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Archaeobotanical analysis of a mountainous metallurgical settlement: Evidence from the Jicha site, Yunnan Province, Southwest China

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ABSTRACT

While there has been recent momentum in the understanding of subsistence strategies among prehistoric communities in southwest China, various mountainous regions, including northwest Yunnan, remain underexplored. To address this knowledge gap, we present new archaeobotanical evidence from Jicha, a Bronze Age settlement (1890–105 cal. BC) well known for its metallurgical activities. The study aims to elucidate the plant-based resource strategies that sustained complex craft production in this highland community. By analyzing plant macro-remains recovered through flotation, our results inform the understanding of diachronic changes in the ancient economy at Jicha. The initial settlement (1890 cal. BC) was sustained by the cultivation of rice (*Oryza sativa*) and millet (*Setaria italica*). Wheat (*Triticum aestivum*) was introduced around 1635–1280 cal. BC and rapidly adopted, becoming a key staple alongside rice. From 780–400 cal. BC, rice and wheat cultivation intensified, with millet as a supplement, ensuring a resilient food surplus. During the late occupational phase (400–105 cal. BC), rice and wheat remained dominant, while millet cultivation appears to have diminished. The integration of high-yield, high-demand cereals (rice and wheat) with ecologically hardy millet resulted in a multi-cropping farming system that exploited the varied landscape near Jicha. Such an economy perhaps may have played a role in sustaining the component of the society specialized in metal production.

1. Introduction

In recent years, Yunnan has emerged as a focal point of archaeological research. Situated at the crossroads connecting East and Southeast Asia, the mountainous terrain of Yunnan has played a pivotal role in cultural connections, migration and exchange of ideas (Higham, 1996; Higham et al., 2011; Li and Hu, 2009; Yao, 2010; Gao et al. 2020). Agriculture was a vital component amid the interactions of material culture, resources, and technologies. Recent archaeobotanical studies in Yunnan have provided valuable insights into the region's ancient economy (d'Alpoim Guedes, 2013; Dal Martello, 2020).

Yunnan lies at the crossroads of the Yangtze Basin, the Mekong and Salween rivers, and the eastern margin of the Qinghai-Tibet Plateau, also known as the Hengduan Mountains. The specificity of geographic location also endows Yunnan with exceptional biodiversity, which has been substantiated by archaeological evidence dating back to the Paleolithic (Ji et al., 2004). However, most archaeobotanical evidence available to date comes from a narrow range of inter-mountain basins, often referred to as the Dian culture area. Higham (1996) argues that such an environment was optimal for rice cultivation to sustain larger populations. Such a notion has been supported by flotation work revealing an abondance of rice as well as wheat remains in association with Dian Cultural sites (Wang, 2014; Yang, 2016; Yao et al.. 2015; Wang et al., 2019; Wang et al., 2022).

In contrast to the Dian cultural area, the hilly terrain in the northwestern Yunnan remains largely uninvestigated. While currently available evidence suggests that rice- and millet-based agriculture was introduced to the region as early as 2600 BCE (Dal Martello et al., 2018), few sites have yielded sufficient data to reconstruct agricultural practices after the Baiyangcun assemblage (Liu et al., 2016a). The

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Haimenkou site in Jianchuan County is the sole site where flotation and archaeobotanical research has been systematically conducted so far. Inhabitants of Haimenkou first practiced rice and millet cultivation around 1600 BCE before wheat cultivation appeared around 1450 BCE. In Haimenkou's later occupational phase, dating between 800 and 300 BCE, archaeobotanical evidence indicates a general decrease in millet and rice production in favour of wheat (Xue, 2010; Jin, 2013; Xue et al., 2022).

Jicha was first excavated in 2022 by the Yunnan Provincial Institute of Cultural Relics and Archaeology in cooperation with the School of Archaeology and Museology, Sichuan University (Fu et al., 2024). The excavation aimed to clarify the site's stratigraphical sequence and chronology, given its long occupational phases from the Neolithic to Iron Age. In this study, we present the archaeobotanical record obtained from a systematic flotation program, along with direct radiocarbon measurements from Jicha. The findings demonstrate that multi-crop strategies were applied during the second and first millennia BCE and evolved over time. A connection is also made between agricultural practice and the support of labour forces specialised in metallurgical work, as revealed by the excavation.

1.1. *Jicha (吉岔) site*

The Jicha site is located approximately 40 km northwest of Weixi Lisu Autonomous County, Diqing Tibetan Autonomous Prefecture, Yunnan Province (99°5′ E, 27°20′N). The site is situated at the crossroads of the Mekong, Yongchun, and Jicha Rivers (Fig. 1). In the Lisu language, *Ji* means "copper" and *cha* denotes the meeting of rivers, similar to Mandarin, in which *cha* also refers to the intersection of rivers or roads. The site occupies a rounded platform north of the Jicha River and west of the Mekong River, at an altitude of 1706 m (Fig. 2).

Today, the primary crops grown in the region include rice, wheat, and maize. In addition to subsistence crops, Weixi County also produces cash (industrial) crops, such as walnuts and tea, which are processed or used as raw materials (Fang and Chang, 2006). Currently, most areas around the site are planted with maize. Weixi Lisu Autonomous County is located in a region with diverse climate and terrain, acting as a transitional zone between the Qinghai-Tibet Plateau and the Yunnan-Guizhou Plateau. The Jinsha River (Upper Yangtze), Lancang River (Mekong river), and Nu River (Salween River) converge in the county.

Fig. 2. Landscape surrounding the Jicha site (from the northeast to the southwest, photograph by J. Fu).

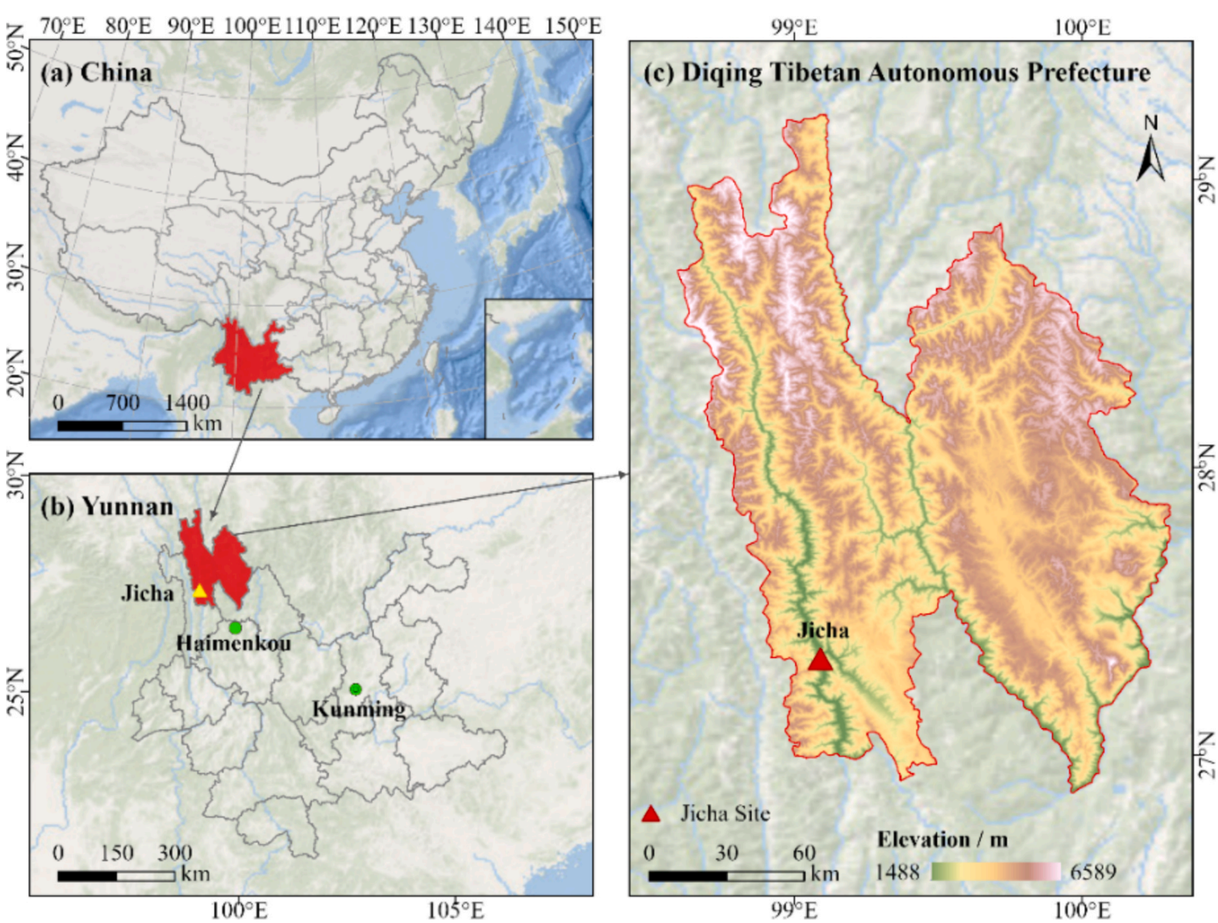

Fig. 1. Location of Jicha site (Map created using ArcGIS Pro.)

With long winters and no distinct summer, the region is characterized by a subtropical to temperate monsoon highland climate, with a seamless transition from spring to autumn. Because of significant altitude differences within the region, the climate shows prominent vertical characteristics. The annual average sunshine duration is 2104.5 h, and the average annual precipitation is 938.1 mm (Weixi Lisu Autonomous County Annals Compilation Committee, 1999).

The Jicha site was discovered in 2012, and archaeological fieldwork was carried out in 2022, with an excavation area of 4000 m^2. The archaeological findings, including structures, infant burials, and metallurgical remains (Fig. 3), provide vital evidence on north–south immigration and technological diffusion through the eastern Qinghai-Tibet Plateau corridor. The most important discovery was the metallurgical production area at the center of the settlement, where archaeologists have revealed the operation chain of metallurgical production, including stone tools, furnaces, and metal products (Fu et al., 2024).

2. Materials and methods

A systematic soil sampling strategy was applied during the 2022 excavation of the Jicha site. A total of 549 samples, representing 4062 L of sediment, were collected from 211 different deposits. All samples were floated near the site using a bucket method as described by Crawford (1983) and Zhao (2004). The light fraction was collected using a 0.25 mm mesh sieve, while the heavy fraction was collected using a 2 mm mesh sieve. In addition to botanical remains, some pottery sherds, beads, bones, and kernels were found.

This study presents the results from 48 analyzed samples from seven different archaeological contexts. The 48 samples were meticulously selected from 549 specimens at the archaeological site to ensure temporal representativeness and methodological rigor (Table 1). Samples were proportionally chosen from each of the four distinct chronological periods identified at the site, utilizing a stratified random sampling approach within each temporal phase. This dual strategy served two critical objectives: maintaining balance of each cultural period to uphold chronological integrity and reducing potential sampling biases to maintain statistical validity.

We sorted and observed the samples at the Archaeology and Cultural Relics Laboratory at Southwest Minzu University. Flotation samples were separated using a series of sieves with mesh sizes of 2 mm, 1 mm, 0.7 mm, 0.5 mm, and 0.3 mm, in preparation for the next identification step. Macrobotanical remains from each fraction were analyzed under a low-power stereo binocular microscope (Zeiss Stemi 2000-C) with magnification up to 50X. We used a Keyence VHX-6000 digital microscope to document selected seeds.

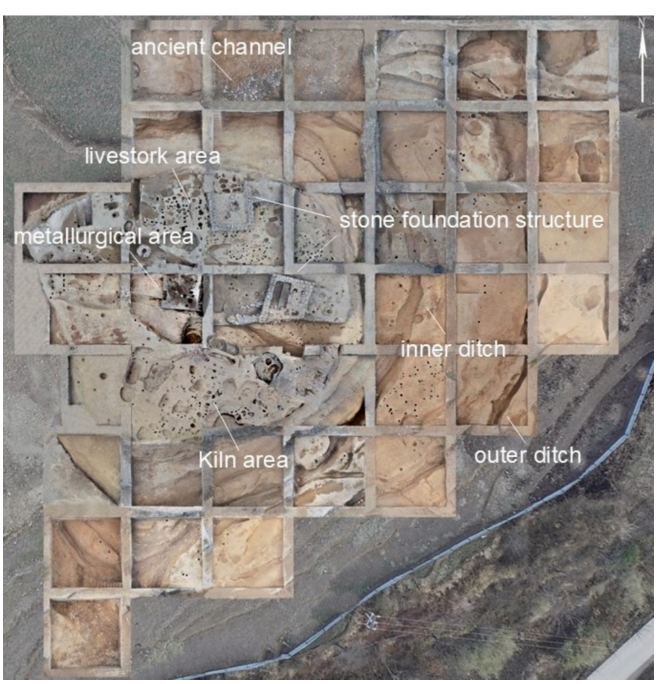

Fig. 3. Morphology of the Jicha settlement. Photographs and figure by J. Fu.

Table 1
Archaeological contexts of analyzed samples.

Phase	Context						
	Pit	House	Ditch	Furnace	Kiln	Cultural layer	Tomb
1			1				
2	6	1		1		5	3
3	7	4	1	3	2		4
4	5	2	2			1	

3. Results

3.1. Radiocarbon dating and chronology

To determine the absolute age of the site, we dated a series of charred seeds of rice, wheat, charcoal, and bones from 19 different deposits (Fig. 4). According to the radiocarbon dating result, archaeological context, and cultural relics, the site is divided into 4 periods as follows:

Phase 1: Late Neolithic remains, characterized by the pottery with elaborately impressed and incised (I&I) patterns (1890–1740 cal. BC).

Phase 2: Early Bronze Age remains, synchronous or earlier than the Haimenkou site, characterized by the disappearance of I&I patterns of pottery (1635–1280 cal. BC).

Phase 3: Late Bronze Age remains, characterized by eared pottery, infant burials, and stone building structures (780–400 cal. BC).

Phase 4: Iron Age remains exhibit traits consistent with Phase 3, with an increased frequency of metallurgy-related relics and the emergence of iron artefacts (400–105 cal. BC).

3.2. Archaeobotanical record

A total of 19,616 carbonized botanical remains from at least 36 taxa were recovered from the 48 samples, including charred seeds, seeds fragments, fruit stones, nut shells, and unidentifiable seeds and fragments. Table 2 presents the absolute counts of the plant remains. The dominant plant remains included crops such as rice, millet, and wheat. These cultivated crops, along with gathered fruits and nuts, collectively represent the diverse food resources available at the site.

4. Discussion

4.1. Crops

4.1.1. Rice (Oryza sativa) and millet (Setaria italica)

Mixed rice and millet agriculture had been established in the northwest Yunnan Plateau as early as 2650 cal. BC (Dal Martello et al., 2018). Subsequent published archaeobotanical evidence from Haimenkou, near Jicha, showed a staged development of agriculture in the region as outlined in the introduction (Xue et al., 2022). The crop assemblage at the Jicha suggests the cultivation of rice and millet since the Late Neolithic, confirming similar traditions at other locations in northwest Yunnan as revealed by other studies (Li et al., 2016). A high ubiquity index for rice—over 80 %—likely suggests its staple status (Fig. 6).

To assess morphological changes over time, we measured the size of 20 randomly selected rice grains from each phase, notwithstanding Phase 1, in which we measured all three recovered grains. In total, 183 grains were analyzed across all phases. Their average length was 4.12 mm (standard deviation [SD] 0.41), width was 2.52 mm (SD 0.31 mm),

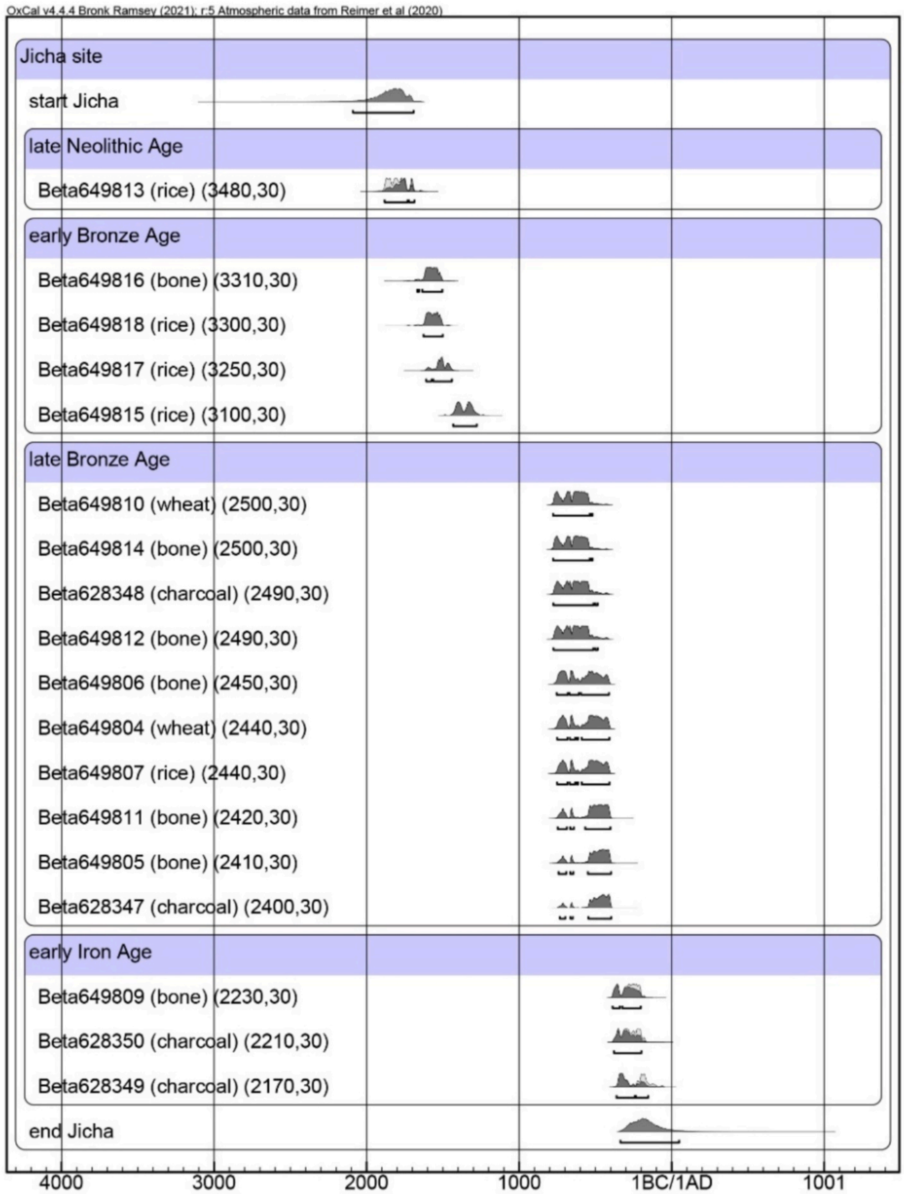

Fig. 4. Bayesian age model for the Jicha site based on calibrated radiocarbon dates. Generated using Oxcal (figure by J. Fu).

and L/W ratio was 1.65 (SD 0.2). These measurements show a trend toward enlarged grain size beginning in Phase 2 (Fig. 5). Based on classification criteria discussed in Harvey and Fuller (2005), Fuller et al. (2016) and Castillo et al. (2016), more than 98 % of the rice grains could be classified as the *japonica* variety (*Oryza sativa* subsp. *japonica,* L/W < 2), while only three grains could be classified as *Oryza sativa* subsp. *indica* (L/W > 2.2).

Given the small sample size in Phase 1, ubiquity analyses were conducted only for Phases 2–4 (Fig. 6). Results show that foxtail millet was more prominent during the initial occupational phase, but its importance notably decreased over time. When considering the relative proportion of thousand-grain weight (Fig. 7), millet played a relatively minor role within the overall crop composition. Crop selection at the site was likely impacted by both environmental conditions and human choices, which could have driven changes in crop combinations revealed here (Fuller and Lucas, 2017; Liu et al., 2016b).

It is noteworthy that broomcorn millet (*Panicum miliaceum*) was not identified in the analyzed samples, as it has been discovered at surrounding sites, including Baiyangcun and Haimenkou. In general, small-grained cereals like foxtail millet do not dominate Jicha's crop assemblage. This pattern may reflect the site's relatively favorable hydrothermal conditions, which reduce the need for drought-resistant foxtail millet. However, foxtail millet may be present in the as-yet-unidentified samples from Jicha.

An interesting trend emerges when comparing Jicha with assemblages recovered from the Chengdu Plain and western Sichuan during a similar period (Fig. 8). At the Guiyuanqiao site, for example, a small portion of foxtail millet, broomcorn millet, and very little rice were recovered from the initial occupational phase (cal. 3100 BCE). By the second phase of Guiyuanqiao (cal. 2600–2390 BCE), the crop package had shifted to a mix of rice and foxtail millet, akin to practices observed in the Baodun cultural sites, dating to similar chronology as Guiyuanqiao Phase 2 (Sichuan Institute of Cultural Relics and Archaeology, 2015). Research has shown that at higher altitudes in the eastern fringe of the Tibetan Plateau, such as Yingpanshan and Karuo, the importance of foxtail increased (d'Alpoim Guedes, 2013; d'Alpoim Guedes and Butler, 2014; Zhao and Chen, 2011; Song et al., 2021). The Jicha site, located in a high-altitude mountainous area and strategically positioned along the north–south cultural migration pathway, reflects this trend. Given foxtail millet's excellent drought resistance and tolerance to high

Table 2
Plant remains recovered from the 2022 excavation of the Jicha site.

	Phase 1 1890–1740 cal. BC	Phase 2 1635–1280 cal. BC	Phase 3 780–400 cal. BC	Phase 4 400–105 cal. BC	Total
No. of contexts	1	16	21	10	48
Crops					
Oryza sativa	4	1626	13,296	102	15,028
Oryza sativa < 1/2	6	3202	3574	95	6877
Oryza spikelet bases		65	710	31	806
Setaria italica	5	60	26	2	93
Triticum aestivum		19	3036	23	3078
Hordeum vulgare			5	1	6
Fragments of wheat /barley		8	1108	4	1120
Pseudo-crop					
Fagopyrum esculentum		8		22	30
Chenopodium sp.	12	549	398	19	978
Pulses					
Leguminosae		2	2		3
Glycine max		1	3	2	6
Fruits and nuts					
Zanthoxylum bungeanum			7		7
Vitis sp.		3		2	5
Rubus sp.			3		3
Diospyros sp.			1		1
Alkekengi sp.		1			1
cf. Pinus			1		1
Prunus persica			7	12	19
Prunus mume			14	3	17
Prunus sp.			4	2	6
Juglans sp. nut shell		2	19	45	66
Rhus chinensis			3		3
Davidia involucrata		2 (fragments)	2 (1 whole)		4
Grasses					
Dryland weeds					
Gramineae	1	9	4	1	15
Setaria sp.	3	11	3	2	19
Echinochloa sp.		4	5		9
Digitaria sp.	2	5	7	2	16
Polygonaceae		2	1	3	6
Persicaria nepalensis	1	5	6	18	30
Wetland weeds					
Cyperaceae	1	2	1	4	8
Scirpus juncoides			1		1
Other weeds					
Lamiaceae		4			4
Perilla frutescens		1			1
Elsholtzia sp.		11	1	2	14
Viola sp.		1	1	1	3
Phyllanthaceae			1	5	6
Acalypha sp.		1		1	2
Caryophyllaceae			4		4
Unknown					
Seeds	2	33	16	11	62
Fruits and nuts		4	37	25	66
unknown pod (fragments)		40	84	1	125
Total seeds (fragments excluded)	35	2354	16,829	224	19,442
Total Nutshell and fruit stone Fragments	0	6	81	87	174

elevational conditions, it can be used as a pioneer crop to cultivate new farmland. As crop cultivation stabilizes and develops, it can thrive in low-input marginal farmland. Foxtail millet cultivation emerged as an adaptive strategy for pioneering settlers, particularly in high-elevation environments.

4.1.2. Wheat (Triticum aestivum) and barley (Hordeum vulgare)

Wheat started to appear in the crop assemblage in Phase 2 of the site and persisted until Phase 4. In contrast, barley was less common, with only three complete barley grains and three broken fragments found in Phases 3 and 4. The timing and pathways of wheat and barley dispersals across Eurasia during the third and second millennia BCE have been clarified by recent studies (Betts et al., 2014; Gao, 2023; Li et al., 2007; Liu et al. 2019; Liu et al., 2016b; Liu et al. 2017; Stevens et al., 2016; Zhou et al., 2020). While both wheat and barley are present at the Jicha site, wheat is much more abundant and exhibits differences in size and morphology, potentially due to diverse landraces commonly appear in vertical landscapes.

A total of 82 grains of wheat were measured (Fig. 9), revealing an average length of 4.2 mm (SD 0.46), width of 3.1 mm (SD 0.44), and L/W ratio of 1.37 (SD 0.19). These values are smaller than those from Haimenkou (Xue et al., 2022), the Gansu-Qinghai region, and other southwestern sites but are more comparable to data from Dian Culture sites (Dal Martello et al., 2021).

Free threshing wheat and naked barley were introduced to ancient China during the second millennium BCE—notwithstanding early appearance in Shandong Peninsula, which remains subject to further discussion—likely via multiple routes, including ones both north and south to the Tibetan Plateau (Liu et al. 2017, Liu et al. 2019). While much scholarly attention has been drawn to the northern route(s)

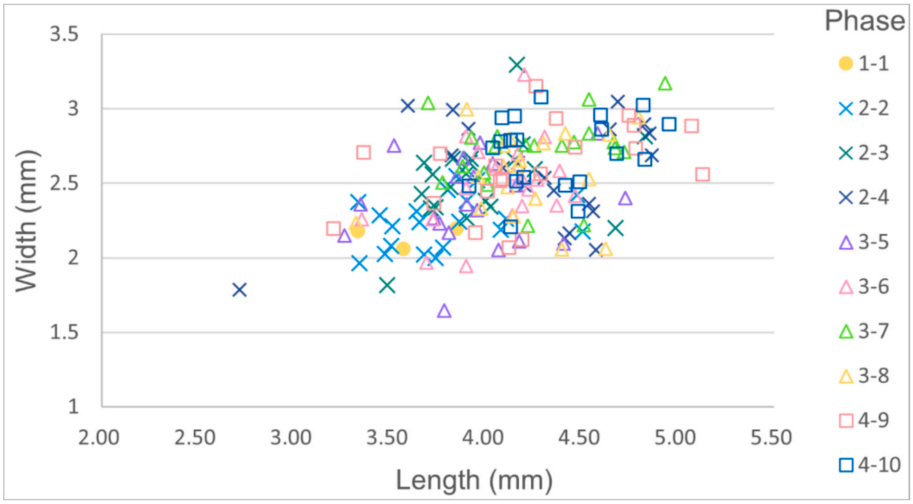

Fig. 5. Scatterplot of length/width data of Jicha rice (*Oryza sativa*) grains.

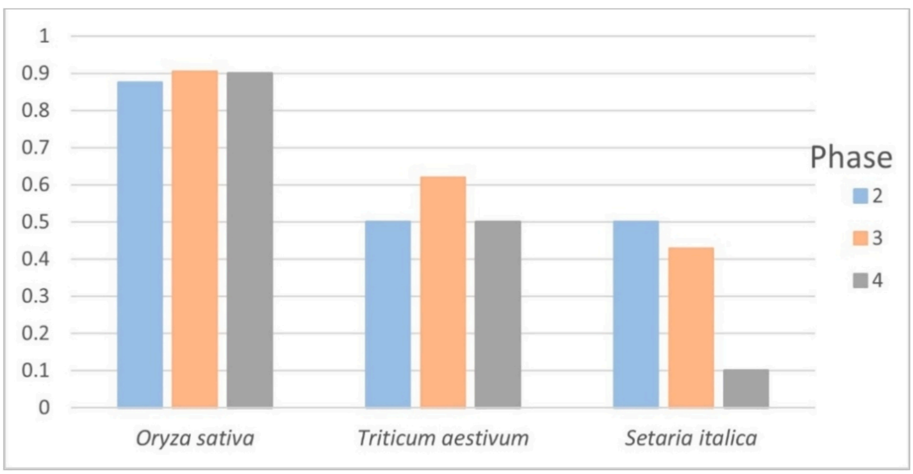

Fig. 6. Ubiquity of major crops across different periods at the Jicha site.

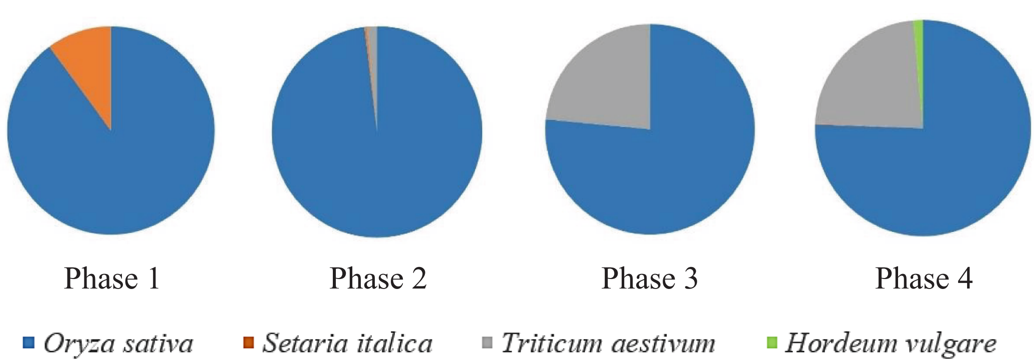

Fig. 7. Relative proportion of major crops at the Jicha site based on estimated thousand-grain weight.

aligned with the historic 'silk route' (e.g. Zhou et al., 2020), the chronology and pathways along the southern route have not yet been clarified. A range of early evidence of wheat and barley from a belt region along the southern fringes of the Tibetan Plateau has recently been reported, mostly dated to 1500 BCE, including Karuo in eastern Tibet along the Mekong River (Liu et al., 2016b; Liu et al., 2017; Song et al., 2021; Tang et al., 2021). The appearance of wheat and barley in Jicha during the second occupational phase adds new insight into this discussion, highlighting the adoption of Fertile Crescent crops in a broader Himalayan region during the middle of the second millennium BCE, now including the Hengduan Mountains (northwest Yunnan). In the subsequent millennium, within the Dian cultural context, wheat maintained its importance in local agricultural systems (Dal Martello et al., 2021; Wang, 2014; Yang, 2016; Yang et al., 2020).

Fig. 8. Location of sites mentioned in text (Map created using ArcGIS Pro) 1. Jicha (1890–105 cal. BC), 2.Haimenkou (1600–300 cal. BC), 3.Yubeidi (700–100 BCE), 4.Baiyangcun (2650–2050 cal. BC), 5.Guiyuanqiao (3100–2000 cal. BC), 6.Baodun (2700–1700 cal. BC), 7.Yingpanshan (3300–2600 cal. BC), 8.Karuo (3350–2100 cal. BC).

4.1.3. Soybean (Glycine cf. max)

Soybean remains were rare at the site, accounting for six grains. They were unearthed from Phases 2 to 4. Piror to this study, only three sites in Yunnan—the Baiyangcun, Haimenkou, and Yubeidi sites—have reported the presence of soybean remains (Dal Martello et al., 2018; Xue et al., 2022; Yang et al., 2020).

4.2. Fruits and nuts

A total of 11 species of charred seeds or fruits were identified at the Jicha site, nine of which were edible, including stone fruits such as peaches and plums, as well as berries such as *Rubus*. Moreover, seven *Zanthoxylum bungeanum* (Sichuan pepper) seeds were discovered. These have been previously found at the Yubeidi site, suggesting a potential culinary or medicinal use (Yang et al., 2020).

Juglans (walnut) was the most common nut found at the Jicha site, present from Phases 2 to 4. In addition to being directly consumed and used as oil, walnuts are also used as a spice locally. In local tradition, burnt walnuts are known to effectively eliminate the strong flavor of meat cooking, such as lamb. While the exact purpose of the walnuts found at the site remains uncertain, such ethnographic analogies offer a broader perspective on their potential uses.

Finally, seeds of *Davidia involucrata* (Chinese dove tree) were also discovered, including one intact and three fragmented seed remains (Fig. 11). This represents the first discovery of this species in Chinese archaeological contexts. A relic species has survived since the Tertiary period. Known for its ornamental value, *Davidia involucrata* also has straight, hard wood suitable for furniture making and as a fuel source.

4.3. Pseudo-cereals

4.3.1. Buckwheat (Fagopyrum esculentum)

A total of eight buckwheat grains were discovered in Phase 2, while 22 were found in Phase 4. These grains were identified as common buckwheat *(Fagopyrum esculentum)*, with grains encased in their husks and others dehusked. We measured 18 intact buckwheat grains, and the

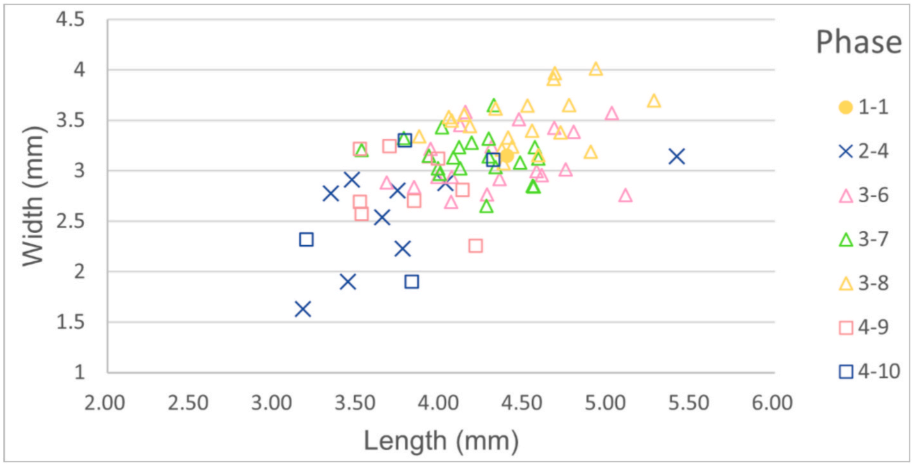

Fig. 9. Scatterplot of length/width data of Jicha wheat (*Triticum aestivum*) grains.

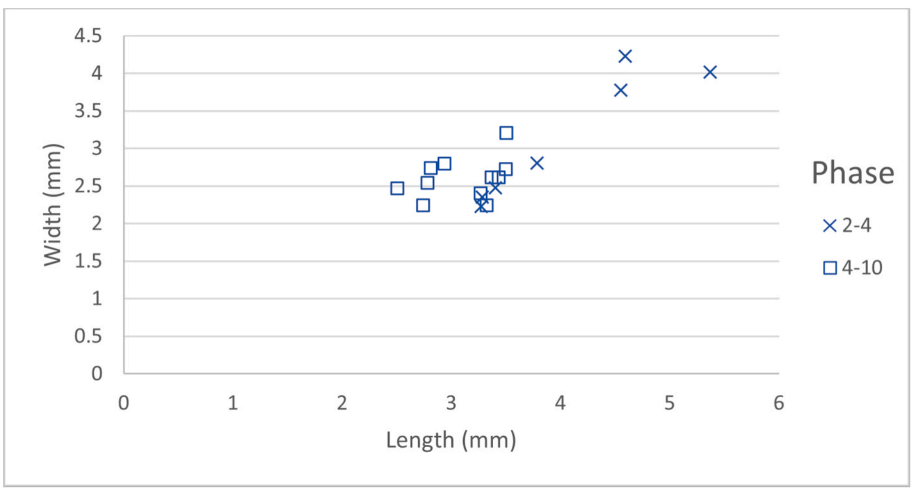

Fig. 10. Scatterplot of length/width data of buckwheat (*Fagopyrum esculentum*) grains found at Jicha.

results are presented in Fig. 10. In recent years, there has been a surge in discussions surrounding the cultivation and use of buckwheat. Evidence from Haimenkou (Xue et al., 2022) shows that by at least the early Bronze Age (1600 BCE), ancient populations in northwest Yunnan were already cultivating buckwheat. Although buckwheat is gluten-free, modern communities use it in various ways, such as making noodles, pastries, pancakes, and even brewing alcohol.

4.3.2. *Chenopodium sp*

Chenopodium is a common campweed often associated with human activities. At Jicha, *Chenopodium* was discovered in all four phases, with a ubiquity of 43.8 %. It has been found in most southwest China archaeological sites, sometimes surpassing the number of crop remains (Zhao and Chen, 2011; Xue et al., 2022). Archaeological discoveries, historical records, and ethnographic materials suggest it served various purposes, including as food via consumption of leaves and seeds and as a walking stick (Gao, 2020).

Scholars have begun to focus on the utilization and domestication of *Chenopodium*, noting a trend of thinning seed coats that accompanied the beginning of domestication. Even in modern contexts, communities worldwide continue to cultivate and use *Chenopodium* (Smith, 1984, 1992). In the Himalayan region, the consumption of *Chenopodium* is more prevalent among those living in lower altitude areas and with lower incomes. *Chenopodium* is prepared in various ways, including grinding into flour for baking, boiling with cornmeal for soups, and mixing with grains such as rice and millet for cooking porridge. It is also combined with pumpkin for cattle feed, as well as used as fuel and in brewing alcohol (to speed up fermentation).

Chenopodium is primarily cultivated in two ways: mixed with rice and soybeans or planted on the edges of potato, maize, and rice fields; the plant is generally not cultivated in fields on its own (Partap and Kapoor, 1985; Wang, 2018). This approach of mixed planting techniques aligns with observations of *Chenopodium* at the Jicha site. *Chenopodium* seeds were frequently found alongside rice; in specific samples, they adhered to the rice. This suggests that the *Chenopodium* plants were included in rice fields and transported back to the site for processing and storage.

4.4. Weeds

The diversity of weed species at Jicha is not extensive, including six common dryland weeds and two wetland weeds, along with seeds of three other weed species (Fig. 11). One *Perilla frutescens* seed was found at Phase 2. This annual herbaceous plant is valued for its medicinal and aromatic properties, and its seeds can be extracted for oil, serving culinary and preservative purposes. *Perilla frutescens* is commonly recovered from archaeological sites in the Sichuan region, particularly in the Chengdu Plain, where a considerable amount of charred *Perilla frutescens* seeds were found at the Yingpanshan site in western Sichuan (Zhao and Chen, 2011). Known for its distinct fragrance, *Perilla*

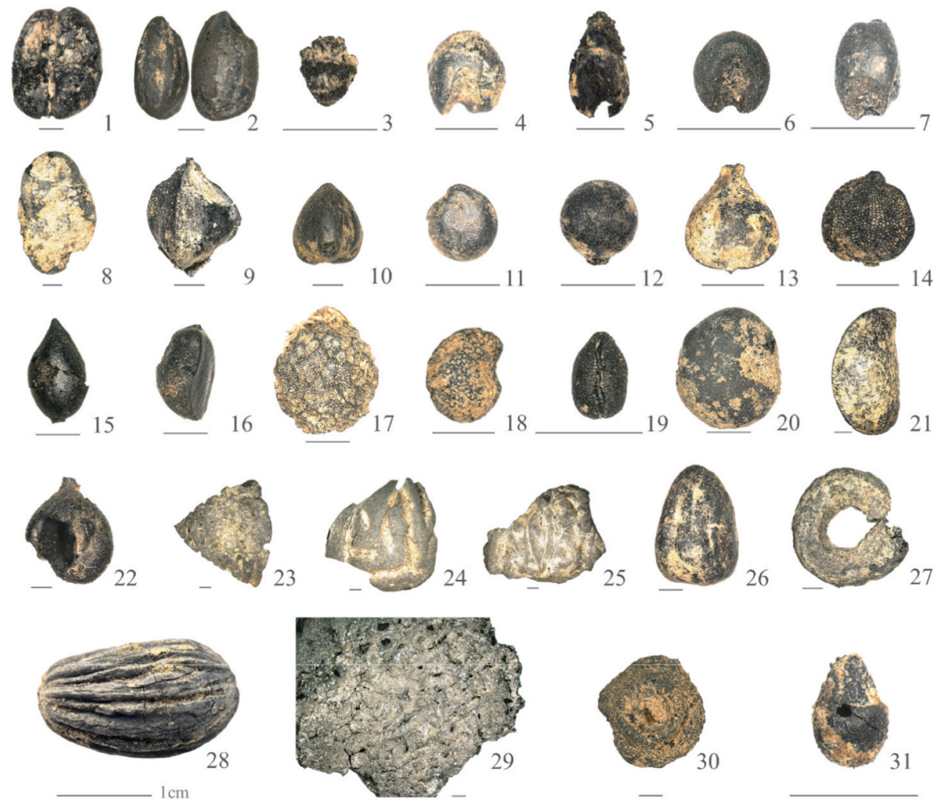

Fig. 11. Photographs of selected plant remains recovered at Jicha.
1. *Triticum aestivum*, **2.** *Oryza sativa*, **3.** *Oryza* spikelet base, **4.** *Setaria italica*, **5.** *Setaria* sp., **6.** *Echinochloa* sp., **7.** *Digitaria* sp., **8.** *Glycine max*, **9.** *Fagopyrum esculentum* (with husk), **10.** *Fagopyrum esculentum* (dehusked), **11.** *Chenopodium* sp., **12.** *Perilla frutescens*, **13.** *Scirpus juncoides*, **14.** *Persicaria nepalensis*, **15.** *Viola* sp., **16.** Phyllanthaceae, **17.** *Zanthoxylum bungeanum*, **18.** *Physaliphorous* sp., **19.** *Elsholtzia* sp., **20.** *Rhus chinensis*, **21.** *Diospyros* sp., **22.** *Vitis* sp., **23.** *Prunus mume*, **24.** *Prunus persica*, **25.** *Juglans* sp. Nutshell, **26.** *cf. Pinus* **27.** unknown pod, **28.** *Davidia involucrata,* **29.** Food crust, **30-31.** Unknown grains.

frutescens was also called *Guiren* (桂荏) in historical texts (as recorded by Hao of the Qing Dynasty in *Erya Yishu*, 尔雅义疏).

4.5. Other botanical remains

Other plant remains included various seeds, fruit, and nut shells that remain unidentified. One taxon worth noting is the screw-type pods/seeds, with a relatively high ubiquity of 39.6 %. This frequency suggests a possible relationship to human activities, although the specific species have not been identified yet. They may belong to leguminous plants.

4.6. Charcoal

Charcoal remains at the Jicha site are relatively abundant, although the specific identification of the charcoal species is ongoing. Among the relics related to smelting, charcoal content is significantly high, suggesting a substantial amount of charcoal was used in the smelting process. The site's high altitude facilitates relatively easy access to tree resources, which likely contributed to the abundant availability of charcoal.

Charcoal pieces larger than 1 mm were weighed, with a total weight of 2700.741 g. The average charcoal content at the site is 15.23 g/L, with the following phase values: 3.14 g/L (Phase 1), 11.82 g/L (Phase 2), 19.13 g/L (Phase 3), and 13.72 g/L (Phase 4). From the early Bronze Age (Phase 2) onward, timber utilization intensified, which corresponds to the changing characteristics of the metallurgy-related artifact assemblages. In Phase 3, pottery *tuyères* and crucibles began to appear, coinciding with an increased proportion of chopping and smashing tools. This growing demand for timber resources is thus reflected in increased charcoal content and tool changes.

5. Implications for social conditions at Jicha and Haimenkou

5.1. Agricultural system fueled metallurgical production

The abundance of metallurgical remains at Jicha, including furnaces and metal artefacts, points to an extensive, specialized craft production. Such activities are both resource- and labour-intensive, requiring not only raw materials and fuel but also a sustainable food supply to support craft workers released from direct food-production (Hansen, 1988; Schwartz et al., 2000). The agricultural system at Jicha, particularly with its high-yielding cereals like rice and wheat, was essential to support such labour forces.

The evidence from Jicha suggests a well-organized community capable of managing both food and metallurgical production. The emphasis on storage and its connection with socioeconomic structures sustaining extensive metallurgical activity has been highlighted previously at other Bronze Age sites across the world (Yang, 2016, Yang et al., 2020; Kıyak, 2025). At Jicha, metallurgical activities seem to have been concentrated in a dedicated production area within the settlement, suggesting a degree of communal organization that might or might not have extended to social structures underpinning food production. This synergy between a productive agricultural economy and advanced metallurgical technology established Jicha as more than a simple farming village: it was a bronze production center sustained by sophisticated agricultural systems that likely held regional significance during the Bronze Age.

The agricultural strategy at Jicha offers a compelling comparison with the nearby Haimenkou site, the only other systematically studied contemporary site in the region. While both sites demonstrate the adoption of a mixed-cropping economy, their developmental trajectories appear to diverge. At Haimenkou, an initial reliance on rice and millet was followed by a gradual shift to wheat as the dominant crop by the first millennium BC. In contrast, our findings at Jicha suggest that while wheat became a major staple, rice cultivation remained equally crucial, forming a dual-pillar system of high-yield cereals. This difference may reflect distinct local adaptations to micro-environmental conditions, such as Jicha's specific riverine setting, or different cultural choices related to food and agricultural management. The combination of summer-harvested crops (rice and millet) with a winter-sown crop (wheat) represents a sophisticated risk-management strategy, ensuring year-round agricultural activity and buffering the community against the failure of any single crop. Such complex husbandry practices can be further understood through functional ecological approaches, which interpret crop and weed assemblages to infer specific farming techniques related to fertility and land use (Charles et al., 1997, Jones et al., 2000). This agricultural resilience was not merely for subsistence but a fundamental enabler of technological and social complexity.

5.2. Consumer or producer?

It should be noted that our samples lack evidence related to crop processing, such as culm, awn, and chaff, and even the number of rice spikelet bases are also relatively low. Whether crops were locally grown or brought in via exchanges has been a focal point of discussion in eastern Tibetan Plateau. (d'Alpoim Guedes, 2016; Lu, 2023). Evidence of crop processing could inform such considerations, but it has to be viewed through the lense of taphonomy (Stevens, 2003). Despite the absence of such by-products at the Jicha site, the location benefits from favourable hydrothermal conditions for crop cultivation, alluding to potential local farming. It is also possible the grain-processing area was located outside the settlement, in the vicinity of the cultivation area, and therefore did not enter archaeology via domestic fire (all macrobotanical remains were charred).

It remains difficult to definitively categorize Jicha community as either a consumer or producer site—so to speak—based plant remains alone. Other elements such as architecture, tools, and traded goods should be considered (Bakels, 2001). Archaeobotanical findings from the Bronze Age site Prigglitz-Gasteil in the Eastern Alps offer a parallel for understanding grain production practices at the mining site. Prigglitz-Gasteil is considered as a copper mining site largely divorced from food production and dependent on external supplies, due to scarcity of whole grains, the absence of grain-processing tools and by-products, and the presence of food remnants containing grains. Cereals were likely brought from outside in the form of ready-to-cook grains and ground flour/meal to be cooked on site for workers (Heiss et al., 2021).

At Jicha, evidence points to a comprehensive metallurgical operational chain—from mining to smelting (Fu et al., 2024), suggesting the labor intensive nature of the bronze production. Additionally, there is no evidence for dedicated space for communal grain processing (Fig. 3). In terms of tools, the number of metallurgy-related tools also exceeds those for agricultural production (Fu et al., 2024). Such observations resonate with Prigglitz-Gasteil.

6. Conclusions

The archaeobotanical evidence from the Jicha site, excavated in 2022, reveals a resilient and diverse agricultural economy established by c.1890 cal. BC, which formed the cornerstone of a thriving Bronze Age community in northwest Yunnan. The inhabitants of Jicha skillfully managed a suite of domesticated crops from diverse geographical origins, creating a stable food production system that not only sustained technological specialization in metallurgy but also facilitated the site's emergence as a significant cultural center. This study adds a vital data point for mapping early agriculture in southwest China and underscores the dynamism and connectivity of prehistoric mountain societies. Jicha stands as a helpful case study of the intricate interplay between agriculture, technology, and cultural exchange, providing a crucial piece of the puzzle for understanding the complex human histories that unfolded along the great river corridors of Asia. Future interdisciplinary work in this promising region will undoubtedly continue to enrich our understanding of human adaptation and innovation at the crossroads of ancient worlds.

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CRediT authorship contribution statement

Yuanyuan Gao: Writing – original draft, Visualization, Software, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Changcheng Hu:** Resources, Project administration, Investigation. **Jie Fu:** Writing – review & editing, Resources, Investigation, Conceptualization. **Gaoyuan Pan:** Writing – review & editing, Investigation. **Qionghui He:** Resources, Investigation. **Xinyi Liu:** Writing – review & editing, Methodology.

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

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Data availability

The data that has been used is confidential.

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