000-2300 BCE)	Qijia (2300-1500 BCE)	Siwa (1500-300 BCE)	Han-Tang (202 BCE-907 CE)	Song, Jin and Yuan (960-1368 CE)	Ming-Qing (1368-1911 CE)
Foxtail Millet (*Setaria italica*)	$\delta^{13}C$ Range (‰)	-12.7~-8.4	-10.2~-8.2	-9.7~-9.1	-12.5~-8.9	-9.6~-8.6	-13.6~-8.8
	$\delta^{13}C$ Average (‰)	-9.6	-9.2	-9.4	-9.6	-9.2	-9.9
	$\delta^{15}N$ Range (‰)	4.7~8.4	4.4~11	5.3~8.6	4.1~12.2	5.6~10.3	3.5~11.3
	$\delta^{15}N$ Average (‰)	6.5	7.9	7.3	7.7	7.9	7.4
Broomcorn Millet (*Panicum miliaceum*)	$\delta^{13}C$ Range (‰)	-13.7~-9.1	-10.9~-9	-10.7~-8.9	-15.9~-9.2	-10.4~-9.4	-10.8~-9
	$\delta^{13}C$ Average (‰)	-9.9	-9.8	-9.9	-10.3	-9.9	-10.2
	$\delta^{15}N$ Range (‰)	4.6~11	4.2~11.6	5.3~9.4	3.8~10.5	6.2~8.4	6~11.1
	$\delta^{15}N$ Average (‰)	6.9	8.3	6.8	7.4	7.3	8.2
Wheat (*Triticum aestivum*)	$\Delta^{13}C$ Range (‰)			15.4~17.6	14.2~18.1	14.9~17.8	14.5~17.3
	$\Delta^{13}C$ Average (‰)		18.4	16.4	15.7	16.5	15.6
	$\delta^{15}N$ Range (‰)			3.4~7.9	4.2~10.4	3.8~9.8	3.4~9.8
	$\delta^{15}N$ Average (‰)		8.7	5.7	6.67	6.0	6.0
Barley (*Hordeum vulgare*)	$\Delta^{13}C$ Range (‰)		16.3~16.7	16.7~17.6	16.3~17.6	15.7~19.8	15.2~17.4
	$\Delta^{13}C$ Average (‰)		16.5	17.0	17.0	17.1	16.4
	$\delta^{15}N$ Range (‰)		5.4~10.4	3.7~10.3	3.5~8.0	6.6~9.9	3.9~11.0
	$\delta^{15}N$ Average (‰)		7.9	6.2	5.3	8.2	6.7

Table S1 Results of plant taxa identification for archaeobotanical assemblages in the Zhuanglang region

Period	Mid Yangshao culture										
Site name and code	Wowoping-H1	Yujiayuan-H3	Tianjiaping-L	Tijiaping-H1	Lishuwa-L	Zhangjiayuan-H2	Yuejiawan-H1	Taijiazui-L	Caojiayuan-L	Caojiayuan-H1	Caojiayuan-H2
Soil (L)	11.70	21.60	13.20	10.20	10.80	11.70	16.20	14.85	16.20	15.30	14.40
Nut (g)	0.33	15.04	5.42	6.19	30.88	0.00	8.74	12.23	0.00	12.74	8.86
Setaria italica					1	312	2058	12	103	62	236
Panicum miliaceum	6		873	57	5	132	292	12	17	69	12
Triticum aestivumLinn.											
Hordeum vulgare L.											
Fagopyrum esculentum Moench.											
Avena sativa L.											
Chinese sorghum											
Lens culinaris Medic.											
Pisum sativum Linn											

Vigna radiata (Linn.) Wilczek											
Glycine max (L.) Merr											
Vigna unguiculata (Linn.)Walp											
L. culinaris											
Sesamum indicum Linn.											
Linum usitatissimum L.											
Cannabis sativa L.											
Brassica campestris L.											
Zanthoxylum bungeanum Maxim.											
Avena fatua L.					20						
Panicum miliaceum L. var. ruderole Kitag			47	2							3
Setaria viridis (L.) Beauv.				2			1	6			4
Echinochloa crusgalli											13
Alopecurus aequalis Sobol.											
Poa annua L.											
Glycyrrhiza Linn.								61			
Glycine soja Sieb. et Zucc							151				
Vicia sepium Linn.											
Astragalus membranaceus (Fisch.) Bunge.							1			1	

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Melilotus suaveolens Ledeb.											
Medicago sativa Linn											
Lespedeza Michx.											
Acalypha brachystachya Hornem											
Crotalaria pallida Ait.											
Pueraria lobata (Willd.) Ohwi								8			
Leguminosae	1									1	
Salsola collina Pall	5									1	2
Chenopodium album											
Kochia scoparia (L.) Schrad.											
Chenopodium hybridum L.											
Corispermum hyssopifolium L.											
Chenopodium aristatum L.											
Chenopodium L.	6		1								84
Rumex L.				1							
Polygonum L.			1								
Polygonaceae											
Carex tristachya											
Cyperaceae											

Galium tricorne Stokes											
Humulus scandens (Lour.) Merr.								1			
Malva Sinensis Cavan								1			
Brassica					2						
Capsella bursa-pastoris								1			
Amethystea caerulea											
Erilla frutescens (L.) Britt.											
Lagopsis supina (Steph.)IK.-Gal											
Rubus corchorifolius L. f.											
Prinsepia utilis											
Hippophae rhamnoides Linn.											
Elaeagnaceae											
Euphorbiaceae											
Papaveraceae											
Convolvulaceae											
Cucurbitaceae											
Xanthium sibiricum Patrin.											
Prunus L.											
Malus Mill.											

Cupressaceae											
Viburnum kansuense Batal											
Artemisia frigida Willd. Sp. Pl											
Valerianaceae											
unknown							1				
Total	12	6	923	62	28	444	2504	102	120	134	354

Continued

Period	Late Yangshao culture																			
Site name and code	Wanerwa-H1	Wanerwa-H2	Wujiachuan-H5	Wujiachuan-H6	Wujiachuan-H7	Wujiachuan-H8	Wujiachuan-H9	Shidongmen-H1	Buziping-H1	Buziping-H2	Buziping-H3	Buziping-H4	Wujiagou	Buziping-L	Wanjiayuan-H1-1	Wanjiayuan-H1-2	Wanjiayuan-H2-1	Wanjiayuan-H2-2	Shidongmen-L	Xuanmaoding-H1
Soil (L)	10.80	12.15	14.40	10.80	9.00	10.80	12.60	12.60	18.00	####	####	9.90	17.10	7.80	9.00	7.90	10.00	8.30	####	11.70
Nut (g)	2.29	19.12	2.98	3.55	0.00	0.64	27.89	2.87	2.67	2.09	2.13	0.83	7.56	0.00	4.30	4.00	4.04	4.42	5.97	7.62

Setaria italica	298	262	5	8	23	11	4	37	10		8	23	555	8	317	300	521	200	77	1235
Panicum miliaceum	117	31	2	6	7	4	2	25	3	6	8	5	172	7	33	30	51	50		551
Triticum aestivumLinn.																				
Hordeum vulgare L.																				
Fagopyrum esculentum Moench.																				
Avena sativa L.																				
Chinese sorghum																				
Lens culinaris Medic.																				
Pisum sativum Linn																				
Vigna radiata (Linn.) Wilczek																				1
Glycine max (L.) Merr															10	5	3			
Vigna unguiculata (Linn.)Walp																	1			
L. culinaris																				
Sesamum indicum Linn.																				
Linum usitatissimum L.																				

Cannabis sativa L.																				
Brassica campestris L.																				
Zanthoxylum bungeanum Maxim.																				
Avena fatua L.																				
Panicum miliaceum L. var. ruderole Kitag	26	12						1							1	1				30
Setaria viridis (L.) Beauv.	234	49						4	2		2				50	45			52	51
Echinochloa crusgalli				1																1
Alopecurus aequalis Sobol.																				
Poa annua L.																				
Glycyrrhiza Linn.																				
Glycine soja Sieb. et Zucc																				
Vicia sepium Linn.																				
Astragalus membranaceus (Fisch.) Bunge.									1			2								
Melilotus suaveolens Ledeb.												1								
Medicago sativa Linn	2																1			2

Lespedeza Michx.						2									1					
Acalypha brachystachya Hornem																				
Crotalaria pallida Ait.																				
Pueraria lobata (Willd.) Ohwi																				
Leguminosae			1																	
Salsola collina Pall	1																			
Chenopodium album																				
Kochia scoparia (L.) Schrad.	1																			
Chenopodium hybridum L.										1					4	2				
Corispermum hyssopifolium L.																				
Chenopodium aristatum L.																				
Chenopodium L.						2			6		1				5	3				
Rumex L.											2									
Polygonum L.																	1			
Polygonaceae																				

Carex tristachya																				
Cyperaceae	1																			
Galium tricorne Stokes																				
Humulus scandens (Lour.) Merr.															6	6				
Malva Sinensis Cavan															2					
Brassica																				
Capsella bursa-pastoris																				
Amethystea caerulea																				
Erilla frutescens (L.) Britt.																				
Lagopsis supina (Steph.)IK.-Gal																				
Rubus corchorifolius L. f.																				
Prinsepia utilis																				
Hippophae rhamnoides Linn.																				
Elaeagnaceae																				
Euphorbiaceae																				
Papaveraceae																				

Convolvulaceae																				
Cucurbitaceae																				
Xanthium sibiricum Patrin.																				
Prunus L.																				
Malus Mill.																				
Cupressaceae																				
Viburnum kansuense Batal																				
Artemisia frigida Willd. Sp. Pl																				
Valerianaceae																				
unknown				1																
Total	680	354	8	16	30	19	6	67	22	7	21	31	727	15	429	392	578	250	129	1871

Continued

Period			Qijia culture

Site name and code	Jiajiaping-H1	Jiajiaping-H2	Xiaodunshan-H1	Xiaodunshan-H2	Yujiayuan-H2	Yuliaobuzi-H1	Yuliaobuzi-H2	Yuliaobuzi-H3	Dazuiliang-H1	Dazuiliang-H2	Duanshanping-H1	Dadichuan-H2	Jiajiangping-H3	Xuanmaoding-H2	Xuanmaoding-H3	Dazuiliang-L	Shimenkou-H1	Yaping-H1	Gaozhuang-H1	Duijiagoumen-L	Siping-H1	Siping-H2	Yumushuwan-H1	Yumushuwan-H2	Xujiacheng-H2	Ximianyuan-L	Sumiaoyuantou-H1-1	Sumiaoyuantou-H1-2	Sumiaoyuantou-L	Yaerzui-L	Xihe-H1	Yuliaobuzi-H4	Daping-H1	Daping-H2
Soil (L)	9.9	1.8	10.8	15.1	16.2	6	6	6.6	12.6	10.8	2.4	9.9	10.8	13.2	10.8	14.4	11.7	14.4	14.4	8.4	10.8	13.5	15.3	13.8	4.05	10.6	7.3	7.4	10.5	16.5	8	9.45	14.4	17.64
Nut (g)	4.64	2.9	11.04	7.82	32.35	0	2.1	3.16	58.01	49.92	0	0.99	10.94	37.59	55.52	40.24	7.94	4.27	9.44	4.38	7.89	29.47	2.24	21.24	88.56	5.38	4.03	5.03	4.62	12.56	3.2	0	24	43.86
Setaria italica	365	3	159	46	73	125	100	66	2	33		347	25	68	2	50	18	1338	105	5	10	134	93	1723		105	303	300	76	946	4	26	91	170

Panicum miliaceum	268		50	27	39	6	60	42	5	7	6	290	12	16	3	18	13	438	26	3	9	16	16	40		81	100	92	8	85	1	33	5	6
Triticum aestivumLinn.																			6															
Hordeum vulgare L.																			3															
Fagopyrum esculentum Moench.																																		
Avena sativa L.																																		
Chinese sorghum																																		
Lens culinaris Medic.																																		

Pisum sativum Linn																													3				4	
Vigna radiata (Linn.) Wilczek																																		
Glycine max (L.) Merr																																		
Vigna unguiculata (Linn.)Walp																																		
L. culinaris																																		
Sesamum indicum Linn.																																		
Linum usitatissimum L.																													1					

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Cannabis sativa L.																																		
Brassica campestris L.																																		
Zanthoxylum bungeanum Maxim.																																		
Avena fatua L.					5																													
Panicum miliaceum L. var. ruderole Kitag												6					1	14						9										
Setaria viridis (L.) Beauv.			18	4		6	1	2	3	1				8		1	1	183	6		1	2		29			10	1	4			5	4	4
Echinochloa crusgalli																		11																

Alopecurus aequalis Sobol.																																		
Poa annua L.																																		
Glycyrrhiza Linn.																																		
Glycine soja Sieb. et Zucc																										4								
Vicia sepium Linn.																																		
Astragalus membranaceus (Fisch.) Bunge.															1							2												
Melilotus suaveolens Ledeb.					1 3														1															
Medicago sativa Linn																	2								1	7								

Lespedeza Michx.												1																						
Acalypha brachystachya Hornem			3		1																			3										
Crotalaria pallida Ait.																										3								
Pueraria lobata (Willd.) Ohwi																																		
Leguminosae											1											2		2			3	3						
Salsola collina Pall			1			5	2					2	1									1												
Chenopodium album			7																							4								
Kochia scoparia (L.) Schrad.																																		

Chenopodium hybridum L.																																		
Corispermum hyssopifolium L.						110	2	5										9														10		
Chenopodium aristatum L.													1																					
Chenopodium L.							1							2		1	1		2		4					2								
Rumex L.						1																												
Polygonum L.																																		
Polygonaceae																																		
Carex tristachya																																		

Cyperaceae																																		
Galium tricorne Stokes																																		
Humulus scandens (Lour.) Merr.						1																												
Malva Sinensis Cavan				1																														
Brassica																																		
Capsella bursa-pastoris																									1									
Amethystea caerulea																																		
Erilla frutescens (L.) Britt.																																		

Lagopsis supina (Steph.)IK.-Gal																			6															
Rubus corchorifolius L. f.																																		
Prinsepia utilis					1																													
Hippophae rhamnoides Linn.																										3								
Elaeagnaceae																																		
Euphorbiaceae																			1															
Papaveraceae																																		

Convolvulaceae																																		
Cucurbitaceae																																		
Xanthium sibiricum Patrin.																																		
Prunus L.																																		
Malus Mill.																																		
Cupressaceae					2																													
Viburnum kansuense Batal																																		
Artemisia frigida Willd. Sp. Pl																																		
Valerianaceae																																		

unknown																	1	1	2							2								
Total	633	3	238	78	134	254	166	115	10	41	11	646	39	94	6	70	37	1994	158	8	24	157	109	1806	2	211	416	396	92	1031	5	74	104	180

Continued

Period	Siwa culture																				Wei Jin South and North dynasties						Tang dynasty		
Site name and code	Gaozhuang-H2-1	Gaozhuang-H2-2	Daping-H3	Shangping-H1	Shangping-H2-1	Shangping-H2-2	Daping-H4	Daping-H5	Dadichuan-H1-1	Dadichuan-H1-2	Hexianzui-H1	Hexianzui-H3	Hexianzui-H2	Xulinian-H1	Shangping-H3	Nanhugucheng-H2-1	Nanhugucheng-H2-2	Nanhugucheng-H3	Sumiaoyuantou-H2	Sumiaoyuantou-H3	Dongshanzui-H1-1	Dongshanzui-H1-2	Dongshanzui-H2	Shaojiaping-H1	Shaojiaping-H2	Chuankouliujia-L	Shuiluocheng-H1	Shuiluocheng-H2	Shuiluocheng-H3
Soil (L)	6	6.24	14.4	8.6	9.8	8	12.6	12.6	5.00	5.35	12.6	14.4	16.2	4.5	13.2	4	5	16.2	10	8	14.4	16.2	16.8	13.5	12.6	15.5	7.2	10.8	14.04

Nut (g)	1	0.91	4.75	7.7	12.55	10	5.21	12.62	9.00	5.50	1.62	5.98	2.14	71.12	34.75	0.22	0.5	0.7	1.26	0.68	6.46	12.88	6.03	1.23	0.16	13.45	9.87	14.19	2.98
Setaria italica	1	1	81	30	916	300	581	97	30	10	27	74	4	5	112	5	7	45	10	3	267	28	70	79	26	168	31	56	57
Panicum miliaceum	6	15	39	1	200	80	173	111	13	3	11	36	14	3	19	4	5		4	4	153	41	50	29	7	87	4	201	11
Triticum aestivumLinn.									2		8	2			3			1		2	191	26	54			2	2	34	3
Hordeum vulgare L.	3				105	90			1	1	8	3	2		2	1	1	2					10			10		45	
Fagopyrum esculentum Moen ch.																								2				43	

Avena sativa L.							3												1				6						
Chinese sorghum																													
Lens culinaris Medic.																					2								
Pisum sativum Linn			2												4						12								
Vigna radiata (Linn.) Wilczek																													
Glycine max (L.) Merr																													
Vigna unguiculata (Linn.)Walp																					2								
L. culinaris																													
Sesamum indicum Linn.																													
Linum usitatissimum L.																												3	

Cannabis sativa L.					4																3								
Brassica campestris L.																													
Zanthoxylum bungeanum Maxim.																													
Avena fatua L.					1																					1			
Panicum miliaceum L. var. ruderole Kitag							16	2													15		2					1	1
Setaria viridis (L.) Beauv.	1		10	10	10	16	326	13				5			1						27	6	16	577	2	16	5	11	3
Echinochloa crusgalli							15																1	1			1		
Alopecurus aequalis Sobol.																													
Poa annua L.																													

Glycyrrhiza Linn.																													
Glycine soja Sieb. et Zucc																													
Vicia sepium Linn.																							5						
Astragalus membranaceus (Fisch.) Bunge.					1																2								
Melilotus suaveolens Ledeb.																													
Medicago sativa Linn																										1			
Lespedeza Michx.																													
Acalypha brachystachya Hornem																													
Crotalaria pallida Ait.																													

Pueraria lobata (Willd.) Ohwi																													
Leguminosae																											1		
Salsola collina Pall	13	10													1	1					3			1				1	
Chenopodium album															1				5							8			
Kochia scoparia (L.) Schrad.																												2	
Chenopodium hybridum L.																													
Corispermum hyssopifolium L.							1								1						4			208					
Chenopodium aristatum L.																													

Chenopodium L.	200	188	2		3	7	693		4	4	4							2			25	135	70	219					
Rumex L.					3								1																
Polygonum L.												3														1			
Polygonaceae																		1						1					
Carex tristachya												2									1								
Cyperaceae												2																	
Galium tricorne Stokes																						16							
Humulus scandens (Lour.) Merr.																										2			
Malva Sinensis Cavan					23	30															2								
Brassica																													
Capsella bursa-pastoris																													

Amethystea caerulea																								8					
Erilla frutescens (L.) Britt.																													
Lagopsis supina (Steph.)IK.-Gal																													
Rubus corchorifolius L. f.																													
Prinsepia utilis																													
Hippophae rhamnoides Linn.					10	18																							
Elaeagnaceae																													
Euphorbiaceae																													
Papaveraceae																													
Convolvulaceae																													
Cucurbitaceae																						1							
Xanthium sibiricum Patrin.															1														

Prunus L.																													
Malus Mill.																													
Cupressaceae																													
Viburnum kansuense Batal								1																					
Artemisia frigida Willd. Sp. Pl	2																												
Valerianaceae					1																								
unknown					1							2			3						3	18							6
Total	226	214	134	41	1278	541	1808	224	47	18	58	129	21	8	148	11	13	51	25	9	712	271	284	1125	35	296	44	397	81

Continued

Period	Song dynasty	Yuan dynasty	Ming dynasty	Qing dynasty	

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Site name and code	Zhangjiayuan-H1-1	Zhangjiayuan-H1-2	Shuiluocheng-L	Taijiguan-L	Xujiacheng-H1	Shimenkou-H2	Jiajiahewan-H1	Jiajiahewan-L	Jiajiahewan-H2	Jiuyuan-H1	Jiuyuan-H2	Yuliaobuzi-H5	Guajiazhuang-H1	Liubuping-H1	Duanshanping-H2	Guandi-H1	Wujiachuan-H3	Nanhugucheng-L	Caiziwa-H1	Caiziwa-H2	Caiziwa-H3	Wujiachuan-H1	Wujiachuan-H2	Wujiachuan-H4	Guanqianmen-H1	Guanqianmen-H2	Taijiguan-H1	Yejiabuzi-H1	Yejiabuzi-L	Yujiayuan-H1	Total
Soil (L)	7.2	8	7.8	3.6	4.85	9.9	12	9	12.6	12.6	11.7	2.7	10.8	13.2	5.7	11.25	12.6	13.5	7.65	7.65	10.8	9	13.5	9	10	12	11.25	8.5	13	####	1351.92
Nut (g)	0	16.00	35.33	13.76	1.65	8.62	4.7	7.31	30.72	6.44	6.84	0	33.19	10.72	17.14	0	22.03	78.04	31.23	38.11	2.17	1.3	5.27	13.39	8.32	11.75	84.95	6.9	8.73	####	1593.99
Setaria italica	4	4	4		2	1	18	2				1	16	5	2	1		65	4	33	5	6		7	8	12	2	138	69	2	17134
Panicum miliaceum	2	0	2		3		2	1	1			1	3	29	49	1	2	49	1	18	2	5		17		3	4	86	77	2	6082

Triticum aestivumLinn.	3	2	3	12		15	156	11		26		3	3	8	1	6	156	50	9	96	386	3				548	249	34	150		2266
Hordeum vulgare L.	1	1			19	1	37	3		3	1		6			2		3		47	12			2			1			22	448
Fagopyrum esculentum Moench.					2			1						1		1	25	8	2	5	2						280	2	3		377
Avena sativa L.					1	5							2	1		2		86	23	164	6	8		3		166		3			480
Chinese sorghum																												2			2
Lens culinaris Medic.					1		103							1			2	12		2	18	3									144
Pisum sativum Linn	1	1								5			2	5						2				3			5				45

Vigna radiata (Linn.) Wilczek																	2								6					9
Glycine max (L.) Merr					1																									19
Vigna unguiculata (Linn.)Walp																														3
L. culinaris																									61		3			64
Sesamum indicum Linn.	1	2								1									4											8
Linum usitatissimum L.																	1										9	1		15
Cannabis sativa L.																	3													10
Brassica campestris L.																		30												30

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Zanthoxylum bungeanum Maxim.								1																							1
Avena fatua L.							4		1					2				4	1		29						3				71
Panicum miliaceum L. var. ruderole Kitag																				1											191
Setaria viridis (L.) Beauv.	3	3			5		5	4	1				1	11				11	1	5		5			11	12			1		1930
Echinochloa crusgalli													2	1																	47
Alopecurus aequalis Sobol.																1															1
Poa annua L.									1							1															2
Glycyrrhiza Linn.																															61

Glycine soja Sieb. et Zucc																															155
Vicia sepium Linn.																															5
Astragalus membranaceus (Fisch.) Bunge.																															11
Melilotus suaveolens Ledeb.							1	1																						1	18
Medicago sativ a Linn							1														2				1			6			26
Lespedeza Michx.																															4
Acalypha brachystachya Hornem							1													1											9
Crotalaria pallida Ait.																															3

Pueraria lobata (Willd.) Ohwi				1																											9
Leguminosae						1										1			1	2							1				21
Salsola collina Pall				5	289		25							2				1	4	3							24			1	405
Chenopodium album																									129			162			316
Kochia scoparia (L.) Schrad.				1			5							4													7				20
Chenopodium hybridum L.				1			2					1															6				17
Corispermum hyssopifolium L.	1	1			11		17											2	5	3						1		56	2		449

Chenopodium aristatum L.																											1		77		79
Chenopodium L.	1			39			3	2				489		6	1	216				1	1	3	733	2			29				3203
Rumex L.																2															10
Polygonum L.																															6
Polygonaceae							1						1					1	1	1											7
Carex tristachya																												28			31
Cyperaceae																				1											4
Galium tricorne Stokes							7			1								411	7		12	5		5			6				470
Humulus scandens (Lour.) Merr.														18											1	8					43

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Malva Sinensis Cavan					1															1							1		2		64
Brassica							4													1									2		9
Capsella bursa-pastoris																															2
Amethystea caerulea														1																	9
Erilla frutescens (L.) Britt.																											1				1
Lagopsis supina (Steph.)IK.-Gal																															6
Rubus corchorifolius L. f.																					1										1
Prinsepia utilis																															1

Hippophae rhamnoides Linn.																															31
Elaeagnaceae																											2				2
Euphorbiaceae																															1
Papaveraceae							2														9						3				14
Convolvulaceae							1																								1
Cucurbitaceae																															1
Xanthium sibiricum Patrin.								24																							25
Prunus L.			1																												0
Malus Mill.																										3					3
Cupressaceae																															2
Viburnum kansuense Batal																															1

Artemisia frigida Willd. Sp. Pl																															2
Valerianaceae																1															2
unknown				1				2		2			2	4	3			35	26	4				6		10	12				148
Total	17	15	9	60	335	23	395	53	4	38	1	##	38	99	56	235	185	744	115	395	485	38	733	45	150	830	637	##	##	28	35104

Table S2 Calibrated radiocarbon dates of charred crop grains from the investigated sites in Zhuanglang country in West Loess Plateau. The calibration was performed using OxCal v4.4 (Bronk Ramsey 2020).

Sample no.	Lab. no.	Dating material	Radiocarbon age (BP)	Calibrated age (cal BC/AD)		Culture/dynasty
				1σ (68.2%)	2σ (95.4%)	

Tianjiaping-L	BA130557	Broomcorn millet	5125±25	3896±75	3895±90	Yangshao
Zhangjiayuan-H2	LZU1415	Foxtail millet	4680±30	3446±70	3448±78	Yangshao
Yuejiawan-H1	LZU1413	Foxtail millet	4640±40	3434±70	3439±82	Yangshao
Caojiayuan-H2	BA130548	Broomcorn millet	4430±25	3159±147	3126±200	Late Yangshao
Wujiachuan-H8	BA130543	Foxtail millet	4395±30	3005±76	3087±174	Late Yangshao
Wanjiayuan-H1-1	BA110881	Foxtail millet	4385±25	2974±48	3003±89	Late Yangshao
Wujiagou-H1	BA110880	Broomcorn millet	4375±25	2969±43	3000±88	Late Yangshao
Buziping-H4	BA130547	Foxtail millet	4345±30	2994±87	2986±90	Late Yangshao
Xuanmaoding-H1	LZU1411	Foxtail millet	4290±45	2943±65	2891±184	Late Yangshao
Yumushuwan-H1	BA130554	Foxtail millet	3825±30	2271±67	2299±152	Qijia
Yaerzui-L	BA110878	Foxtail millet	3770±25	2209±67	2173±115	Qijia
Yuliaobuzi-H2	LZU1418	Foxtail millet	3760±60	2164±122	2212±233	Qijia
Siping-H2	BA130553	Foxtail millet	3715±40	2116±79	2126±150	Qijia
Daping-H1	LZU1407	Foxtail millet	3710±30	2114±77	2092±108	Qijia
Xiaodunshan-H1	LZU1416	Foxtail millet	3670±45	2056±80	2063±136	Qijia
Yujiayuan-H2	LZU1410	Foxtail millet	3625±30	1987±43	2010±116	Qijia

Sumiaoyuantou-L	BA110879	Foxtail millet	3600±25	1961±57	1958±68	Qijia
Dadichuan-H2	LZU1409	Foxtail millet	3555±45	1868±92	1888±138	Qijia
Gaozhuang-H1	BA130551	Wheat	3265±25	1550±50	1534±78	Qijia
Xihe-H1	BA120219	Foxtail millet	3230±60	1512±86	1476±154	Qijia
Dadichuan-H1	Beta-347952	Barley	3110±30	1367±57	1364±78	Siwa
Gaozhuang-H2-1	BA130549	Barley	2860±25	1023±83	1024±93	Siwa
Hexianzui-H3	BA130552	Foxtail millet	2810±25	963±36	973±73	Siwa
Shangping-H2-1	BA130555	Barley	2190±20	275±78	266±93	Siwa
Shaojiaping-H1	Beta-347951	Foxtail millet	1610±30	476±58	477±65	Weijin
Dongshanzui-H2	BA130550	Wheat	1565±20	493±57	496±64	Weijin
Shuiluocheng-H2	BA130544	Buckwheat	1270±25	725±42	744±76	Tang
Jiajiahewan-H1	BA130542	Wheat	1085±25	909±85	956±64	Tang-Song
Zhangjiayuan-H1	Beta-347949	Wheat	1030±30	1010±16	1023±123	Song
Guajiazhuang-H1	BA130545	Barley	710±25	1286±10	1324±56	Song-Yuan
Liubuping-H1	Beta - 347950	Wheat	480±30	1434±10	1431±25	Ming
Guandi-H1	LZU1414	Wheat	390±50	1534±88	1536±100	Qing
Nanhugucheng-H1	LZU1406	Oat	385±35	1535±84	1537±95	Qing
Taijiguan-H1	LZU1408	Wheat	265±35	1660±134	1650±150	Qing

Caiziwa-H2	LZU1412	Oat	235±35	1719±80	1666±142	Qing
Guanqianmen-H1	BA120685	Wheat	215±20	1726±72	1724±79	Qing
Wujiachuan-H3	BA130546	wheat	85±20	1804±104	1806±111	Qing
Yejiabuzi-H1	BA120686	Wheat	70±25	1804±104	1806±111	Qing
Yujiayuan-H1	BA130558	Barley	45±20	1804±104	1806±111	Qing

Table S3 The isotopic results of foxtail and broomcorn millet, wheat, and barley in Zhuanglang country in the West Loess Plateau.

Table S3 The isotopic results of foxtail and broomcorn millet, wheat, and barley in Zhuanglang country in the West Loess Plateau.												
Site	Sample No.	Time/Archaeological Culture	Foxtail Millet (*Setaria italica*)		Broomcorn Millet (*Panicum miliaceum*)		Wheat (*Triticum aestivum*)			Barley (*Hordeum vulgare*)		
		(Cal BC/AD)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\Delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{13}C$ (‰)	$\Delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Tianjiaping	TJP-H1	Middle Yangshao	-	-	-13.7	10.2	-	-	-	-	-	-
Tianjiaping	TJP-L	3980-3806 (Middle Yangshao)	-	-	-9.4	4.8	-	-	-	-	-	-

Zhangjiayuan	ZJY-H2	3622-3370 (Middle Yangshao)	-9.2	4.7	-	-	-	-	-	-	-	-
Taijiazui	TJZ-L	Late Yangshao	-9.3	7.7	-10	6.8	-	-	-	-	-	-
Yuejiawan	YJW-H1	3618-3350 (Late Yangshao)	-10	6.7	-10	6.5	-	-	-	-	-	-
Caojiayuan	CJY-L	Late Yangshao	-9.2	5.5	-9.2	5.7	-	-	-	-	-	-
Caojiayuan	CJY-H1	Late Yangshao	-9.4	5.7	-10.1	8	-	-	-	-	-	-
Caojiayuan	CJY-H2	3376-2928 (Late Yangshao)	-9.4		-10	8.2	-	-	-	-	-	-
Wanerwa	WEW-H1	Late Yangshao	-9.4	6.9	-9.6	7.1	-	-	-	-	-	-
Wanerwa	WEW-H2	Late Yangshao	-9.4	7.7	-9.4	7.4	-	-	-	-	-	-

Wujiachuan	WJC-H5	3101-2911(Late Yangshao)	-8.4	5.8	-9.1	7.7	-	-	-	-	-	-
Wujiachuan	WJC-H6	Late Yangshao	-9.6	5.6	-9		-	-	-	-	-	-
Wujiachuan	WJC-H9	Late Yangshao	-	-	-9.5	8.4	-	-	-	-	-	-
Shidongmen	SDM-L	Late Yangshao	-9.1	7.5	-9.6	11	-	-	-	-	-	-
Buziping	BZP-H1	Late Yangshao	-11.1	7.8	-10.6	5.4	-	-	-	-	-	-
Buziping	BZP-H3	Late Yangshao	-9.4	6.5	-10.4	6.6	-	-	-	-	-	-
Buziping	BZP-H4	Late Yangshao	-9.6	5.9	-9.8	5.9	-	-	-	-	-	-
Buziping	BZP-L	Late Yangshao	-	-	-9.6	6.3	-	-	-	-	-	-

Wujiagou	WJG-H1	3086-2912 (Late Yangshao)	-9.6		-9.6	6.3	-	-	-	-	-	-
Wanjiayuan	WJY-H1-1	3089-2917 (Late Yangshao)	-12.7	5.8	-9.5	5.5	-	-	-	-	-	-
Wanjiayuan	WJY-H1-2	Late Yangshao	-8.9	5.8	-10	-	-	-	-	-	-	-
Wanjiayuan	WJY-H2-1	Late Yangshao	-9	6.8	-9.7	4.6	-	-	-	-	-	-
Wanjiayuan	WJY-H2-2	Late Yangshao	-9	5.6	-9.8	5.5	-	-	-	-	-	-
Xuanmaoding	XMD-H1	3077-2761 (Late Yangshao)	-9.2	8.4	-9.5	7.7	-	-	-	-	-	-
Xuanmaoding	XMD-H2	Qijia	-	-	-9.7	7.5	-	-	-	-	-	-
Xiaodunshan	XDS-H1	2196-1928 (Qijia)	-9.2	10.5	-9.6	10.5	-	-	-	-	-	-

Xiaodunshan	XDS-H2	Qijia	-9.2	6.3	-9.8	10.2	-	-	-	-	-	-
Yujiayuan	YJY-H2	2196-1928 (Qijia)	-10.3	8.4	-10.5	7.6	-	-	-	-	-	-
Yuliaobuzi	YLBZ-H1	2435-1979 (Qijia)	-9.1	9.6	-9	9.4	-	-	-	-	-	-
Yuliaobuzi	YLBZ-H2	Qijia	-9.9	7.6	-10	8.6	-	-	-	-	-	-
Yuliaobuzi	YLBZ-H3	Qijia	-9.7	5.9	-9.7	7.1	-	-	-	-	-	-
Dadichuan	DDC-H2	2021-1763 (Qijia)	-8.7	5.1	-	-	-	-	-	-	-	-
Jiajiaping	JJP-H1	Qijia	-8.8	10.8	-9.7	6.4	-	-	-	-	-	-
Jiajiaping	JJP-H2	Qijia	-8.9	4.4	-10.9	4.6	-	-	-	-	-	-
Dazuiliang	DZL-L	Qijia	-9.4	6.2	-10.2	6.9	-	-	-	-	-	-
Dazuiliang	DZL-H1	Qijia	-8.9	10	-9.1	7.8	-	-	-	-	-	-
Yaping	YP-H1	Qijia	-8.9	6.7	-10.2	7.4	-	-	-	-	-	-
Gaozhuang	GZ-H1	1614-1464 (Qijia)	-8.8	9	-9.2	8.3	-24.4	18.4	8.7	-22.8	16.7	10.4
Siping	SP-H1	2272-1978 (Qijia)	-9.8	5.6	-10.1	11.6	-	-	-	-	-	-

Siping	SP-H2	Qijia	-9.4	7.2	-9.9	10.7	-	-	-	-	-	-
Yumushuwan	YMSW-H1	Qijia	-9.9	9.9	-10.5	7.5	-	-	-	-	-	-
Yumushuwan	YMSW-H2	2453-2147 (Qijia)	-8.2	6.2	-9.4	9.7	-	-	-	-	-	-
Ximianyuan	XMY-L	Qijia	-9.2	9	-9.9	9.7	-	-	-	-	-	-
Sumiaoyuantou	SMYT-H1-1	Qijia	-9.1	6.7	-9.5	6.9	-	-	-	-	-	-
Sumiaoyuantou	SMYT-H1-2	Qijia	-9	8.6	-9.7	7.9	-	-	-	-	-	-
Sumiaoyuantou	SMYT-L	Qijia	-8.6	6.5	-	-	-	-	-	-	-	-
Yaerzui	YEZ-L	2287-2063 (Qijia)	-9.4	11	-9.7	4.2	-	-	-	-	-	-
Daping	DP-H1	2199-2025 (Qijia)	-9.3	8.9	-10	11	-	-	-	-	-	-
Daping	DP-H2	Qijia	-9.8	10	-9.4	10.2	-	-	-	-	-	-

Gaozhuang	GZ-H2-1	1113-935 (Siwa)	-	-	-	-	-	-	-	-22.5	16.3	5.4
Daping	DP-H3	Siwa	-9.2	7	-9.9	6.2	-	-	-	-	-	-
Daping	DP-H4	Siwa	-9.1	7.6	-9.4	7	-	-	-	-	-	-
Daping	DP-H5	Siwa	-9.1	7.7	-10.6	5.3	-	-	-	-	-	-
Shangping	SP-H1	Siwa	-9.7	8.6	-9.6	6.5	-	-	-	-	-	-
Shangping	SP-H2-1	359-193 (Siwa)	-9.5		-10.3	9.4	-21.5	15.4	3.4	-22.8	16.7	10.3
Shangping	SP-H2-2	Siwa	-	-	-10.1	8	-	-	-	-22.9	16.8	4.5
Dadichuan	DDC-H1-1	1436-1288 (Siwa)	-9.2	5.3	-9.8	5.3	-23.7	17.6	7.9	-	-	-
Dadichuan	DDC-H1-2	Siwa	-	-	-9.1	5.4	-	-	-	-	-	-
Gaozhuang	GZ-H2-2	Siwa	-	-	-10.1	7.3	-	-	-	-	-	-
Hexianzui	HXZ-H1	Siwa	-9.5	7.3	-9.8	6.5	-22.5	16.3	-	-23.7	17.6	3.7
Hexianzui	HXZ-H2	Siwa	-9.5	7.7	-10.7	6.3	-	-	-	-	-	-
Hexianzui	HXZ-H3	1023-901 (Siwa)	-	-	-8.9	7.8	-	-	-	-	-	-
Nanhuguch eng	NHGC-H2-1	Han	-9.5		-9.6	6.8	-	-	-	-22.5	16.5	4

Nanhuguch eng	NHGC-H2-2	Han	-9	6.7	-9.6	10.5	-	-	-	-23.6	17.6	4.8
Nanhuguch eng	NHGC-H3	Han	-12.5	12.2	-	-	-20.4	14.2	8	-22.3	16.3	7.8
Shangping	SP-H3	Han	-9.3	-	-	-	-	-	-	-	-	-
Sumiaoyua ntou	SMYT-H2	Han	-	-	-15.9	8.7	-	-	-	-	-	-
Dongshanz ui	DSZ-H1-1	Wei, Jin and Northern Dynasty	-9.3	8.9	-9.8	7.3	-22.1	16.1	4.2	-	-	-
Dongshanz ui	DSZ-H1-2	425-544 (Wei, Jin and Northern Dynasty)	-9.9	10.9	-9.3	7.9	-22.6	16.6	5.2	-	-	-
Dongshanz ui	DSZ-H2	Wei, Jin and Northern Dynasty	-	-	-9.9	8.5	-20.4	14.3	8.2	-23.4	17.5	3.6
Shaojiaping	SJP-H1	392-538 (Wei, Jin and	-9.5	6.9	-10.2	6.6	-	-	-	-	-	-

		Northern Dynasty)										
Shaojiaping	SJP-H2	Wei, Jin and Northern Dynasty	-9	-	-9.7	8	-	-	-	-	-	-
Chuankouliujia	CKLJ-L	Wei, Jin and Northern Dynasty	-9.2	6.1	-9.5		-20.4	14.3	5.5	-23.5	17.6	8
Shuiluocheng	SLC-H1	Tang	-9.3	5.3	-9.2	6.3	-21.9	15.9	5.8	-	-	-
Shuiluocheng	SLC-H2	670-774 (Tang)	-8.9	7.8	-10.2	3.8	-22	16	5.6	-22.6	16.7	3.5
Shuiluocheng	SLC-H3	Tang	-9.4	4.1	-	-	-24	18.1	10.4			
Zhangjiayuan	ZJY-H1-1	901-1116 (Song and Jin)	-9.2	8.8	-10	7.4	-21	14.9	8.8	-22.6	16.5	9.9
Zhangjiayuan	ZJY-H1-2	Song and Jin	-	-	-9.8	8.4	-	-	-	-	-	-
Xujiacheng	XJC-H1	Song and Jin	-	-	-	-	-	-	-	-22.5	16.5	7.2

Shimenkou	SMK-H1	Song and Jin	-8.6	5.6	-9.4	6.2	-22.2	16.1	4.9	-25.7	19.8	7.5
Jiajiahewan	JJHW-H1	Song and Jin	-9.4	10.3	-	-	-22.8	16.8	4.3	-24	18	8.3
Jiajiahewan	JJHW-L	Song and Jin	-	-	-	-	-23.8	17.8	9.8	-21.8	15.7	6.6
Jiuyuan	JY-H1	Yuan	-	-	-	-	-22.4	16.3	3.8	-22.2	16.1	9.8
Guajiazhuang	GJZ-H1	1261-1381 (Yuan)	-9.6	7	-10.4	-	-23	17	4.4	-	-	-
Liubuping	LBP-H1	1408-1452 (Ming)	-8.9	3.5	-10.2	7.8	-20.9	14.8	4.1	-	-	-
Duanshanping	DSP-H2	Ming	-13.6	7.5	-10.8	10.7	-	-	-	-	-	-
Guandi	GD-H1	1435-1635 (Ming)	-	-	-	-	-21.7	15.7	9.8	-23.4	17.4	4.5
Wujiachuan	WJC-H3	1694-1919 (Ming)	-	-	-	-	-21.8	15.8	7.6			
Wujiachuan	WJC-H4	Qing	-	-	-	-	-22.1	16.2	5.3	-21.2	15.2	8.4
Guanqianmen	GQM-H1	1647-1938 (Qing)	-9.4	11.3	-9	11.1	-	-	-	-	-	-

Guanqianmen	GQM-H2	Qing	-9.7	8.6	-	-	-20.5	14.5	5.1	-	-	-
Taijiguan	TJG-H1	1494-1942 (Qing)	-	-	-	-	-	-	-	-23	17.1	11
Caiziwa	CZW-H1	1524-1929	-8.8	6.6	-	-	-21	15	7.4	-	-	-
Caiziwa	CZW-H2	Qing	-9.3	9	-10	6.8	-21.3	15.3	7.3	-22.8	16.9	3.9
Caiziwa	CZW-H3	Qing	-9.7	6.7	-	-	-21.9	15.9	4.7	-21.3	15.3	5.8
Yejiabuzi-H1	YJBZ-H1	1694-1919 (Qing)	-9.8	7.3	-10.6	6.6	-21.4	15.4	5.4	-	-	-
Yejiabuzi-L	YJBZ-L	Qing	-9.8	6.3	-10.5	6	-23.2	17.3	3.4	-	-	-