



Full length article

Patterns of spread and adoption of millet agriculture along the eastern rim of the Tibetan Plateau: Archaeobotanical evidence from Houzidong, Southwest China (4200–4000 cal. BP)

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ABSTRACT

The spread of domesticated crops has commonly occurred alongside broad patterns of long- and short-distance human movements and culture contact across regions. While exchange across Eurasia along the so-called Silk Road has been much discussed, recent work has revealed increasingly more evidence for early north-south contact along the eastern rim of the Tibetan Plateau. Main points of debate concern the timing and direction of the spread of agriculture and domesticated crops. This paper contributes to these discussions by presenting new data from macrobotanical remains and phytoliths from Houzidong in southwest Sichuan, a Neolithic site on the eastern rim of the Tibetan Plateau. The results show that the main crops during the late Neolithic (4200–4000 cal. BP) were foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*), with a small amount of rice (*Oryza sativa*), but that agriculture was overall not a major focus. Rather, the subsistence at Houzidong like at other sites in the region was highly diverse, relying on gathering, hunting, and small-scale cultivation with considerable crop diversity aimed at minimizing the impact of potential crop failure. This paper shows that subsistence practices differed markedly between sites, local populations exploiting the rich natural resources in the respective ecological niches in various ways. We argue that the wide variety of food sources available in southwest China allowed people to mitigate risk but also made them more receptive to new food sources such as plant crops, experimenting with them and adding them to their portfolio. Similar patterns can be seen in the adoption and adaptation of other outside influences with each community picking and choosing what suited them best, thus creating the rich and varied patchwork of highly localized cultural phenomena that came to characterize southwest China.

1. Introduction

Human migration and interaction across regions have long been pivotal issues in archaeological research (Jettmar, 1972; Hein, 2014c). While in earlier decades the focus of such discussions has been on the exchange of objects and the spread of technologies and burial customs, recent decades have seen an increased interest in how domesticated plants and animals were adopted and adapted to new regions and environments. The last ten plus years of intensified paleobotanical research have shown that trans-regional movement of people and various forms of inter-group interaction have been crucial in the dispersal of crops (Bettinger et al., 2007 and Bettinger et al., 2010; Jones et al., 2011; Fuller, 2011; Dong et al., 2017; Deng et al., 2020; Liu et al.,

2019). Besides the much-discussed exchange across Eurasia along what later came to be known as the Silk Road (e.g. Spengler, 2019) and other contact networks, recent research has also revealed increasingly more evidence for early north-south culture contact along the eastern rim of the Tibetan Plateau. In the Chinese literature, this route of exchange is often referred to as Tibetan-Yi Corridor based on it being an area of contact between the Han, Tibetans, and Yi in recent history (Shi, 2018). The idea of this being an “ethnic corridor” is often extended far back into prehistoric periods (Shi, 2018), which raises conceptual issues (Hein, 2014c). As Tibetans and Yi as ethnic groups emerged in this region only in more recent historical times and as the ethnic identity of prehistoric groups living in this region is unclear, we have chosen the descriptive geographic term of eastern rim of the Tibetan Plateau. Nevertheless,

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while the term “ethnic” is problematic, the term “corridor” seems quite suitable. The Hengduan Mountains which make up large parts of the eastern rim of the Tibetan Plateau are north-south trending with high mountain ranges and deep river valleys forming a corridor that allows for north-south and south-north movement while making contact between east and west more difficult, though by no means impossible (Hein, 2014b).

Recent genetic and linguistic studies suggest that human movement and exchange has been taking place along this corridor already for thousands of years (Zhang et al., 2019; Zhang et al., 2021). There is also plenty of archaeological evidence for human movement and exchange since early prehistoric times (Li, 2007; Li, 2011; Chen and 陈苇, 2012; Luo, 2012; Hein, 2013; Liu, 2018; Hung, 2021). Some of these connections run as far as from northwest China via the eastern Tibetan Plateau and into northern and western Yunnan, exemplified for instance by painted pottery for the Neolithic and double-handled ceramic jars and various types of weapons and ornament for the Bronze Age (Chen and 陈苇, 2012). Other aspects of material culture such as personal ornaments, tools, weapons, and burial structures seem to be shared over shorter distances such as between Yunnan and southwest Sichuan (Li, 2011; Liu, 2018) or even be highly localized (Liu, 1992; Hein, 2013, 2014b, and Hein, 2017).

Research on the spread of agriculture furthermore has pointed to the corridor being a significant route for the exchange of crops (Li, 2005; Chen and Han, Enrui 韩恩瑞, 2013; Deng et al., 2020), but systematic

archaeobotanical studies in this region are relatively limited. Local prehistoric crop patterns are poorly understood and the process of the spread and adoption of various crops and their cultivation in the region are still largely unclear. The present study helps fill that gap by presenting the results of archaeobotanical work on material from Houzidong in Huili County, southwest Sichuan (Fig. 1). Below, we provide new evidence not only on timing and routes of dispersal of various crops across western China, but also for the various types of local adoption and adaptation of non-local crops and farming practices. Furthermore, we are discussing the highly localized ways in which subsistence practices were shaped by a combination of the movement of humans and plants, the possibilities that the various local environmental niches offered, and human decision-making on a local basis. The paper thus provides insights into prehistoric life at this particular site while placing it within the larger context of culture contact and human movement along the eastern rim of the Tibetan Plateau and contributing to broader discussions on human-environment and human-plant interaction, as well as culture contact and exchange.

2. Previous research on the emergence of crop production in the region

The ways in which various types of contact and exchange lead to the spread of various domesticates beyond their original homelands has long been a topic of interest to archaeologists, much helped in recent

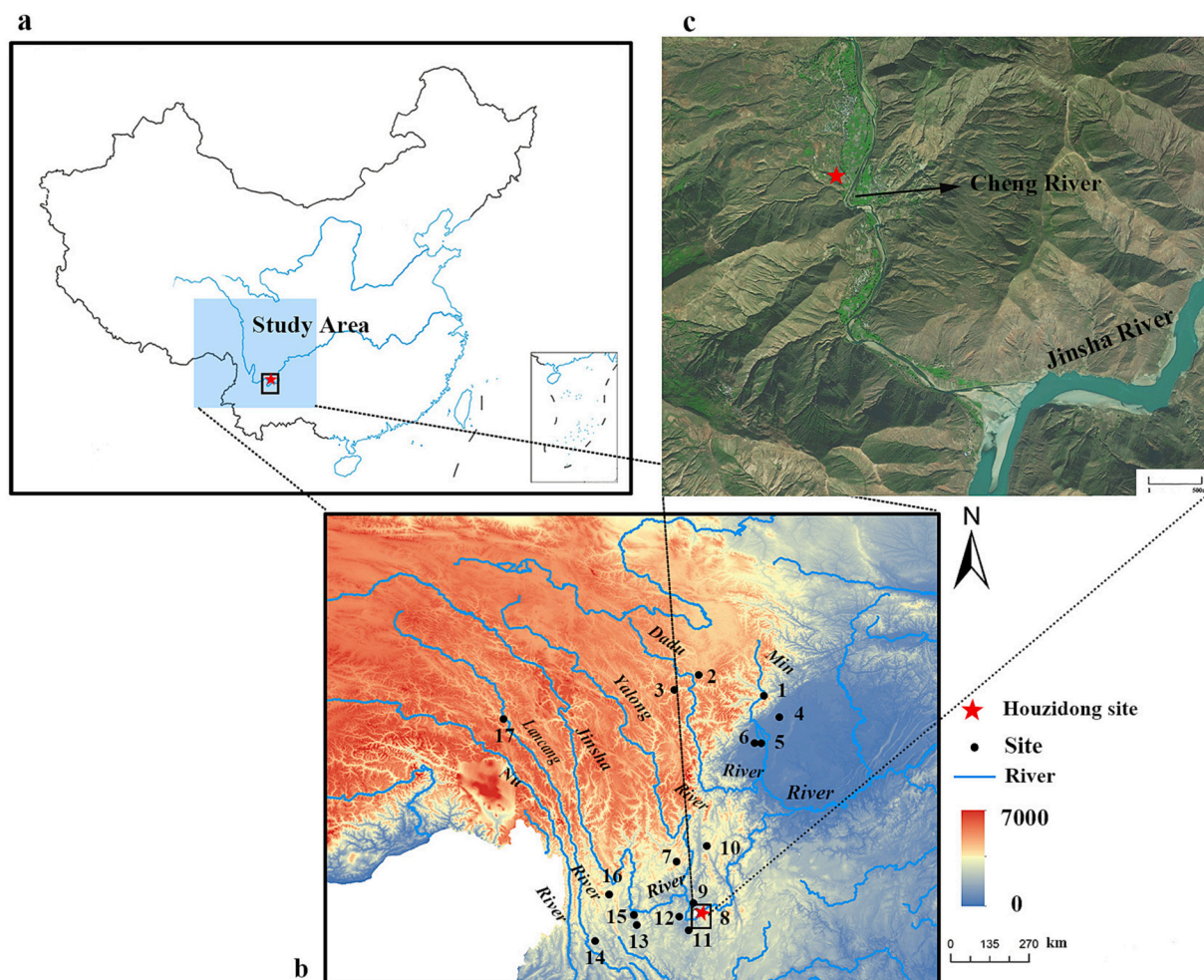


Fig. 1. Map showing the sites mentioned in this article, including **a** the position of the study area within China; **b** the precise location of the relevant sites in relation to the six river valleys discussed in this article, 1 Yingpanshan; 2. Haxiu; 3. Liujiashai; 4. Guiyuanqiao; 5. Baodun; 6. Gaoshan; 7. Guijiaobao 8. Houzidong; 9. Liantang; 10. Henglanshan; 11. Dadunzi; 12. Caiyuanzi; 13. Baiyangcun; 14. Xinguang; 15. Duizi 16. Haimenkou 17. Karuo, **c** an aerial view of Houzidong's geographic location.

decades by advances in paleobotanical research as well as isotope studies. It has long been established that rice and millet agriculture started in the region of what is now China. Foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliacium*) were the staple crops of the dry-land farming area in prehistoric northern China, originating from what Ren (2016) have dubbed China's Fertile Arc stretching from the eastern part of the Western Liao River and the Taihang Mountain to the middle and lower reaches of the Yellow River, while the first traits of domestication had fully introgressed into the broader population at the latest by 8000 cal. BP (Lu et al., 2009; Zhao, 2011; Yang et al., 2012; Ren, 2016; Liu et al., 2018; Liu et al., 2019). The possible center for rice (*Oryza sativa*) domestication lies in the Middle and Lower Yangzi River valley starting no later than 8500 cal. BP (Jiang and Liu, 2006; Zheng et al., 2016). Once they reached the eastern rim of the Tibetan Plateau, together these two domesticated crops of different origins provided a diverse and reliable crop supply allowing to maintain a stable population among communities in these foothill regions (d'Alpoim Guedes, 2011).

The region is furthermore of interest for research into the dispersal of these domesticates into Mainland Southeast Asia (Weber et al., 2010; Dal Martello et al., 2018; d'Alpoim Guedes et al., 2020; Gao et al., 2020). The earliest evidence to date suggests that the emergence of agriculture in southwest China corresponds to an expansion of millet farmers from northwestern China (d'Alpoim Guedes and Hein, 2018). The earliest evidence for millet agriculture in southwest China was found at Yingpanshan (5300–4600 cal. BP) in western Sichuan and at Karuo (5500–3750 cal. BP) in eastern Tibet, in both cases associated with ceramic types showing evidence for contact with northwestern China, most strikingly painted pottery (Jiang, 2004; Chen and Chen, Xuezhai 陈学志, 2006; Zhao and Chen, Jian 陈剑, 2011; d'Alpoim Guedes et al., 2014; He, 2015; d'Alpoim Guedes et al., 2015; Sagart et al., 2019; Song et al., 2021). Evidence from Guijiabao in Sichuan shows that rice and millets first co-occurred here around 5000 cal. BP at the latest, much earlier than previously assumed (Huan et al., 2022). Limited evidence from previous studies with direct AMS dates demonstrates that mixed millet and rice agriculture was practiced consistently at many sites in southwest China after 4700 cal. BP. The site of Baodun revealed some of the earliest evidence for mixed millet and rice agriculture in the Chengdu Plain of Sichuan, dating to approximately 2700 BCE; Baodun's inhabitants relied mostly on rice agriculture with millets as a supplementary (Jiang et al., 2009; Chen and Han, Enrui 韩恩瑞, 2013). Similar agricultural patterns also appear at Gaoshan (Chengdu Wenwu Kaogu Yanjiusuo 成都文物考古研究所, 2016). In Yunnan, rice and millets have been found at the site of Baiyangcun (2650–2050 BCE) (Dal Martello et al., 2018). Slightly later, mixed farming can be seen in the early phases of Haimenkou at ca 1600 BCE (Xue et al., 2022). Similarly dated finds come from the site of Dadunzi in Yuanmou (Jin et al., 2014). It has also been shown that at many sites in the region hunting and gathering remained important components of local subsistence practices (Zhang et al., 2019).

Based on this evidence, two different routes of millet agricultural dispersal into southwest China have been proposed, one from northwest China via the high mountains on the eastern rim of the Tibetan Plateau into the southwest (Wan, 2013; d'Alpoim Guedes, 2011; d'Alpoim Guedes and Butler, 2014), the other with the Chengdu Plain serving as a transit point for millet farming from northwest China into the southwest (Sun, 2008; Gao et al., 2020). It remains controversial if foxtail millet, broomcorn millet, and rice were introduced from northwest China and the middle Yangtze valley separately at various points (d'Alpoim Guedes et al., 2013; d'Alpoim Guedes, 2015; He et al., 2017; Dal Martello et al., 2018), or if they reached the region as a package at a later point (Huan et al., 2022). Recent years have furthermore seen considerable debate on the dates and extend of the early occupation of the Tibetan Plateau and the role that various domesticates had in this development (Chen et al., 2015; d'Alpoim Guedes et al., 2015; Lü, 2016; Lü et al., 2021; Tang et al., 2022; Tang et al., 2023).

Building on this previous work, the present study conducts systematic analysis on macro-botanical remains and phytoliths analysis at a late Neolithic site in the southeastern part of the Hengduan Mountain Range, namely at Houzidong, Huili County, combining it with direct radiocarbon dating to provide new evidence for the timing and mechanisms of the spread and adoption of western crops and at the same time gain further insight into subsistence practices at a particular site in the region. Houzidong is located in the southernmost tip of Sichuan at the border to Yunnan (Fig. 1). While this is a modern administrative division, it is based on a real geographic barrier, namely the Jinsha River which wraps around the southern edge of Sichuan and is nearly impossible to cross except for at very few points. Nevertheless, archaeological data from Huili has shown not just strong local characteristics in object assemblages but also evidence for cultural exchange since Neolithic times, especially across the Jinsha River into Yunnan but also with areas further north, east, and west (Tang, 1999; Sichuansheng Wenwu Kaogu Yanjiuyuan 四川省文物考古研究院 et al., 2009; Chengdu Wenwu Kaogu Yanjiusuo 成都文物考古研究所 et al., 2010; Hein, 2013, 2014a, 2014b, 2014c, and Hein, 2015).

While only very few prehistoric sites were known from that region until the mid-2010s, recent dam construction activities have led to a flurry of excavation work around Huili, one of the most extensive and successful projects being at the late Neolithic site of Houzidong (Fig. 2). Excavations revealed settlement remains and burials with well-preserved skeletons that were analyzed using a variety of methods. Based on osteoarchaeological studies, it has been suggested that some of the individuals may have shared ancestral links with inhabitants of Duizi in Yongsheng, northwest Yunnan (Zhang et al., 2021). The teeth revealed a low incidence of dental caries, so the researchers speculated that these individuals had a low-carbohydrate diet, meaning a low intake of grains (Zhang and Liu 刘化石, 2018). The results of stable isotope research on the same individuals suggests that they had a varied diet, with a large proportion of animal-based food consumed in addition to plant food (Wang, 2020). Zooarchaeological remains retrieved from the site include aquatic animals and mammals, with aquatic animals such as shellfish than mammals dominating the assemblage, and among mammals, wild animals and domesticated animals were both present (Zhu Xuchu, personal communication, 2021). The present study provides further insights into subsistence practices by systematic analysis on macro-botanical remains and phytoliths, at the same time helping to bridge the gap in our understanding of subsistence practices in prehistoric southwest Sichuan, and it also provides evidence for the reconstruction of the spread route of crops from north to south along the rim of the Tibetan Plateau.

3. Material and methods

3.1. Site location and previous research

Houzidong (102°6' 9"E, 26°8'55" N) is a settlement site located in the southwestern part of the Liangshan Yi Autonomous Region of Sichuan Province, at the southeastern edge of the Hengduan Mountain Range (Fig. 1b). It is situated on a second-level terrace at 1080 m asl. on the western bank of the Cheng River, a tributary of the Jinsha River, about 3 km north of the intersection of Cheng and Jinsha Rivers (Fig. 1c; Fig. 2a). Across the river from Yuanmou, an important prehistoric site in northern Yunnan. Houzidong was discovered in 1991, underwent surveys in 2002 and 2009 (Sichuansheng Wenwu Kaogu Yanjiuyuan 四川省文物考古研究院 et al., 2009), and was excavated in 2017–2018. So far, no full excavation report has been published, so the amount of information on object assemblages and settlement features is limited. When discussing the material culture below, we are thus relying on a combination of short overview publications and information on other contemporaneous sites in the region.

Huili County is dominated by mountains and intersected by a multitude of river valleys, the elevation ranging widely between 930 and

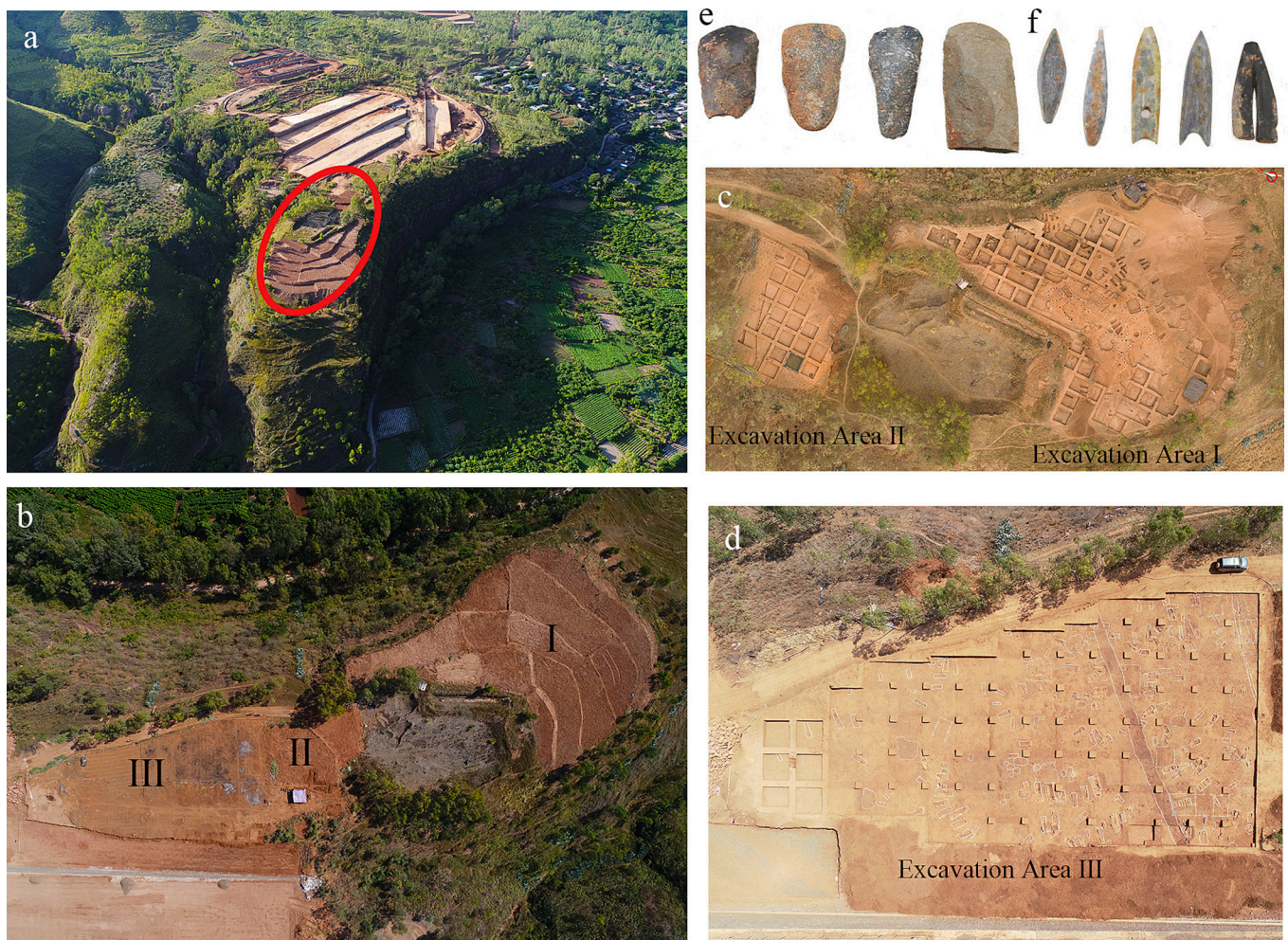


Fig. 2. a. The Houzidong site in its environmental and geomorphological context; b-d. the three excavation areas and features; e and f. selection of stone axes and arrowheads found at the site.

2074 m asl. The present-day climate is hot and dry and varies vertically between the mountains and the valleys, with a large temperature difference between day and night. The average annual temperature is 19.9 °C. The mountains allow for cultivating dryland crops, the river valleys supporting rice, vegetables, and subtropical fruits. Grasses are the dominant type of natural vegetation, which are suitable for grazing (Sichuansheng et al., 2009). Paleocological research in the region is still in its infancy, but the results of climate modelling providing insights into the suitability of the environment for various subsistence patterns will be discussed further down below.

The 1991 estimate was that the settlement area extended over 2500 m² (NS 1000 m, EW 250 m) and the associated cemetery over 2000 m², but in 2017–18 this was amended to 15,000 m². The 2009 trial excavations revealed three poorly preserved stone-construction graves with further stone slates and scattered fragments of pottery and stone tools on the surface dated by the excavators between Neolithic and the Warring States period (i.e. c. 1st mill. to 2nd c. BCE) (Sichuansheng et al., 2009). In 2017–2018, 425m² were excavated, uncovering 121 stone-construction graves (called stone-cist graves by the excavators, though there are notable differences in structure and associated burial customs between graves found in various parts of western China using stone as a building material; see Hein, 2017 for a discussion), 19 building features, 78 refuse pits, four hearths, six ash ditches of unclear function, and a considerable number of object finds, mostly ceramics, but also spindle whorls and stone tools (Liu, 2018; Liu and Gao高寒, 2020) (Fig. 2). Based on object typology, the excavators confirmed the earlier estimate

in dates and gave 5000–48,000 BP as earliest absolute date for the oldest Neolithic settlement layers, the graves being later in date (Liu et al., 2018). The earliest graves were relatively dated to the same period as those at Yunnan Yongren Caiyuanzi which have yielded an absolute date of 4300 ± 135 cal. BP (Yunnansheng Bowuguan 云南省博物馆, 1985; Yunnansheng Wenwu Kaogu Yanjiusuo 云南省文物考古研究所 et al., 2003).

While bone preservation at Caiyuanzi was extremely poor, the skeleton remains in the Houzidong graves were better preserved. Many of them were double burials, and there were 17 cases of deviant burials, most of them associated with violent deaths, several of them by arrowhead-induced trauma (Liu, 2018). There was a lack of elderly individuals, the average age at death being around 27 years. Another interesting phenomenon is the custom of tooth extraction, mostly maxillary lateral incisors (Zhang and Liu刘化石, 2018; Zhao et al., 2022). Differences in grave sizes, construction, and content also allows for some insights into social differentiation, most graves being very small and with no burial goods, but some as long as 3 m and containing ceramics, stone arrowheads, antlers, and cowrie shells suggesting far-flung contacts (Liu, 2018). Isotope analysis on 76 human bones and 42 M teeth suggest subsistence mostly based on C3 plants with a small amount of C4 plants (fitting with what a time was likely a forested environment) and a certain amount of animal protein, likely either from both wild and domesticated animals (Wang, 2020) or mostly from wild animals, as other researchers suggest (Zhang and Liu刘化石, 2018). No differences were found between male and female individuals, but slight

differences existed between younger and older individuals. In terms of dental health, the caries rate was very low (c. 15%), so it has been suggested that the diet was low in starch and thus low in grains, pointing at a non-agricultural mode of subsistence (Zhang and Liu 2018). This will be further examined here via analysis of paleobotanical materials.

3.2. Sample collection and processing

The 2017–2018 excavations covered three areas (Fig. 2b). Throughout all areas, layers 5–7 were the main layers bearing cultural material dating to the late Neolithic period. Altogether 210 flotation samples were taken (140 samples from area I, 1 sample from area II, and 69 samples from area III), adding up to a volume of 1379.5 L taken from archaeological features in these three layers (310.5 L from layer 5, 825 L from layer 6, and 244 L from layer 7), including houses, pits, trenches as well as from the layers themselves (Table 1). Sixteen phytolith samples were collected during the Zhang and Liu 2018 excavation, sampling features in excavation area III. Soil samples were floated at the site using the bucket flotation method. Plant macro-remains were collected in sieves with the smallest mesh size of 0.2 mm, then air-dried. Identification and further analysis were carried out in the Joint International Research Laboratory for Environmental and Social Archaeology at Shandong University. All samples were weighed before being sorted under a binocular stereomicroscope. Crop seeds, weeds, charred fruits, etc. were separated from wood charcoal. Identification was conducted by referring to modern collections, atlases of plants and weeds (Guo, 1998; Liu et al., 2008; Zhao, 2010), and previous archaeobotanical reports.

Phytoliths were extracted by heavy liquid flotation (Wang and Lü, 2003; Houyuan 1993; Piperno, 2006). First, 2 g of soil were weighed and poured into test tubes. Each sample was then mixed sequentially with 30% H₂O₂ and 10% HCl to eliminate organic materials and carbonates. Next, distilled water was added and centrifuged, a process that was repeated several times to rinse the residual acid, and then phytoliths were separated by ZnBr₂ (density 2.37 g/cm³) heavy liquid. The extracted phytoliths were transferred into a new tube and washed and dried. They were finally mounted on slides with neutral resin and fixed with a cover glass. Phytolith identification and counting were conducted using a Nikon YS100 light microscope at 400× magnification. At least 400 phytoliths were counted and recorded in each sample.

4. Results

4.1. Radiocarbon dating results

Four cereal grain samples from Houzidong were sent to the Beta Analytic Radiocarbon Dating Laboratory for dating, and all samples produced radiocarbon dates successfully (Table 2). The lowest cultural layer 7 did not yield enough carbonized crops, but all submitted radiocarbon samples from refuse pits and trench from layer 6 resulted in dates of 4200–4000 cal. BP which falls within the late Neolithic period suggested based on object assemblages and burial characteristics.

Table 1
Context of flotation and phytolith samples from Houzidong.

Archaeological features	No. of flotation samples			No. of phytolith samples
	Layer 7	Layer 6	Layer 5	
Houses	13	100	27	4
Pits	14	30	8	8
Trenches	8	2	0	1
Stratigraphic Layers	0	2	6	3
Total	35	134	41	16

4.2. The archaeobotanical assemblage

A total of 2308 plant remains were identified from 210 samples of three excavation areas (Table 3), which included the specimens could not be identified because of breakage or not known. Identifiable remains were classified into 3 species of cereals, 10 species of weed, and 4 species of fruits, almost all the seeds from excavation area I (Fig. 3). The average seed density is about 1.7 seeds per liter. Crops are the most important part in the assemblage of plant remains, taking up 62.1% of all remains.

The total number of crop samples retrieved from the three excavation areas is 1433. Three distinct types of crops have been recognized, foxtail millet (*Setaria italica*), broomcorn millet (*Panicum miliacium*), and rice (*Oryza sativa*). Among these, 99.6% of the crops were concentrated in Area I, indicating that this was the primary location for crop consumption (see discussion below). Measures of relative percentage and ubiquity indicate that foxtail millet is the most prevalent species, representing 73.1% of all crops, followed by broomcorn millet at 25.6%. Only 1.3% rice were found, which represents extremely low proportions of the crop remains in all samples. In terms of the ubiquity in which they appear, although the frequency is not high, foxtail millet is still the most abundant, followed by broomcorn millet, and rice is the least common (Fig. 4). (See Fig. 5.)

These three types of cereals have been found in high frequency in houses and trash pits near the houses. Besides the abundant crop remains, some categories of weedy plants have been recovered from these trash pits, including *Setaria viridis*, *Digitaria* sp. and very small amounts of other species of weeds. Different stages of crop processing leave different grain forms, phytolith types, and weed combinations, resulting in a changing ratio of crop grains to weeds, immature to mature crop grains (Harvey and Fuller, 2005; Song et al., 2012). Fuller et al. (2014) argued that if the pre-storage process is comprehensive and labor-intensive, the amount of grain husks, stalks, and mixed weed seeds left by archaeological discoveries for daily consumption will be relatively small. Based on this, the paleobotanical remains recovered from Houzidong are closely tied to food consumption and waste disposal, with people taking the final steps of crop processing outside their houses, then preparing and consuming foods inside, and disposing the remains in trash pits next to their homes.

Altogether 416 seeds of weeds were collected from all Houzidong samples, representing only a small fraction of the total plant remains. All identified weeds can be further classified into four groups based on utilization and ecological implications: fabaceae, grasses, other edible species, and fruits. Not many fabaceae remains were recovered, only adzuki bean (*Vignasp.*), vetch (*Vicia*), soybean (*Glycine* sp.), and sweet clover (*Melilotus officinalis*) were identified. Adzuki bean, vetch, and soybean belong to the Fabaceae family and are not only edible but also an essential source of oil and vegetable protein (Zong et al., 2017). Furthermore, legume-cereal crop rotation increases grain yields (Zeng et al., 2016). Animal feed is another way to utilize fabaceae; sweet clover is mainly used for this purpose. However, the numbers of fabaceae remains in the samples was quite small, so it is difficult to estimate the significance of these plants, but it could suggest that farming was not intensive enough to require crop rotation.

The edible species included chenopodium (*Chenopodium* sp.), perilla (*Perilla frutescens*), and Sichuan pepper (*Zanthoxylum bungeanum*) possibly collected for eating. Leaves and seeds of chenopodium are edible and are still consumed as vegetables in some parts of China. Sichuan pepper and perilla may be used as seasoning. The remnants of Sichuan pepper recovered at the site are one of the oldest finds of Sichuan pepper, whose peculiar flavor has become one of the most characteristic spices of Sichuan food in modern China. This finding of Sichuan pepper in a late Neolithic context indicates that the inhabitants of Sichuan had already noticed and began to utilize this plant early, a tradition that continues to the present day.

Grasses include three taxa: green bristlegrass (*Setaria viridis*), crabgrass (*Digitaria* sp.), and barnyard grass (*Echinochloa* sp.), all in the

Table 2

Radiocarbon dating results from the Houzidong site (calibrated with OxCal 4.4 and the IntCal 20 curve).

Lab Code	Dated material	Context No.	Cal. date BP	Calibrated age BP (68.2% prob.)	Calibrated age BP (95.4% prob.)
Beta - 614,193	Rice	H6	3770 ± 30	4230–4085	4240–3995
Beta - 614,195	Millet	H6	3760 ± 30	4225–4015	4240–3990
Beta - 617,157	Millet	G2	3750 ± 30	4155–4005	4235–3985
Beta - 617,158	Millet	H29	3720 ± 30	4145–3965	4155–3975

Table 3

Summary of flotation samples and plant remains by context type.

Context Species	Layer 7	Density (244 L)	Layer 6	Density (825 L)	Layer 5	Density (310.5)	Total counts
Cereals							
<i>Setaria italica</i>	3	0.01	1016	1.23	29	0.09	1048
<i>Panicum miliacium</i>	1	0.004	360	0.44	6	0.02	367
<i>Oryza sativa</i>	1	0.004	17	0.02			18
Grasses							
<i>Setaria viridis</i>	12	0.05	99	0.12	1	0.003	112
<i>Digitaria</i> sp.			76	0.09	2	0.006	78
<i>Echinochloa</i> sp.			12	0.01			12
Wild Fabaceae							
<i>Vigna</i> sp.			15	0.02	2	0.006	17
<i>Vicia</i>			2	0.24	2	0.006	4
<i>Glycine</i> sp.			1	0.12			1
<i>Melilotus officinalis</i>			2	0.002			2
Other			1	0.001			1
Other edible species							
<i>Chenopodium</i> sp.	13	0.05	60	0.07	72	0.23	145
<i>Zanthoxylum bungeanum</i>	1	0.004	2	0.002	3	0.01	6
<i>Perilla frutescens</i>			2	0.002	1	0.003	3
Fruits							
<i>Thladiantha dubia</i>			5				5
<i>Physalis alkekengi</i>			2	0.002			2
<i>Ziziphus jujuba</i> var. <i>Spinosa</i>			2	0.002			2
Solanaceae					1	0.003	1
Nut fragments			3	0.004	1	0.003	4
Unidentified seeds frag.	15	0.06	436	0.53	29	0.09	480
Total counts	46	0.18	2113	2.58	149	0.48	2308

Paniceae subfamily, which were identified as field weed species. These grasses are well adapted to cultivated fields, and commonly co-exist with crops. Green bristlegrass and crabgrass are the most frequently found of dryland weeds; barnyard grass is commonly found in connection with wetland rice farming. The ubiquity and proportion of dryland weeds was much higher than that of paddy field weeds, suggesting that the former was much more common than the latter.

Three fruit species were recovered, wintercherry (*Physalis alkekengi*), and jujube (*Ziziphus jujuba* var. *Spinosa*), making up a very low percentage in plant assemblage, but they may also have been a food resource.

4.3. Phytoliths

All phytoliths samples have been collected from Zone III of Houzidong site. Phytoliths are preserved in poor condition and heavily weathered. Thirty morphotypes of phytoliths have been identified in 16 samples (Fig. 6), but the majority were unidentifiable to genera or species, of which two were confirmed from crops. Only double-peaked phytoliths from rice husks and rice bulliform phytoliths appeared in 5 samples (Fig. 6). The proportions of these rice phytoliths were very low, accounting for 1% and 0.03% of the total respectively. No foxtail millet or broomcorn millet phytolith was found despite the existence of abundant samples of charred millet seeds. A possible reason could be that the scale and quantity of samples collected are too limited, or that the preservation conditions were too poor to retrieve sufficient identifiable phytoliths. The Neolithic site of Guijiabao in the Sichuan plain presents a similar situation (Huan et al., 2022). Bilobate phytoliths from

Panicoideae were found in most of the samples. Other morphotypes like rondel from Pooideae, long saddle from Bambusoideae, middle saddle from Arundinoideae, short saddle from Chloridoideae have also been recorded in most samples with quite low proportion. (See Fig. 7.)

The presence of bulliform from rice leaves, although the proportions were not very high in samples, demonstrates the existence of local rice cultivation. Relatively high proportions of double-peaked phytoliths from rice husks, revealing a strong relationship between deposits in these contexts and rice dehusking activities at the site.

5. Discussion

5.1. People and plants on the eastern rim of the Tibetan Plateau

The eastern rim of the Tibetan Plateau is a geographical ecotone connecting the Qinghai-Tibet Plateau, the Yunnan-Guizhou Plateau, and the Western Sichuan Plain. The region has a complicated and fractured terrain, characterized by a variety of environments including uplands, valleys, plains, and wetlands located in close proximity of each other. In this special environment, the many small ecological niches provide a variety of resources that could have been exploited in the past, requiring different forms of human adaptation. It is therefore not surprising that archaeological evidence from the region indicates varied and diverse subsistence practices not relying solely or even majorly on crop agriculture or domesticated animals but rather taking advantage of the broad range of edible plants and animals the local environment provided.

The carbonized plant remains found at Houzidong reflect a mixed



Fig. 3. Selection of plant remains from Houzidong. 1 foxtail millet (*Setaria italica*), 2 broomcorn millet (*Panicum miliacium*), 3 barnyard grass (*Echinochloa* sp.), 4 crabgrass (*Digitaria* sp.), 5 green bristlegrass (*Setaria viridis*), 6 wintercherry (*Physalis alkekengi*), 7 chenopodium (*Chenopodium* sp.), 8 perilla (*Perilla frutescens*), 9 rice (*Oryza sativa*), 10 Sichuan pepper (*Zanthoxylum bungeanum*), 11 adzuki bean (*Vigna* sp.), 12 manchou tubergourd (*Thladiantha dubia*). Scale bar 1 mm. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

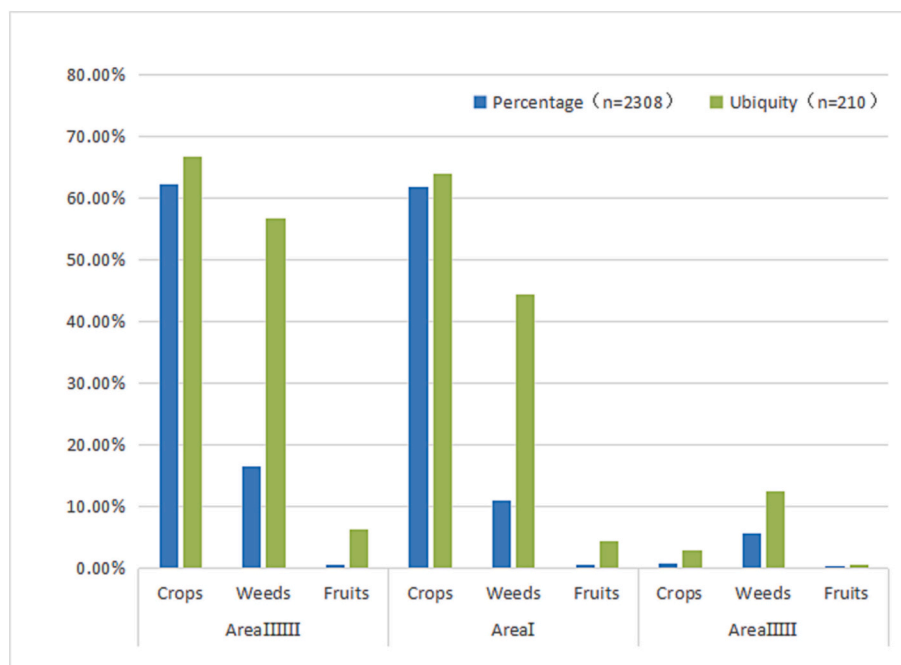


Fig. 4. Plant remains from the three excavation areas comparing Area I and combined Areas II and III.

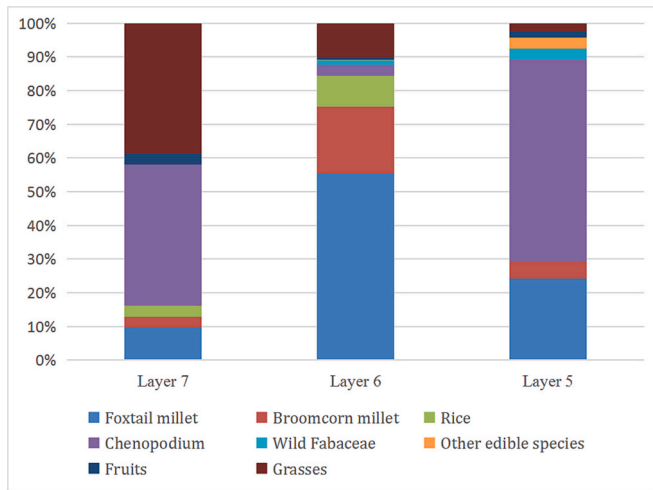


Fig. 5. Plant taxa from different layers of Houzidong.

exploitation of domesticated millets and rice in 4200–4000 cal. BP. Foxtail millet and broomcorn millet are the two main crops, with foxtail millet being prominent, and a small amount of rice in the diet. Beyond that, stable isotope results measured from human skeletal remains indicate a diet consistent with direct or indirect consumption of C4 plants at a significant scale by the inhabitants of Houzidong (Wang, 2020), which is consistent with the results gained from analysis of the macro-botanical remains. Phytoliths were characterized by low proportions of crop morphotypes, most of which were double-peaked phytolith from rice husks, indicated crop dehusking activities at the site (Harvey and Fuller, 2005). Paleopathological observations indicated low prevalence of dental caries which is usually associated with low levels of starchy crop food (Zhang and Liu, 2018). Together with the evidence from macro-botanical remains and phytoliths, this indicates that crops were not a major part of the diet at Houzidong during the late Neolithic. Rather, people exploited the abundant and varied wild resources, pursuing a diversified subsistence strategy that relied on a broad range of food sources, thus buffering failure in any one of them at any given time. In addition to crops, a range of the edible wild plants were found in house remains and trash pits at the site, suggesting that they have been gathered for food. Stone adzes, stone arrowheads, stone axes, and other tools normally associated with hunting activities were

found in Houzidong (Li, 2007; Hein, 2015). Evidence of zooarchaeological and isotope analysis likewise reflect hunting and fishing activities. Overall, the subsistence strategies at Houzidong thus were characterized by a combination of limited crop cultivation with hunting and gathering of a broad range of local plants and animals. Additionally, spices were used to make the food more palatable.

Other prehistoric sites in the mountains of Sichuan, Yunnan, and eastern Tibet similarly show a combination of crop cultivation, gathering, and hunting (see Fig. 8 for location and date of the sites discussed in the following). The percentages of foxtail millet, broomcorn millet, and rice vary in the different locations, likely depending both on differences in local environment and human decision making. Yingpanshan, located in a fertile though narrow river valley, has the earliest evidence for pig domestication and millet farming in this region (He et al., 2009; Zhao, 2011). The single millet farming at the high-elevation sites of Karuo, Haxiu, and Liujiazhai suggests that here dryland corps may have been chosen for their short growing season and tolerance to aridity, and hunting also played a more dominant role in the local diet rather than pig husbandry like at Yingpanshan (Chen and He, Kunyu 何锐宇, 2007; d'Alpoim Guedes, 2015; d'Alpoim Guedes, 2018; d'Alpoim Guedes and Hein, 2018). Communities living in valleys and plains located on or surrounded by mountains made greater use of mixed-crop farming strategies, a diversification which would have helped to minimize the risk of crop failure. There was already combined cultivation of rice and millet prior to 5000 BP, as evidence from Guojiabao shows (Huan et al., 2022), but most of the archaeobotanical evidence for crop cultivation in the region dates to after 5000 cal. BP with a continued diversification of plant use and subsistence practices. Some sites show clear evidence for experimentation with various subsistence regimes, most notably Haimenkou whose inhabitants initially relied much on rice and millet agriculture (though always combined with gathered plants), trying out a variety of different plants and combinations of crops and gathered foods, and later came to rely more heavily on wheat (Xue et al., 2022).

At Baiyangcun, rice remains decreased substantially in the later phase of occupation, showing changes over time, be it as a result of experimenting with various food resources, be it due to changes in the local environment or culturally determined changes in food preferences (Dal Martello et al., 2018). Dadunzi is located in the Yuanmou Basin, and the Longchuan River runs through the site, making the low-lying area with sufficient groundwater sources suitable for rice cultivation. Meanwhile, the dry and hot valley environment with little precipitation makes the land in the hillside area far from the river drier, which

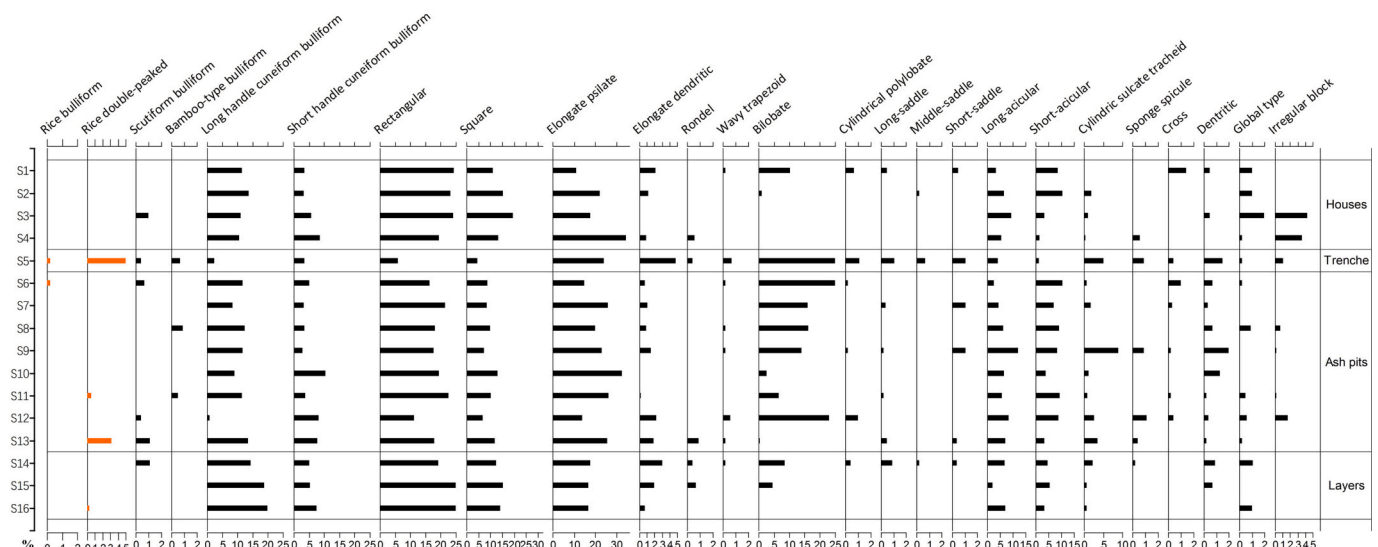


Fig. 6. Percentage of phytoliths from Houzidong.

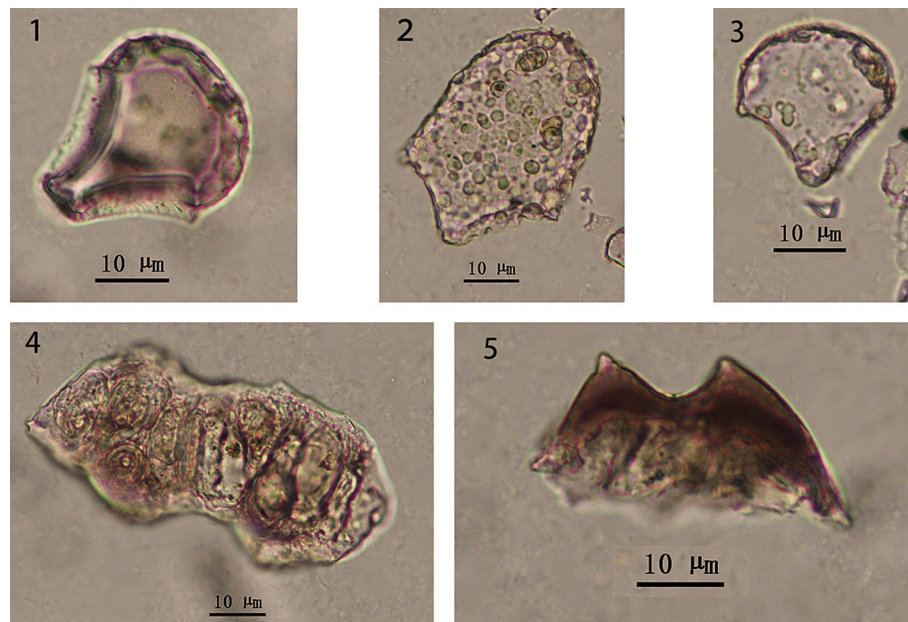


Fig. 7. Crop phytoliths from Houzidong. 1 Bulliform phytolith from rice leaf 2 scutiform bulliform phytolith from reed leaf 3 Short handle bulliform 4–5 Double-peaked phytoliths from rice husks.

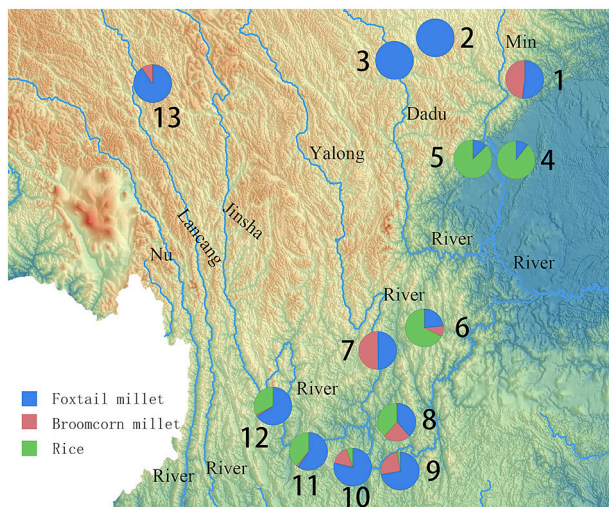


Fig. 8. Crop assembles distribution in the eastern rim of the Tibetan Plateau . 1 Yingpanshan (5300–4600 cal. BP); 2. Haxiu(5500–4700 cal.BP); 3. Liujiazhai (5300–4700 cal.BP) 4. Baodun (4700–3650 cal.BP); 5. Gaoshan(4500–4200 cal. BP); 6. Henglanshan (4700–4500 cal.BP); 7. Guijiaobao(Phase I 5000–4500 cal. BP, PhaseII 4500–3700 cal. BP); 8. Liantang(4160–3960 cal.BP); 9. Houzidong (4200–4000 cal.BP); 10. Dadunzi (4000–3600 cal.BP); 11. Baiyangcun (Period I 4600–4250 cal.BP, Periods II/III 4150–4000 cal.BP); 12. Haimenkou (Phase I 3550–3400 cal. BP, PhaseII 3400–3050 cal BP, Phase III 3750–2250 cal BP); 13. Karuo (5500–3750 cal. BP).

provides conditions for dryland farming. In modern-day and historic-period cuisine as far as accounted for by textual accounts, edible wild plants are rarely used, indicating that the complex landform environment provided the inhabitants with natural conditions for planting a variety of crops, so that they could rely more on agricultural production rather than wild resources (Jin et al., 2014). Henglanshan is located on a hillside, and there are no terraces on either side of the river at the foot of the hills. When the water rises in the rainy season, the floodplains on both sides of the river are submerged. Therefore, there is very little land available for farming, and large-scale crop production cannot be carried

out. Gathering, fishing, and hunting account for a large proportion of its economic activities in the present and probably did so throughout the past as well (Liu and Wang, Hao 王昊, 2007; Chengdu Wenwu Kaogu Yanjiusuo 成都文物考古研究所, 2016). The great variety of crop patterns reflects adaptations to a variety of habitats. Baodun and Gaoshan, both located in the Chengdu Plain, adopted rice agriculture readily (Chen et al., 2015; Wan and D'Alpoim Guedes, 2015; Lee et al., 2019), not surprising given that the flat expanse of land, abundant water supply, and warm humid climate lend themselves to wet-land rice agriculture. Indeed, it resembled the middle and lower Yangtze River Valley in many respects (D'Alpoim Guedes et al., 2013) and – spurred on by intensive agriculture – was able to support high population numbers with large walled sites developing in the Neolithic (Fuller and Qin, 2009). No such sites have been found in the foothills and mountains on the eastern rim of the Tibetan Plateau. While animal bone assemblages from Chengdu Plain sites point to increasing importance of domesticated animals, especially pigs, the study of animal remains and production tools from the mountain sites reveal that in terms of meat acquisition, at most – but not all – of these sites livestock was raised in addition to hunting (Yunnansheng Bowuguan 云南省博物馆, 1977; Yunnansheng Bowuguan 云南省博物馆, 1981; Yunnansheng Wenwu Kaogu Yanjiusuo 云南省文物考古研究所 et al., 2003), however, hunting remained dominant in most locations especially at high-elevation sites in the more mountainous parts of the region (Chen and He, Kunyu 何锟宇, 2007; d'Alpoim Guedes, 2015; Hein, 2015; Liu and Wang, Hao 王昊, 2007).

In addition to millet grains, many small wild herbaceous plant seeds were recovered from sites in southwest China, as all of them suitable as food resources. The most prevalent species is chenopodium. Chenopodium is cultivated in the modern Himalaya region and Tibet (Gao, 2021). Large quantities of chenopodium have been found at Yingpanshan, Karuo, Liujiazhai and Haimenkou, and they appear in smaller numbers at many other sites. Therefore, it is highly possible that chenopodium was exploited by people as non-crop food plants in the mountainous regions of southwest China. Besides chenopodium, we see the evidence for the consumption of Glycine sp. and Vigna sp. at Yingpanshan, Henglanshan, Houzidong, Haimenkou, Baiyangcun, and Dadunzi. Wild fruits, including *Vitis*, *Rubus*, *Crataegus*, *Prunus cf. persica*, and peach, together with nuts, indicates gathering of wild forest products mainly in July to September, which is roughly the same time when

crops would have been harvested, though some of the wild plant resources like chenopodium can be gathered in May and June.

All this evidence shows that the past inhabitants of these sites exploited the environment in various ways depending on the season and their individual locations, but that they also experimented with various plants and subsistence practices, making decisions based on feasibility, assessment of risk, and food preferences. Outside of the Chengdu Plain where crop farming came to be dominant, mixed subsistence patterns in which crops often played only a minor role were the norm, reflecting that people were very aware of their local environment and its potential. The eastern rim of the Tibetan Plateau represents a unique multi-niche environment and indeed a bio-diversity hotspot that was exploited in the past using various types of mixed economy combining hunting, gathering, and farming, with varying emphasis on one or the other depending on specific location and community preferences.

These human activities, including gathering, farming, and hunting, of course did not occur in isolation, nor did they take place in a static local environment. Holocene cooling and drying events had an influence on developments of and changes in subsistence economies on the eastern rim of the Tibetan Plateau, though the exact relations are difficult to assess due to the highly localized micro-climates dominating this region and our limited understanding of how global patterns of climate change played out locally. It is clear, however, that all communities had diversified subsistence practices that were highly adaptable to both annual fluctuations in weather patterns and more long-term changes, and could also easily be adjusted should any group or individual decide to move to a different ecotone within the region.

Most of the region belongs to the alpine climate zone, which is generally characterized by low precipitation, low humidity, and sufficient sunshine. The vertical climate change is obvious, showing vertical change from subtropical climate to permanent snow area. Because of the large differences in elevation between river valleys and high mountains, the temperature decreases by 0.5 °C for every 100 m increase in elevation (Shi and 石硕., 2009). Climate is a vital factor that influenced crop selection. Paleoclimate studies on Sichuan, Yunnan, and Guizhou suggest that from about 5500 cal. BP, the climate in southwest China, started with a strong drying and cooling, there is a sudden cooling event around 4000 a BP (Zhang et al., 2004; Hong et al., 2005; Dearing et al., 2007). Around 4200 cal. BP, with the further decline of the paleo-monsoon and sharply decrease in rainfall, the upper Yangtze River experienced a rapid change from warm humid to cold dry climate (Yasuda, 2008; Zhu et al., 2014). Even within same region, between different subregions have lots of microclimates will have an impact on the selection of crop varieties (Hein, 2015). d'Alpoim Guedes et al. (2014a) explored the range of crops suitable for cultivation in southwest China using a thermal niche model, testing it using modern and cold temperature conditions. The results suggest that most areas of the Three Gorges, Daba Mountain, northwestern Guizhou, and northern Yunnan are not suitable for rice cultivation; only the Sichuan Basin and southern Yunnan are ideal for rice growing in southwestern China. Under such climatic conditions, millets are a more desirable choice than rice. Nevertheless, at some sites that were not within the suitable niche, people still decided to explore the potential of rice cultivation, like for instance at Haimenkou, where this turned out to be a short-lived experiment. This is partially due to climate, partially due to the local geomorphology.

The six main rivers dominating this region run parallel from north to south, their valleys cutting deep into the terrain and creating a sharp contrast between high mountain peaks and deep river valleys, dividing the area into several geomorphological sub-regions (Li, 1989). Because of the complicated topography, it is difficult to establish the complex irrigation system required to grow rice, thus incurring a lot of effort and risk. Given the availability of a broad range of other plant foods easily gathered, rice agriculture may not have seemed worth pursuing. In contrast, millets are not only better adapted to growing in a broad range of different environments due to their cold and drought tolerant

properties, but they are also easy to manage, with only a small investment of input producing a considerable output (Saseendran et al., 2009). The systematic flotation at the site of Baiyangcun in Yunnan supports that hypothesis. Here, in a subsistence system based on a mixed millet and rice crop economy, rice had a more prominent role in Period 1 (2650–2300 cal. BCE), but became secondary to foxtail millet during Period 2 (2200–2050 cal. BCE) (Dal Martello et al., 2018) suggesting experimentation with different subsistence regimes, the final decision leading to a de-emphasizing (but not complete abandonment) of rice agriculture. The emphasis on millets in the eastern part of the Tibetan Plateau is also in line with the predictions by D'Alpoim Guedes et al. (2013) based on climate modelling.

Similar pattern were also found in Southeast Asia. Archaeobotanical analysis of material from Khao Wong Prachan Valley in eastern-central Thailand confirmed the arrival of millets in this region during 4400–4100 cal. BP (Weber et al., 2010; d'Alpoim Guedes et al., 2020). Rice was incorporated into the crop assemblages till 3450–3150 cal. BP. The inhabitants did not invest labour in the construction and maintenance of irrigated paddy fields. Instead, they focused on less intensive dryland rice and millet cultivation systems, wild rice continued to be gathered by inhabitants of the sites. Furthermore, compared to animal husbandry, hunting was also an important part of the subsistence (Weber et al., 2010; d'Alpoim Guedes et al., 2020). This pattern of dryland, rain-fed cultivation was a continuation within local forager subsistence practices in later periods. Pollen and phytolith studies have demonstrated that anarboreal expansion with higher sea levels 4000–5000 years ago made agriculture difficult in this area, With a decline in forests and an increase in grasses, the resulting “tropical savannah” environment became better suited for dryland agriculture (Weber et al., 2010).

Overall, given the adaptation to climate and geomorphology, focus on millet exploitation over rice has long played an important role in crop cultivation of these mountainous foothills, but overall subsistence patterns at each site still depend on the microclimate and topography around it, leading to considerable intra- and inter-regional diversity which is also reflected in the material culture (e.g. Hein, 2014b).

5.2. The role of the eastern rim of the Tibetan Plateau in facilitating the spread of agriculture and cultigens

The eastern rim of the Tibetan Plateau having been eroded by various rivers and carved into a succession of high mountains and deep valleys form a natural north-south corridor. The varied environment leading to an uneven distribution of natural resources requires regional diversification in subsistence practices and at the same time promotes contact and cooperation between groups inhabiting adjacent niche environments (Hein, 2015). Similarities in archaeological remains such as ceramics, stone tool, and for later periods metal object but also rare items such as cowrie shells and other materials and cultural customs such as particular grave forms and burial practices reflect various types of contact between various sub-region (Tong, 1986; Hein and Zhang, Zhenwei 张正为, 2015).

The southwest edge of Sichuan including Huili, is surrounded by high mountains that isolate it from other parts of the region (Hein, 2017). The terrain here slopes gently down toward northern Yunnan and moving south is relatively easy; here the Cheng River runs directly into the Jinsha River, providing a link to Yunnan, and the archaeological record shows many characteristics in material culture that connect the area to neighboring parts of Yunnan. Stone-construction burials are a particularly striking phenomenon that appears in various locales across what Tong Enzheng called the crescent-shaped cultural-communication belt stretching from the far northeast of China over its northwest in Gansu all the way to Yunnan in the southwest (Tong, 1986; Hein, 2014c). However, these graves vary considerably in form, content, and date throughout that vast region (Hein, 2017). The grave form, funerary objects, and burial customs associated with the stone-construction

graves of Houzidong are largely identical with those seen at Dadunzi and Caiyuanzi just across the border in Yunnan (Tong, 1986; Liu et al., 2018), and it has been argued that the human remains show close affinity between the two groups (Zhang et al., 2021), thus suggesting that they are closely related. At the same time, the ceramics and stone tools found at Houzidong closely resemble finds from eastern Tibetan and the western Yunnan Plateau (Hein, 2014b; Hein, 2017). Some decorative programs like incised line designs and impressed points on the ceramic vessel body are common at Houzidong and they also occur at Dadunzi, Baiyangcun, and Xinguang (Yunnan, 1977; Yunnansheng Bowuguan 云南省博物馆, 1981; Yunnan et al., 2003). Considering relative and absolute dates of these sites, some scholars argue that the origin of these features lie with the Karuo culture of eastern Tibetan which ended up influencing groups on the central and western Yunnan Plateau, including the Liangshan region of Sichuan, leading to significant changes to local Neolithic cultures (Sun, 2008; Chen and 陈苇, 2012; Wan, 2013). Some of the Houzidong stone tools such as coarsely flaked shouldered axes and adzes strongly resemble finds from Yunnan and Karuo (Tang, 1992; Sichuansheng et al., 2009; Hein and Zhang, Zhenwei 张正为, 2015; Hein, 2017). This shows that southwest Sichuan at the time was well-connected to Yunnan and also to areas much further north.

In terms of domesticated crops, millet appearing in southwest Sichuan was likely one of the by-products of cultural contact across this considerable expanse of land, possibly via down-the-line exchange or individual human movement. As one of the earliest millet-bearing sites in the southwest is Yingpanshan which is located in the upper reaches of the Min River in western Sichuan, Gao (2021) proposed the existence of a cultural communication channel from the Chengdu Plain via the mountains of western Sichuan and onto the Yunnan-Guizhou Plateau emerging from 4500 a BP. However, western Sichuan and Houzidong which is located at the middle reaches of the Jinsha River are separated by Min River, Dadu River, and Yalong River, and there is no evidence suggesting east-west contact across this expanse during the Neolithic; indeed, material culture and burial customs are entirely distinct. Karuo in the upper Lancang River, on the other hand, seems to play an important role in long-distance exchange in this region. The Lancang and Jinsha Rivers flow side by side, making traveling between them easier. This hypothesis is supported by archaeological evidence such as similarities in ceramic decorations and stone tool shapes.

The archaeological evidence discussed above implies that southwest Sichuan was a key region for early culture contact between eastern Tibet and northwestern Yunnan. Based on comparison of object types, Chen and 陈苇 (2012) argued that there was evidence for the existence of an exchange route from the Lancang River to the Jinsha River (Fig. 8). This also fits with the paleobotanical evidence discussed in this paper. Based on direct AMS radiocarbon dating on grains from Houzidong and other sites discussed above, we propose the following progression. Millet agriculture reached the eastern edge of the Qinghai-Tibet Plateau around 5000 cal. BP where the inhabitants of Karuo began to cultivate foxtail millet. Subsequently, the crops and the knowledge of how to tend to them were carried south along the Lancang River to western Yunnan, reaching the middle reaches of the Lancang River around 4800 cal. BP. They reached northwest Yunnan and southwest Sichuan around 4500 cal. BP or possibly earlier with people on the north and south banks of the Jinsha River adopting the practice of dry-land farming and planting millets locally. According to the evidence currently available, rice and millet appeared in southwest Sichuan simultaneously, however, as for whether they arrived there as a package or if they were introduced from two separate places remains an open question.

6. Conclusion

The analysis of macro-botanical remains and phytoliths from Houzidong site presented here together with an evaluation of previously published data from other sites across the region has thrown light on

patters of crop utilization during the Late Neolithic in southwest China, their integration into complex and varied patterns of subsistence, and the long-distance spread of domesticated crops and the knowledge of how to tend to them. While southwest China is now a major rice-growing region, archaeological research shows that around 4200–4000 cal. BP rice used to play a minor role while millets where a much more important crop even in the Chengdu Plain, let alone at higher elevations. This study has confirmed that the north-south trending mountain ridges and river valleys on the eastern rim of the Tibetan Plateau have been corridors of various types of human movement and exchange from early prehistoric times, reflected not only in shared material culture and burial customs, but also in the spread of crops. We have shown that adoption of these crops has varied significantly between different sites, depending both on ecological niches and cultural choices, with communities experimenting with different crops and subsistence patterns, but always opting for a range of different food sources, both wild and domesticated, to mitigate risk. The combination of paleobotanical research, AMS radiocarbon dating, and the evaluation of archaeological evidence together with a consideration of geomorphology and climate presented here has proven to be a powerful tool to trace and explain past human behavior leading – among other things – to the spread of domesticated crops and the knowledge of how to tend to them. It is remarkable that the high mountains of western China, far from being a barrier to human movement and exchange, have actually been a conduit to it from early prehistoric times. The diversity in natural resources – for this early period in particular edible plants and animals – and ecological niches with varying degrees of suitability for dry and/or wetland planting of various crops seems to have generated an openness toward various types of subsistence and new plants, the drive to experiment while still maintaining a diverse portfolio of food sources to mitigate risk, and apparently also an interest in moving and/or being receptive to outside cultural influences. Each community picking and choosing what suited them best in their ecological niche and with their specific social structures and cultural perceptions, they created a rich and varied patchwork of highly localized cultural phenomena that were nevertheless connected by certain shared features and allowed for the dispersal of new domesticates, agriculture, and other technologies during the Neolithic and later periods.

Author contributions

Bingyan Wang: Writing - original draft, Investigation, Data curation, Formal analysis. **Huashi Liu:** Project administration, Conceptualization. **Yang Liu:** Data curation. **Zejuan Sun,** Data curation. **Xuexiang Chen:** Conceptualization, Writing - review & editing, Project administration, Funding acquisition, Resources, Supervision. **Anke Hein:** Conceptualization, Writing - review & editing, Data curation, Funding acquisition, Validation, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ara.2023.100448>.

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