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The Emergence of Rice and Millet Farming in the Zang-Yi Corridor of Southwest China Dates Back to 5000 Years Ago

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The Zang-Yi Corridor is of pivotal significance for the interactions between northwest China, southwest China, and mainland Southeast Asia. It has been hypothesized that the formation of mixed farming in this region and its surrounding areas was based on multiple waves of crop dispersal, with foxtail millet and broomcorn millet arriving first from northwest China around 5,300 cal. BP and rice from middle Yangtze valley after 4,700 cal. BP. Based on the systematic sampling and direct dating conducted at the Guijiabao site, Sichuan Province, this study demonstrates that by no later than 5,000 cal. BP, mixed farming had already emerged in the south part of Zang-Yi corridor, which was much earlier than expected before. With this new evidence, it is argued that the transformation into farming in Southwest China was based on the dispersal of a crop package comprising foxtail millet, broomcorn millet, and rice instead of different waves of introduction. A further comparison of all archaeobotanical data in this region revealed that crop patterns varied significantly between different sites because of their diverse environmental conditions.

Keywords: rice, millet, phytolith, mixed farming, crop dispersal, southwest China, mainland Southeast Asia

INTRODUCTION

The emergence of agriculture is of profound significance in human history, as it brought thorough change to the lifestyle of human beings and set a solid economic foundation for the further progress of human societies (Childe, 1936; Bellwood, 2005; Bellwood, 2013; Fuller and Stevens, 2019). However, the transformation into farming for most parts of the world was counted on the diffusion of domesticated plants and related technologies (Bellwood, 2013; Fuller and Lucas, 2017), as the origin of agriculture only happened in limited centers around the world (Diamond, 2002; Fuller, 2010). Continued interactions and exchanges between these independent agriculture origin centers brought local and exotic crops together, enabling a more diverse dietary and stable crop production to support a larger population (Jones et al., 2016; Liu et al., 2016). Hence, the study of agricultural diffusion is of crucial significance to our understanding of ancient social development and interregional communications.

With two distinct agricultural systems, China is a key center for the investigation of agriculture origins (Fuller et al., 2014; Larson et al., 2014; Lu, 2017). Early farming practice in northern China

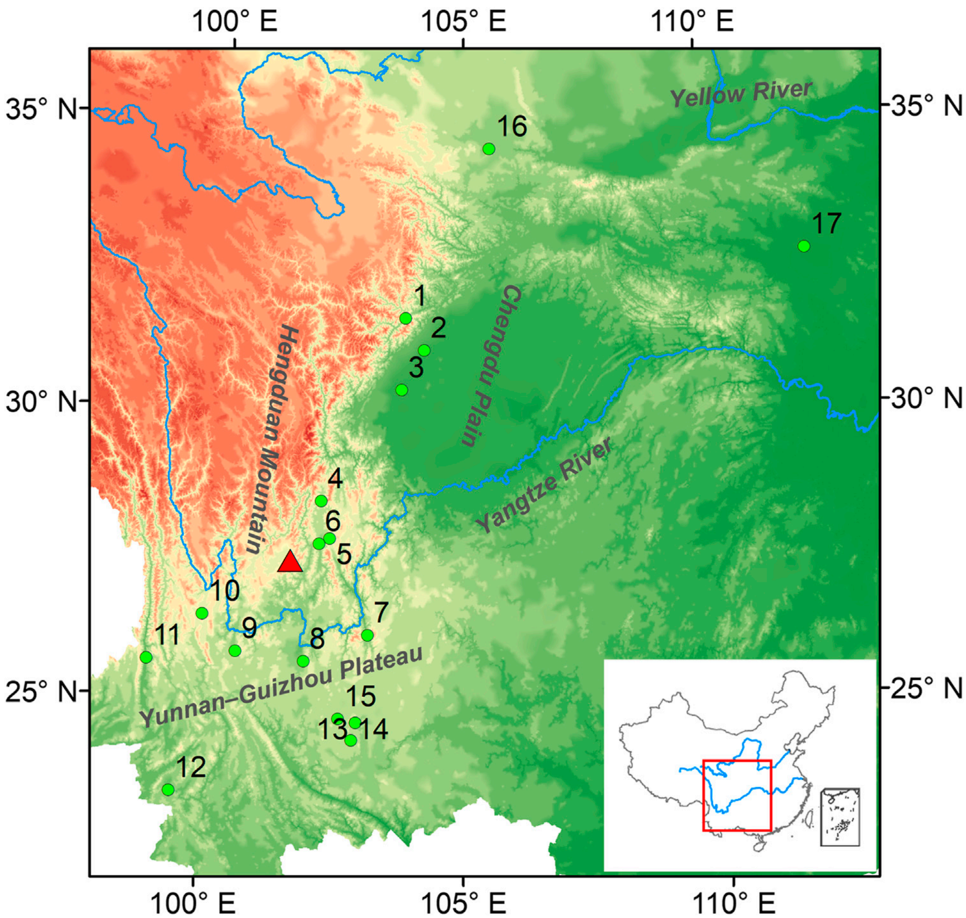

FIGURE 1 | Location of the Guijiabao site (red triangle) and other sites mentioned in the study. 1-Yingpanshan, 2-Guiyuanqiao, 3-Baodun, 4-Gaopo, 5-Henglanshan, 6-Shapingzhan, 7-Yubeidi, 8-Dadunzi, 9-Baiyangcun, 10-Haimenkou, 11-Shilinggang, 12-Shifodong, 13-Xueshan, 14-Guangfentou, 15-Heposuo,16-Xishanping, 17-Baligang.

was based on local domestication of foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) (Lu et al., 2009a; Yang et al., 2012), while in southern China, especially the middle and lower Yangtze Valley, rice (*Oryza sativa*) had been domesticated no later than 8,500 cal. BP and cultivated as a staple crop since then (Deng et al., 2015; Zuo et al., 2017; Huan et al., 2021). In this case, the agriculturalization of other regions was all realized through population expansion and agriculture dispersal from these two centers. With the progress in archaeological research over the past decades, it has become increasingly evident that the southward dispersal of agriculture in China was mainly along three main routes, among which the Zang-Yi Corridor is of critical significance in subsistence transformation and social development in southwest China, including the Chengdu Plain, the Yunnan-Guizhou Plateau, and the Tibetan Plateau (He et al., 2017; Deng et al., 2018; Gao et al., 2021). Further influence of this route could even have reached mainland Southeast Asia and joined the long-distance communications along the southern foothills of the Himalayan Mountains with south Asia and beyond (Gao et al., 2020). Therefore, many researchers have been dedicated to investigating the dispersal and development of farming in this region.

To date, the earliest evidence of agriculture in the Zang-Yi Corridor is from the Yingpanshan site on the northern edge of this region. Large amounts of foxtail millet and broomcorn millet have been recovered there and traced back to ca. 5,300 cal. BP (Zhao and Chen, 2011). Typological comparisons of pottery from this site revealed the strong influence of contemporary Majiayao culture in the Gansu province. Hence, it is widely believed that these earliest Neolithic populations migrated from northwest China. A detailed chemical composition analysis of painted pottery from Yingpanshan also supports close interactions between local people and the Majiayao communities (Hung, 2011). Whereas, plant remains from many later sites of southwest China all suggest a mixed pattern of crop assemblages, comprising foxtail millet, broomcorn millet, and rice (Guo, 2011; Huang et al., 2011; Yan et al., 2013; Jin et al., 2014; Jiang et al., 2016a; Jiang et al., 2016b; Dal Martello et al., 2018). Among these discoveries, the earliest evidence came from Guiyuanqiao and Baodun, where rice was directly dated to ca. 4,700 cal. BP (Guedes et al., 2013; Guedes and Wan, 2015).

TABLE 1 | AMS Radiocarbon dating results of Neolithic contexts from the Guijiabao site. All dates were calibrated by OxCal v4.4.4, using the IntCal 20 Atmospheric curve (Reimer et al., 2020).

Lab code	Context no	Dated Material	Uncalibrated ^{14}C Date (BP)	Calibrated Dates (2σ)
BA170230	H1	Foxtail millet	4,480 ± 40	5,300–4,975
BA192710	TN22E39②	Broomcorn millet	4,455 ± 45	5,290–4,883
BA170249	H20	Rice	4,365 ± 25	5,030–4,856
BA190411	TN32E37⑦	Broomcorn millet	4,205 ± 25	4,845–4,626
BA190424	F21	Broomcorn millet	4,065 ± 20	4,787–4,442
BA190402	TN30E34③	Broomcorn millet	4,045 ± 25	4,612–4,421
BA190436	H127	Broomcorn millet	3,885 ± 25	4,413–4,239
BA190403	TN30E34④	Foxtail millet	3,770 ± 35	4,245–3,988
BA190437	H135	Broomcorn millet	3,635 ± 30	4,081–3,849
BA190389	H166	Rice	3,505 ± 25	3,847–3,693

In this regard, it is hypothesized that the formation of mixed farming in southwest China is based on two waves of agricultural dispersal: first from northwest China with the introduction of foxtail millet and broomcorn millet around 5,300 cal. BP, and second from the middle Yangtze valley with the introduction of rice after 4,700 cal. BP (Guedes et al., 2013). However, this speculation is still debatable for two reasons. Firstly, whether the earliest crop pattern only consists of foxtail millet and broomcorn millet or the entire package of millets and rice is still ambiguous, as there is no evidence from other contemporary sites of Yingpanshan. Secondly, no evidence reveals interregional communications between the middle Yangtze Valley and Southwest China prior to 4,500 cal. BP (Jiang et al., 2020), making the speculated introduction of rice from the middle Yangtze valley questionable. Therefore, a more targeted study should be conducted at these early sites in the region to test or modify this model.

Here, we report the systematic phytolith analysis at the Guijiabao site in Sichuan Province. The new results, along with radiocarbon dating, reveal mixed farming had already emerged in the southern part of the Zang-Yi Corridor no later than 5,000 cal. BP, which is much earlier than expected before. With this new discovery, it is quite possible that all these crops, including foxtail millet, broomcorn millet, and rice, were introduced into this region as a package, and the source of agriculture introduction into this region should also be re-examined, especially the possibility of middle Yangtze valley.

MATERIALS AND METHODS

Sample Collection

The Guijiabao site (101.6°E, 27.45°N) (**Figure 1**) is situated in the Yanyuan County of Sichuan Province and is surrounded by the middle part of the Hengduan Mountains (Zhong et al., 2016; Hao et al., 2022). As a crossroad in the southern part of the Zang-Yi Corridor, this region has played a crucial role in interregional interactions along this route. Guijiabao was first discovered in 2015, and a systematic field survey and small-scale excavation were conducted to confirm the preservation conditions and major remains in the site. Subsequently, excavations were carried out in three seasons from 2016 to 2018.

According to archaeological investigations, the total area of Guijiabao is around 30,000 m^2, but cultural deposits have been heavily disturbed by modern activities. Even though, a large number of ancient ruins have been unearthed, including house foundations, pits, tombs, and many artifacts such as pottery, stone tools, and spindle whorls (Hao et al., 2022). All of these remains could be grouped into three periods, namely: Neolithic, Bronze Age, and historical period, among which the Neolithic remains could further be divided into two phases. According to the result of systematic radiocarbon dating at the site (**Table 1**), Phase I of the Neolithic period at this site occurred around 5,000–4,500 cal. BP, and Phase II around 4,500–3,700 cal. BP. Moreover, the beginning of human activities in this period probably could reach 5,300 cal. BP as revealed by radiocarbon dates of foxtail millet grains from context H1 and broomcorn millet grains from context TN22E39②. The date of the Bronze Age remains at the site is roughly 3,200–2,700 cal. BP, where a hiatus of 500 years after the Neolithic period could be observed. Historical relics occurred much later, mainly stretching from the late Northern Song dynasty to the Ming dynasty (ca. 1,200–500 cal. BP).

In order to detect Neolithic agriculture practices at the Guijiabao site, soil samples for phytolith analysis have been collected during the excavations. In total, 154 samples from the Neolithic period were obtained, of which 16 were from Phase I and 138 from Phase II (details in **Supplementary Table S1**). These sampled contexts cover different types of archaeological features of the site, including cultural layers (sample codes start with T), pits (sample codes start with H), house foundations (sample codes start with F), and ditches (sample codes start with G).

Phytolith Extraction and Identification

Phytoliths were extracted from soil samples according to established methods (Piperno, 1988; Lu et al., 2002) with minor modifications. Initially, approximately 2 g of each sample was weighed and treated with 30% H_2O_2 and 15% HCl to remove organic matter and carbonate. The samples were then subjected to heavy liquid flotation using $ZnBr_2$ (density, 2.35 g/cm^3) to separate the phytoliths, which were subsequently mounted on a slide using Canada Balsam. After air-drying, the phytoliths on the slide were counted and identified using a Leica microscope at ×400 magnification. More than 400 phytolith particles in each sample were identified and recorded according to previously published

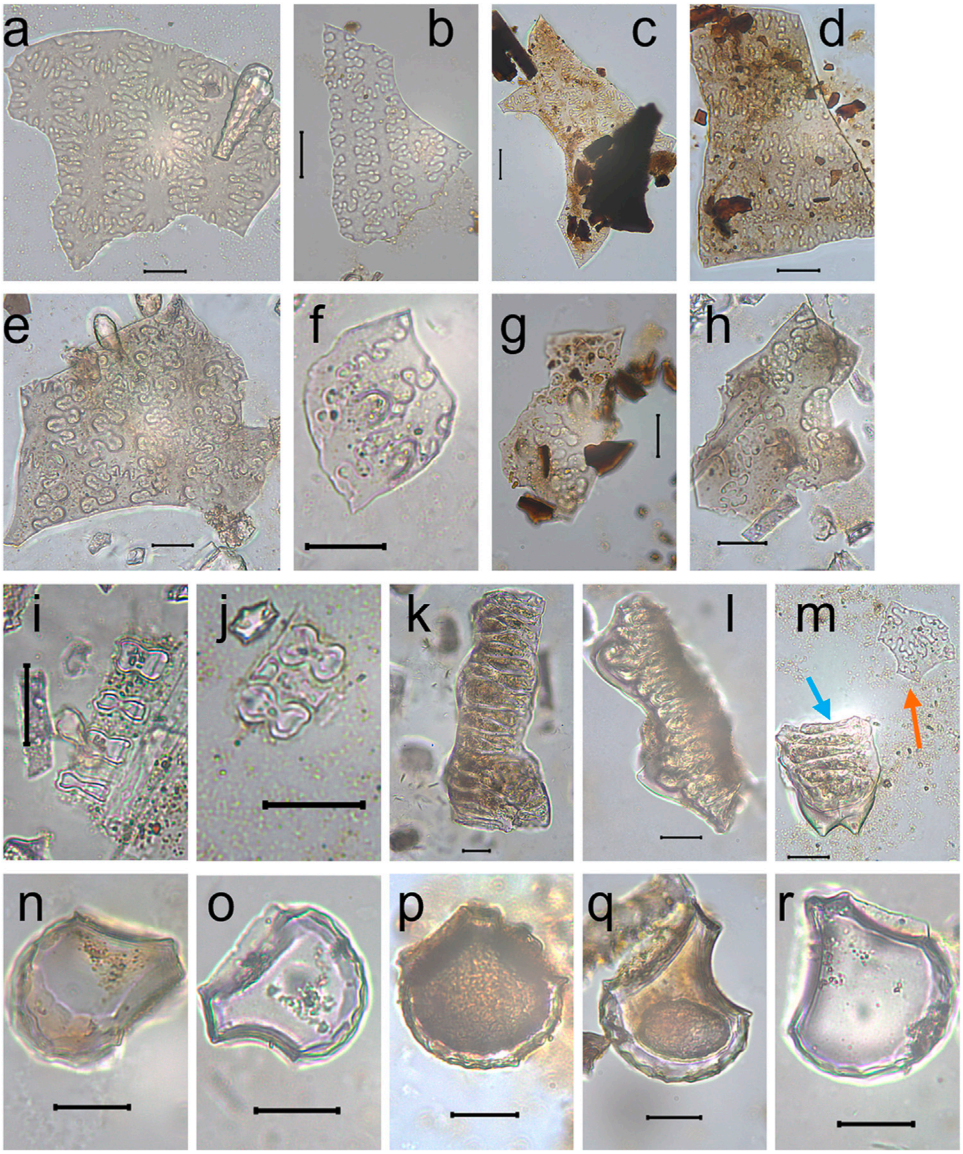

FIGURE 2 | Crop phytoliths obtained from the Guijiabao site. **(A–D)**: broomcorn millet η-type; **(E–H)**: foxtail millet Ω-type; **(I,J)**: rice parallel bilobate; **(K,L)**: rice double-peaked; **(M)**: rice double-peaked (blue arrow) and broomcorn millet η-type (orange arrow); **(N,O)**: rice bulliform with <9 scales; **(P–R)**: rice bulliform with ≥9 scales (scale bar = 20 μm).

references and criteria (Wang and Lu, 1993; Lu et al., 2006; Lu et al., 2007; Lu et al., 2009b; Ge et al., 2018; Ge et al., 2020a; Ge et al., 2020b). In particular, for samples with rice phytoliths, the slides were scanned until 50 rice bulliform phytoliths with clear and countable scales were observed to calculate the proportion of rice bulliform phytoliths with ≥9 scales (Wang and Lu, 2012; Huan et al., 2015; Huan et al., 2020).

RESULTS

All 154 samples yielded abundant phytoliths. In total, 26 phytolith morphotypes were identified, of which five were confirmed from crops, including double-peaked, bulliform, and parallel-bilobate types from rice, η-type epidermal long cell phytoliths from the upper lemma and palea of broomcorn millet, and Ω-type from foxtail millet (**Figure 2**). Other main phytolith types include elongate psilate, square, rondel, hair cell, rectangle, bilobate, elongate echinate, bulliform, and long saddle.

Phytolith assemblages in the Guijiabao site were characterized by high proportions of elongate psilate, elongate echinate, square, rectangle, rondel, hair cell, and bilobate, along with a low proportion of rice and a relatively lower proportion of broomcorn millet morphotypes (**Figure 3**; **Supplementary Table S1**). Foxtail millet phytoliths appeared in Phase II, but their proportions were much lower than those of broomcorn

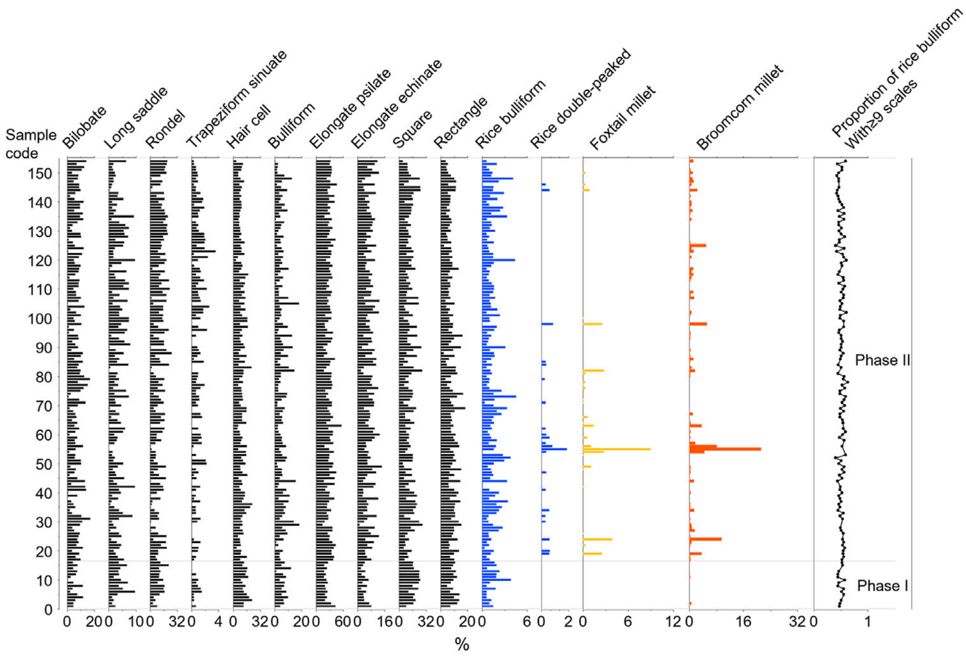

FIGURE 3 | Percentage diagram of major phytolith types at the Guijiabao site. Sample code in **Supplementary Table S1**.

millet and rice (**Figure 3**). It is also worth noting that the phytolith assemblage of Phase II was characterized by the presence of double-peaked types of rice husk, revealing a strong relationship between cultural deposits in these contexts and rice dehusking activities at the site (Harvey and Fuller, 2005). The presence of bulliform and parallel-bilobate types from rice leaves and stems also demonstrates local cultivation of rice.

Based on the preservation conditions, 139 samples were selected for further analysis of scales on the edge of rice bulliform phytoliths, including 14 from Phase I and 125 from Phase II (**Figure 3**; **Supplementary Table S1**). For each sample, at least 50 bulliform phytoliths with clear and countable scales were carefully observed. The average proportion of bulliform phytoliths with ≥9 scales was 49.40 ± 4.44% in Phase I and 50.63 ± 4.63% in Phase II.

DISCUSSION

The Emergence of Mixed Farming in Southwest China

The Zang-Yi Corridor is a significant channel for interregional communications and human movements in southwest China during historical and modern times (Fei, 1980). Archaeological investigations in the past decades further suggest that cultural interactions, population migration, and the flow of raw materials and technologies along this route started much earlier than previously thought (Huo, 2005). The Neolithization process of the entire southwest region was based on the introduction of these innovations and possible human migrations, among which the emergence of agriculture was no doubt in the central place.

The new data presented in this study clearly show that abundant rice bulliform phytoliths were present in all samples from Phase I (5,000–4,500 cal. BP) at the Guijiabao site, together with the typical η-type phytoliths of broomcorn millet. A detailed analysis of scales on the edge of rice bulliform phytoliths suggested that the proportion of rice bulliform phytoliths with ≥9 scales in Phase I was 49.40 ± 4.44% (**Figure 3**), which was close to Phase II level (50.63 ± 4.63%) and modern domesticated rice (Huan et al., 2015; Huan et al., 2020). Considering the current AMS radiocarbon dates of this phase, especially one direct date of rice grain (BA170249, 5,030–4,856 cal. BP, 95.4% probability), these lines of evidence could confirm that rice had already been cultivated together with broomcorn millet in the southern part of Zang-Yi Corridor prior to 5,000 cal. BP.

The continuation of this mixed farming strategy could be demonstrated by crop assemblages from Phase II (4,500–3,700 cal. BP) of Guijiabao, when phytoliths of rice, broomcorn millet, and foxtail millet were found together in nearly all samples (**Figure 3**). A comparison of these phytoliths revealed that their proportions varied greatly among different samples, but generally rice and broomcorn millet were more important than foxtail millet. Nevertheless, given the different preservation conditions of these phytoliths, the specific crop pattern needs to be further confirmed by other evidence, such as macroscopic plant remains and stable isotope analyses of human bones. Another point that needs to be clarified here is the absence of foxtail millet phytoliths in all samples of Phase I in this study, which may have resulted from the relatively poor preservation conditions of foxtail millet phytoliths, as foxtail millet grains have been recovered in this phase and directly dated (**Table 1**). Another possible reason is that the samples from Phase I in this study were limited.

Overall, the present study clearly suggests that rice was cultivated together with foxtail millet and broomcorn millet from 5,000 cal. BP to 3,700 cal. BP at the Guijiabao site. Along with discoveries from other sites, it could be confirmed that they were introduced simultaneously as a package into the Zang-Yi Corridor and then other parts of southwest China at the very beginning of the Neolithic period in the region, which differs from the previously assumed process of multiple waves of crop introduction (d'Alpoim Guedes, 2011). Actually, the pure millet crop pattern of Yingpanshan, which is the main evidence of the previous model, is also questionable. The absence of rice at the Yingpanshan site might have resulted from insufficient sampling, as only 45 L of soil samples from nine contexts were processed (Zhao and Chen, 2011). Another piece of evidence in support of this query is that stable isotope analysis of human bones from two contexts of Yingpanshan indicated that their long-term diets after childhood consisted of both C_3 and C_4 foods instead of pure C_4 millets (Lee et al., 2020). In this case, these lines of evidence all tend to support a dispersal of crop package including foxtail millet, broomcorn millet and rice into this region.

On the other hand, the hypothesis that the middle Yangtze region as the source of rice for Southwest China is also unreliable, as no evidence supports the early communication between these two regions prior to 4,500 cal. BP. Even around 4,000 cal. BP, except for the sparse traits of pottery styles that are speculated to be influenced by the middle Yangtze region, no other evidence has been found (Jiang et al., 2020). In contrast, the southern part of Gansu Province is not a pure millet farming region as assumed before. Previous studies have shown that mixed farming has been carried out in many regions of Northern China since 7,500 cal. BP (Zhang et al., 2012; Wang et al., 2017; Wang et al., 2018), and the westernmost discovery was at the Xishanping site of Gansu Province, where charred seeds and phytoliths of foxtail millet, broomcorn millet, and rice have been dated back to 5,300–4,800 cal. BP (Li et al., 2007a; Li et al., 2007b). Plant remains from a regional survey in the Li County of southern Gansu also found rice grains in three sites (Ji, 2007). Therefore, it is quite possible that mixed farming was practiced at many sites in the southern part of Gansu province, and the crop package of millets and rice in southwest China was introduced from this region at the same time.

From a broader view, another possible region related to the emergence of mixed farming in Southwest China is the upper Han River valley, where mixed farming should also have been practiced prior to the Yangshao period, referring to the discoveries in the middle Han River Valley (Deng et al., 2015). Typological comparisons of pottery from the Luojiaba site in the Jialing River valley revealed influences of the Yangshao culture in the upper Han River valley (Li, 2018), thus this channel may serve as another parallel dispersal route in the eastern part of the Sichuan Basin. To clarify the emergence of mixed farming in Southwest China, more targeted research in these regions is needed in the future.

Crop Patterns and Regional Diversity in the Zang-Yi Corridor of Southwest China

With the flow of populations and emergence of innovative technologies, the adoption, adaptation, and integration of exotic elements has been a unique cultural feature of the Zang-Yi Corridor, which could also be observed in the farming strategies. The mixed cropping system has been widely practiced not only in the Neolithic Age, but also in later periods, owing to its complex ground features and environmental conditions. There are seven mountains and six large rivers in the Hengduan Mountainous region, which can be divided into 13 geomorphological zones, covering 19 climatic zones from the tropical zone to plateau frigid zone (Li, 1989; Zhang, 1989). The flexibility of farming practices is clearly reflected in the regional diversity and chronological changes in the cropping systems of this region.

During the Neolithic Period (ca. 5,300–3,600 cal. BP), although foxtail millet, broomcorn millet, and rice were widely cultivated in most sites, the proportion of each crop varied considerably among the four sites with systematic archaeobotanical work (**Figure 4**). Foxtail millet and broomcorn millet were cultivated at the Yingpanshan site and played almost equivalent roles in its farming system (Zhao and Chen, 2011). However, in Phase I of Baiyangcun (4,600–4,300 cal. BP), rice was undoubtedly dominant in the farming system, and foxtail millet was also important. Nevertheless, broomcorn millet only accounted for 2.21% of all crop remains (Dal Martello et al., 2018). This pattern is similar to that of Henglanshan, but plant remains of this site are too limited, and the data are not sufficiently representative (Jiang et al., 2016a; Jiang et al., 2016b). In Phases II and III of Baiyangcun (4,200–4,050 cal. BP), a noticeable change occurred when foxtail millet became the most important crop, followed by rice. The Dadunzi site in Yunnan Province (4,000–3,600 cal. BP) presented a different pattern dominated by foxtail millet, where broomcorn millet was also important. However, the proportion of rice was relatively low (Jin et al., 2014). In addition, wild soybeans were also found at Yingpanshan and Baiyangcun during this period, which was possibly utilized on a small scale.

Archaeobotanical evidence from the early phase of Bronze Age (ca. 3,600–2,800 cal. BP) was more limited as macroscopic plant remains were only recovered from four sites. Unlike the previous period, rice was the main cereal crop in all these sites, accounting for 62.5 to 97.7% of all crop remains. The proportion of foxtail millet in the early phase of Haimenkou was more than 22.88% (Xue, 2010; Xue et al., 2022), but less than 5% in Shifodong and Shapingzhan (Zhao, 2010; Yan et al., 2016b). Broomcorn millet was very rare during this period, with only one grain from Gaopo and two grains from Haimenkou reported (Xue, 2010; Jiang et al., 2013). Another significant change in farming practices of this period is the adoption of wheat and barley, as indicated by the plant remains from Haimenkou, where 261 wheat and seven barley grains have been found. Although wheat and barley were dispersed into the northwestern part of Xinjiang around 5,000 cal. BP (Zhou et al., 2020), the earliest evidence in the Hexi Corridor was only approximately 4,000 cal. BP (Dodson et al., 2013) and 3,600 cal. BP in Central China (Deng et al., 2020). Therefore, the mountainous area of the Zang-Yi Corridor was one of the earliest regions to adopt wheat and barley in southern China. By contrast, no solid evidence of wheat has been reported in the contemporary Chengdu Plain. Cannabis and buckwheat were also found in Haimenkou, revealing more diversified crop patterns since early Bronze Age.

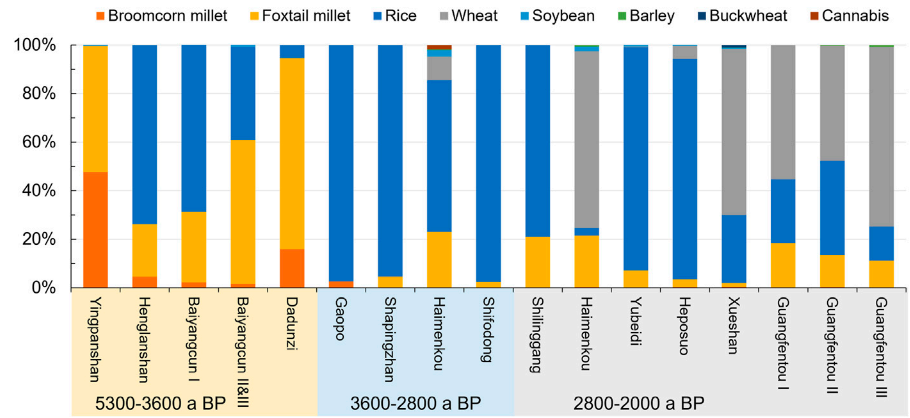

FIGURE 4 | Diachronic charts of crop patterns in the Zang-Yi Corridor of southwest China.

During the late Bronze Age (ca. 2,800–2000 cal. BP), the importance of wheat was greatly improved, which has been found in nearly all sites except for Shilinggang, and is dominant in the crop assemblages of Haimenkou, Guangfentou, and Xueshan (Xue, 2010; Li et al., 2016; Li and Liu, 2016; Wang et al., 2019). Even though, the specific crop patterns at these sites were still different from each other. Foxtail millet was the secondary important crop in the late phase of Haimenkou, with rice and broomcorn millet accounting for a small portion of the entire assemblage (Xue, 2010; Xue et al., 2022). However, in the three phases of Guangfentou and Xueshan, the proportion of rice is much higher than that of foxtail millet (Li and Liu, 2016; Wang et al., 2019). In addition, plant remains from Heposuo and Yubeidi both demonstrated a rice-dominated crop pattern, and the proportions of foxtail millet and rice were slightly different from each other (Yang et al., 2020; Yang et al., 2021). In contrast, broomcorn millet, barley, and soybean were only sparsely found at these sites, which could possibly be used as risk-buffering crops by the locals.

Overall, a comparison of crop patterns from all sites in the different periods of the Zang-Yi Corridor clearly demonstrates that mixed farming and regional diversity are the main characteristics of the agricultural practices in the region. During the Neolithic period, foxtail millet, broomcorn millet, and rice were all staple crops, although their proportions greatly varied in different sites. With the introduction of wheat in approximately 3,600 cal. BP, this exotic crop became the most fundamental crop along with foxtail millet and rice in the Bronze Age, while broomcorn millet was only discovered sparsely and accounted for a low proportion. The conditions were similar for the newly introduced barley. Soybeans, cannabis, and buckwheat have also been utilized on a small scale by local people, forming a more diversified crop pattern.

CONCLUSION

Based on systematic phytolith analysis and direct dating of plant remains from Guijiabao in the south part of the Zang-Yi Corridor, this study shed new light on our understanding of the emergence of farming practice in Southwest China. The new data demonstrated that prior to 5,000 cal. BP, rice, foxtail millet, and broomcorn millet were cultivated and consumed together at the Guijiabao site. With new evidence, the previous hypothesis on the dispersal of agriculture in Southwest China needs to be reconsidered. Rice should have been introduced into this region together with foxtail millet and broomcorn millet as a package around 5,000 cal. BP or even earlier, instead of from the two waves of dispersal from Northwest China and the middle Yangtze Valley, respectively. Plant remains from the late period of Guijiabao and comparison with archaeobotanical remains from other sites further revealed that mixed cropping systems had been widely practiced throughout the Neolithic and Bronze Age in the Zang-Yi corridor. Moreover, great regional diversity could be observed with specific crop patterns, which could have resulted from adaptation to complex ground features and environmental conditions. With the introduction of wheat around 3,600 cal. BP, local crop patterns became more complex, starting a new era in the history of agricultural development in this region.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

XHu and ZD designed the study. ZD, ZZ, XY, XHa, and QB conducted archaeological excavation and sample collection. XHu, ZD, and HL completed sample processing and identification. XHu and ZD analyzed the data and wrote the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feart.2022.874649/full#supplementary-material

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