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Article

New radiocarbon and archaeobotanical evidence reveal the timing and route of southward dispersal of rice farming in south China

Xiaoyan Yang [a,b,*], Qiuhe Chen [a,c], Yongchao Ma [d,*], Zhao Li [e], Hsiao-chun Hung [f], Qianglu Zhang [g], Zhiwei Jin [h], Suoqiang Liu [i], Zhenyu Zhou [j], Xianguo Fu [j]

[a] Key Laboratory of Land Surface Pattern and Simulation, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[b] Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] School of Archaeology and Museology, Peking University, Beijing 100871, China
[e] School of Archaeology and Ancient History, University of Leicester, Leicester LE1 7HR, UK
[f] Department of Archaeology and Natural History, Australian National University, Canberra ACT 0200, Australia
[g] Guangzhou Municipal Institute of Archaeology and Cultural Relics, Guangzhou 510627, China
[h] School of Society & Anthropology, Sun Yat-sen University, Guangzhou 510275, China
[i] Guangdong Provincial Institute of Archaeology and Cultural Relics, Guangzhou 510075, China
[j] Institute of Archaeology, Chinese Academy of Social Sciences, Beijing 100710, China

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ABSTRACT

The origins and spreads of rice agriculture have been enduring topics, yet the timing and southward dispersal from the Yangtze River Basin have been difficult to trace, due to the scarcity of archaeobotanical data, especially systematic macro-plant remains examination, combined with the poor preservation in the humid climate and acidic soils of China's southern provinces. Here, we report new radiocarbon dating and preserved rice phytolith evidence, derived from three Late Neolithic archaeological sites in south China, dated about 5,000–4,100 cal a BP. Our results demonstrate that rice farming had spread southward through the mountainous regions of Wuyi and Nanling, then entered the areas of Western Fujian and North Guangdong by 5,000 cal a BP, followed by continued expansion into coastal areas of East China Sea and South China Sea, also crossing the Taiwan Strait, around 4,500–4,000 cal a BP. The North River, East River, Min River, and possibly other river systems likely were influential as pathways or conduits.

1. Introduction

The origins and spreads of rice agriculture have been studied for decades [1–6]. Compared with the two well documented expansion waves of rice resource utilization in northern China [7–10], its southward-spreading route has remained unclear. Although the possibility of native rice cultivation still cannot be rejected [11–14], increasingly mounting evidence supports the impression that rice-farming immigrants created significant cultural influences throughout South China, indicating a southward flow of rice farming from the Yangtze River Basin and further connections southward with the Austronesian and Austroasiatic language-speaking populations of Southeast Asia [15–19].

Cross-regional studies have depicted the geographic spread of Austronesian-speaking populations and southward dispersal of traits such as pottery traditions, tool technologies, and language, departing from southern subtropical China around 5,000 years ago, then spreading incrementally across the Asia-Pacific region into parts of Pacific Oceania by 3000 years BP [20,21]. This cross-regional view so far has been missing direct evidence of rice farming in most of the region and sub-areas of the picture, although fair amounts of rice remains have been found in sites of Jiangxi, Guangdong, Fujian, and Taiwan (Fig. 1) [22–26]. More recently, archaeological research in Guangdong and Fujian provided new evidence about the timing and routes of rice farming expansion into South and Southeast China [27–29], but the findings still could be strengthened and clarified. In order to resolve the missing piece in the puzzle of the southward dispersal of rice, here we report new discoveries of radiocarbon dating and rice remains derived, from three Late Neolithic archaeological sites of approximately

* Corresponding authors.
E-mail addresses: xyang@itpcas.ac.cn (X. Yang), yongchao0226@126.com (Y. Ma).

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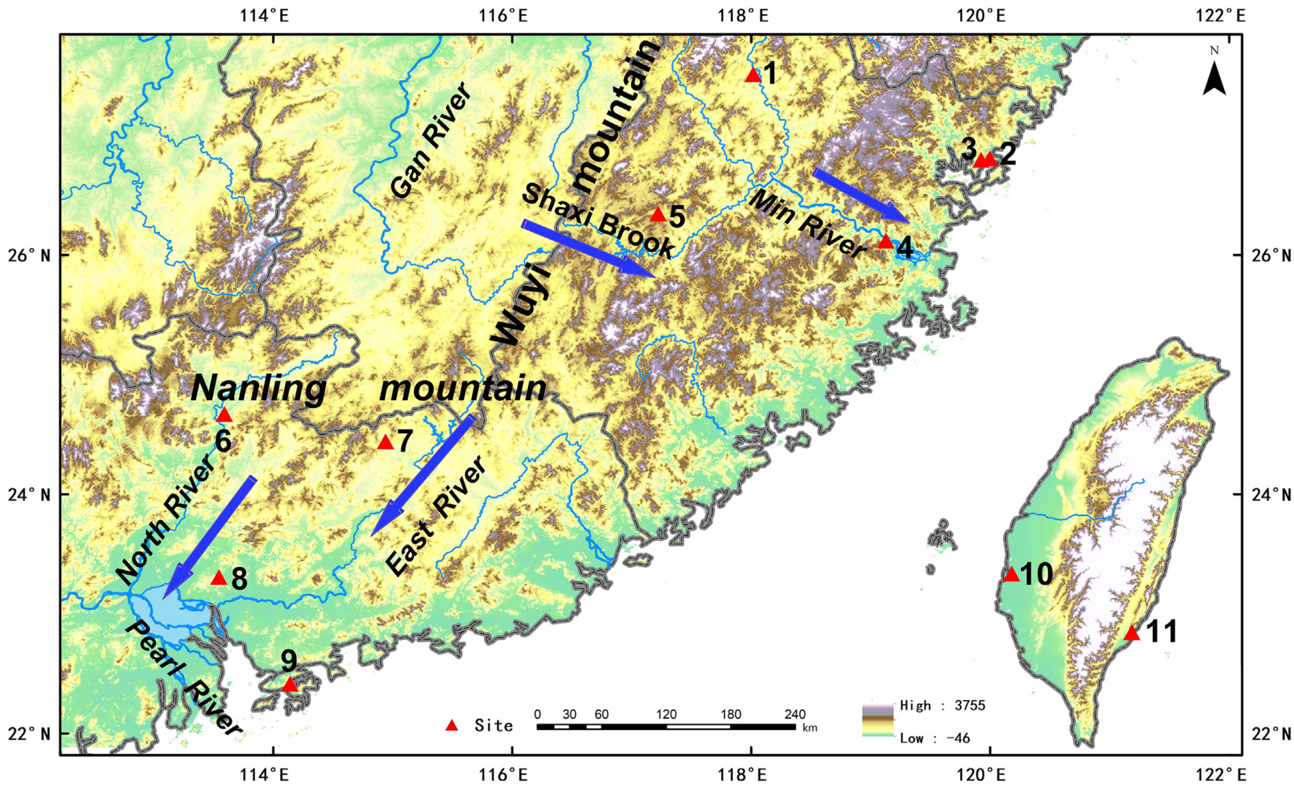

Fig. 1. Location of archaeological sites mentioned in the text and the possible southward dispersal routes of rice. Arrows indicate the possible routes. 1, Hulushan; 2, Pingfengshan; 3, Huangguashan; 4, Tanshishan and Zhuangbianshan; 5, Nanshan; 6, Shixia; 7, Laoyuan; 8, Chaling and Gancaoling; 9, Shaxia; 10, Nanguanli Dong; 11, Chaolaiqiao.

5,000–4,100 cal a BP in northwest Fujian Province, north Guangdong Province, and the Pearl River Delta (Fig. 1).

2. Materials and methods

2.1. Nanshan Site in northwestern Fujian

The Nanshan Site (26°21′20.1″N, 117°13′3.1″E) is situated in a basin of the upper portion of the Min River, about 320–388 m above sea level in the east piedmont of the Wuyi Mountains in Northwest Fujian Province (Fig. 1). At the site, two caves (Cave 3 and Cave 4) and a patch atop the hill were excavated by a joint team of the Institute of Archaeology, Chinese Academy of Social Sciences, Fujian Provincial Museum, and Mingxi County Museum, in 2012–2017. Cave 4 revealed 4-m-thick cultural deposits in 28 layers, embedding five burials, eight pits, four living floors, 12 hearths of the Neolithic Age, and large amounts of artifacts. Animal bones and plant remains were extremely abundant, especially from the layers numbered 10 through 23, including tens of thousands of carbonized seeds of rice and millets [30].

Four charcoal specimens from layers 10, 16, 20, and 22, plus one carbonized rice seed from Layer 22 were dated by the AMS ^{14}C (Table 1).

2.2. Laoyuan Site in the North Guangdong

The Laoyuan Site (24°32′02.39″N, 114°56′06″E) is in hilly terrain of North Guangdong, about 100 km east of the Shixia Site where abundant rice remains were excavated from layers dated to 5,000–4,100 cal a BP (Fig. 1). The site is at 198 m a.s.l, on the spur of a hill with a gentle slope. A branch of the Heping River, secondary of the East River, flows along the hill. The Laoyuan Site is estimated to cover about 5,000 m^2 according to auguring examination, and 433 m^2 was excavated from September to December of 2017, by a joint team of Sun Yat-sen University, Guangdong Provincial Institute of Archaeology and Cultural Relics, and Heping County Museum. From layers 3 and 4, the excavations revealed 135 post holes, 8 burials, and 45 pits, with stone adzes, arrows, and pottery findings of jars (*Guan*), pedestal plates (*Dou*), and tripods (*Ding*). The pottery and stone tools show the mixed cultural characteristics of Late Shixia Culture and Tanshishan Culture.

We collected five samples from the interior fill material of four pits for phytolith analysis. From the filling of pit H3, we selected two carbonized rice seeds (Fig. 2a), and one was used for AMS ^{14}C dating. Three charcoal specimens from the same layer were dated as well (Table 1).

2.3. Chaling Site in the Pearl River Delta

The Chaling Site (23°18′28′N′, 113°32′38″E) is located on a hilltop at 52 m a.s.l. in Northeast Guangzhou City, near a branch of the Pearl River (Fig. 1). The site was excavated by the Guangzhou Municipal Institution of Archaeology and Cultural Relics during the period of Aug. 2017–Jan. 2018, ahead of construction of a main road in the area. The findings included 112 burials, 83 pits, and numbers of house foundation and postholes. Pottery forms of pedestal plates (*Dou*) and tripods (*Ding*) were buried with the dead, along with stone adzes. These discoveries indicate that Chaling was occupied for a long time and that it may have been a major population center of this area. Furthermore, the pottery traditions, structure of burials, and funeral rites are very similar with the late phase of the Shixia Culture, as seen in the Shixia Site in the hilly terrain of northern Guangdong Province. In the absence of materials for radiocarbon dating, the age of Chaling is estimated accord-

Table 1
AMS ^{14}C data from Laoyuan site and Nanshan site.

Site	Lab No.	Sample No.	Material dated	^{14}C(a BP)	Calibrated age (cal a BP, 2σ)
Laoyuan	Beta-491901	Layer 3–1	Rice seed	3900 ± 30	4419–4246
	Beta-489448	Layer 3–2	Charcoal	3840 ± 30	4406 (8.4%) 4366 4358 (87.0%) 4151
	Beta-489446	M1	Charcoal	3800 ± 30	4288–4088
	Beta-489447	H33	Charcoal	3740 ± 30	4224 (3.3%) 4205 4158 (92.1%) 3984
Nanshan	Bata-397667	Layer 22–1	Charcoal	4500 ± 30	5296–5046
	Bata-397672	Layer 22–2	Rice seed	4340 ± 30	4973–4845
	Bata-397671	Layer 20	Charcoal	4330 ± 30	4968–4843
	Bata-397663	Layer 16	Charcoal	3990 ± 30	4524–4415
	Bata-397664	Layer 10	Charcoal	4020 ± 30	4569 (3.0%) 4555 4549 (1.3%) 4542 4537 (91.0%) 4420

Note: All the data are calibrated based on IntCal 13 atmosphere curve [31] through OxCal v4.3.2 [32].

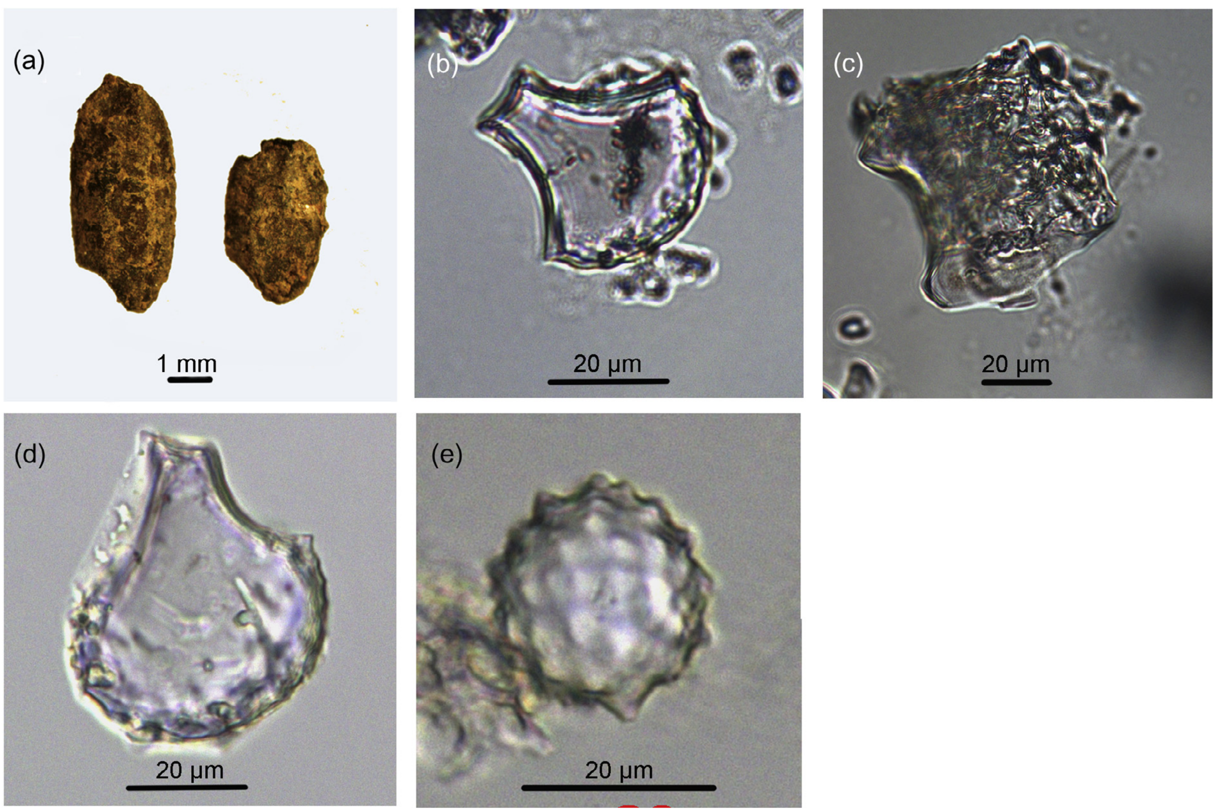

Fig. 2. Rice and palm remains from the sites of Laoyuan and Chaling. (a)–(c). Rice charred seeds, bulliform and double-peaked phytoliths from the Laoyuan Site. (d), (e) Rice bulliform and globular echinate from Aracaceae phytoliths from the Chaling Site.

ing to the pottery assemblage, equivalent with the late phase of the Shixia Culture, most likely around 4,300 and 4,000 cal a BP. The Shixia Culture (~5,000–4,000 cal a BP) has been represented by the Shixia Site (Fig. 4), in total divided in three phases. From M21 of the late phase, one AMS ^{14}C date for a carbonized rice seed points to an age of 4,300–4,100 cal a BP (Fig. 4). From the interior fillings of six pits of late Shixia pottery association, we collected 13 samples for phytolith analysis.

The charcoal specimens and carbonized seeds recovered from Nanshan and Laoyuan were isolated for AMS ^{14}C dating by Beta Analytic Laboratory. The phytolith extraction and identification were conducted in the laboratory of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. For each sample, 5 g soil was treated with 30% H_2O_2 and 10% HCl, then with 2.35 g/cm^3 $ZnBr_2$ to extract the phytoliths. All of the samples were examined under a Zeiss optical microscope (magnification × 400) and identified according to Wang and Lu [33] and Xu et al. [34]. Phytolith nomenclature and descriptions were consistent with International Code for Phytolith Nomenclature 1.0 [35]. For each sample, 300–330 phytoliths were counted.

3. Results

The new radiocarbon dating pointed generally in a range of 5,000–4,100 cal a BP, toward the earlier range at Nanshan and toward the later range at Laoyuan. For the Nanshan Site layers with abundant plant remains, the radiocarbon dating indicated an age around 5,000–4,500 cal a BP (Table 1, Fig. 4). The carbonized rice seed and charcoal specimens from the Laoyuan Site yielded dating results around 4,400–4,100 cal a BP (Table 1, Fig. 4).

The new archaeobotanical examinations indicated definite presence of domesticated rice, among other findings. A small number of rice bulliform, rice double-peaked and globular echinate from Arecaceae (Palmae) phytoliths were recovered from the sites of Laoyuan and Chaling (Figs. 2 and 3). Other types could not be further classified. Rice bulliform and double-peaked phytoliths from the Laoyuan Site account for around 1%, which is similar to that of globular echinate from Arecaceae (Palmae). The rice phytoliths from Chaling accounts for around 1% of total as well, but the percentage of Arecaceae (Palmae) could reach 30.8%, which is different from Laoyuan. According to the number of fish-decorations of well-preserved rice bulliform phytoliths [36,37], all of them were domesticated. Rice seeds from Laoyuan were identified as *Oryza sativa* subsp. *japonica* based on the shape and size by the botanist from the Institute of Botany, Chinese Academy of Sciences [22].

4. Discussion

4.1. Age of rice farming introduced into Fujian

Based on prior studies, rice farming appears to have reached the lower Min River by 4,500 cal a BP and then spread into the coastal border of the East China Sea around 4,000 cal a BP at the latest. These prior studies included work with rice remains from the Tanshishan Site (4,800–4,300 cal a BP) [15,38] and a series sites during about 4,300–3,800 cal a BP, including Huangguashan [29,39], Hulushan [40], Pingfengshan [29,41] and Zhuangbianshan [42,43] (Figs. 1, 4, Table S1 online). Even with this prior body of work, the direct evidence of the early arrival of rice was uncertain for the area of Fujian, until now with the new discovery of charred rice seeds from the Nanshan Site.

Large amounts of charred seeds from foxtail millet (*Setaria italica*), broomcorn millet (*Panicum miliaceum*), and rice were recovered from layers 10–23 at Cave 4 of the Nanshan Site, especially from layers 19–23 [30,44]. Our dating results demonstrate these plant remains were at the age of 5,300–4,400 cal a BP (Table 1, Fig. 4). Among them, one date of 4,973–4,845 cal a BP was derived from a charred rice seed recovered from layer 22, and this result was slightly younger than the dating of approximately 5,000 cal a BP for a piece of charcoal from the same layer (Fig. 4). In the most conservative reading, the results prove the presence of domesticated rice at least as early as 4,845 a BP but probably older. For the associated layer as a whole, the probabilities of dating results suggest an age of at least 5,000 a BP, meaning that rice farming most likely had spread into northern Fujian at 5,000 cal a BP.

4.2. Dates of rice farming introduced into the Pearl River Delta

In a cross-regional view, North Guangdong should be the place where domestic rice first appeared in Guangdong. Besides the Shixia Site, a few other archaeological sites reported rice remains in North Guangdong, such as Niling, Chuangbanyang, and Xiajiaolong, all sharing a similar artifact assemblage with the Shixia Culture, including a wide variety of cooking vessels [45,46]. Unfortunately, none of those charred rice remains yet have been dated.

Laoyuan is the single site where both domesticated charred seeds and phytoliths of rice were recovered in the hilly region of North Guangdong. The AMS ^{14}C date derived directly from a charred rice seed was around 4,400–4,100 cal a BP, equal with

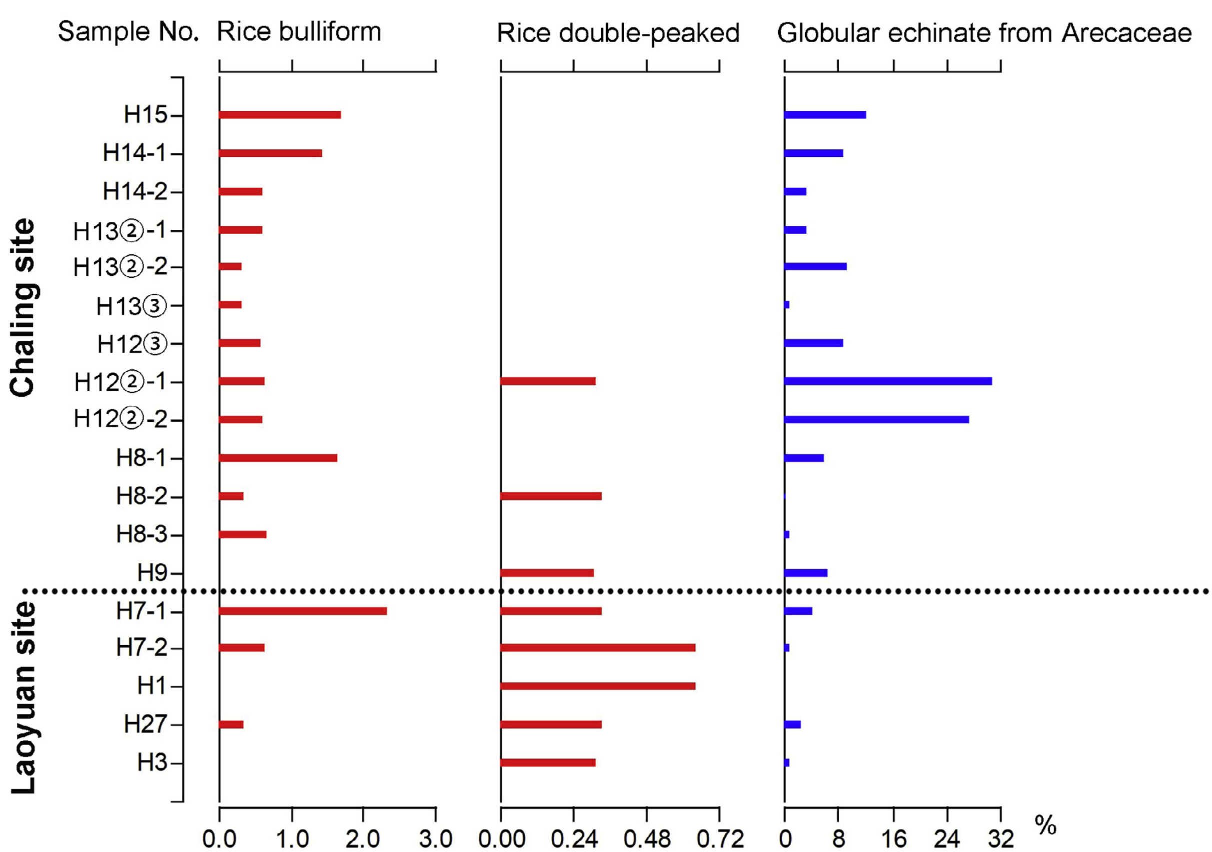

Fig. 3. (Color online) The percentage of phytoliths from the sites of Laoyuan and Chaling.

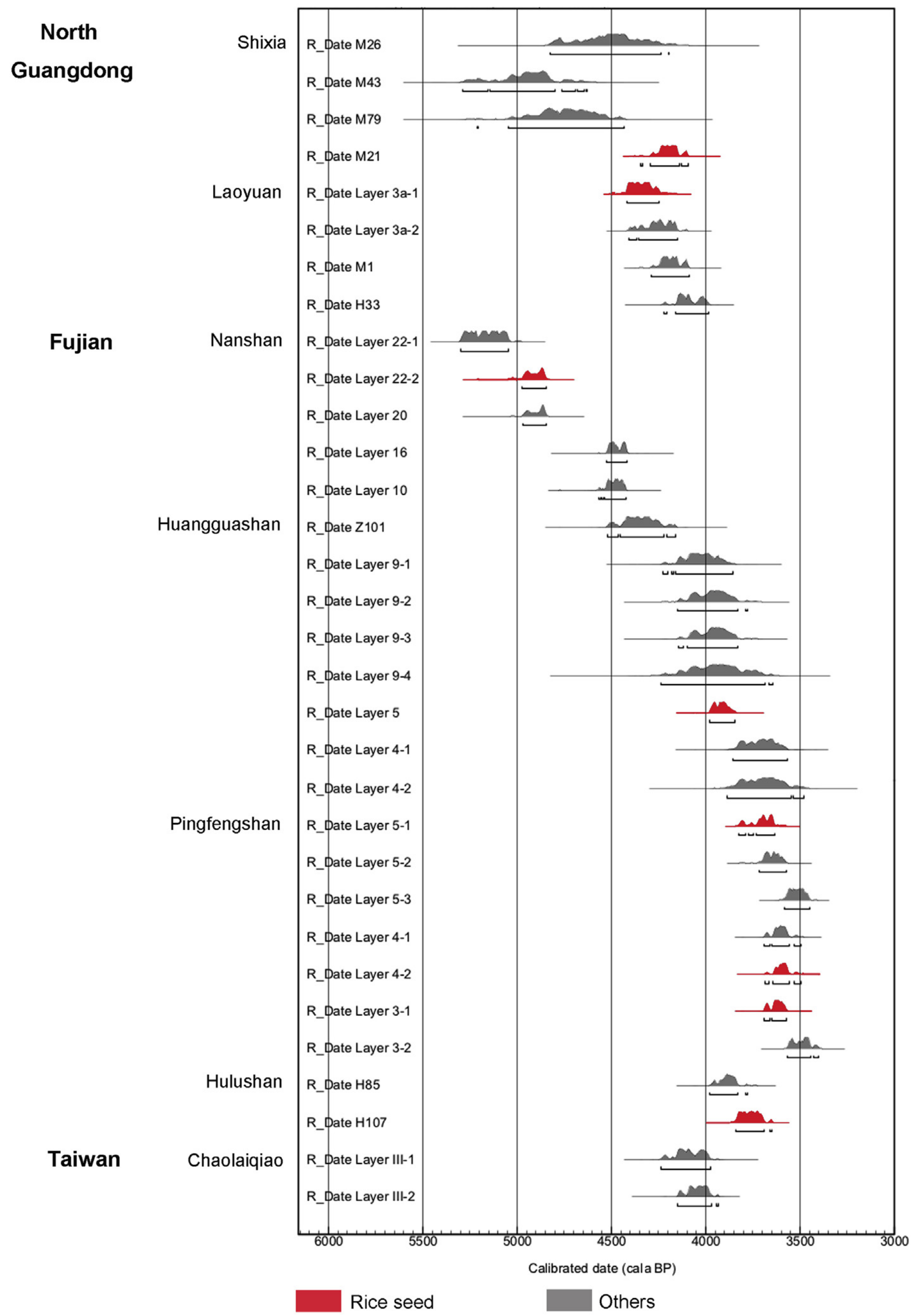

Fig. 4. (Color online) Calibrated ^{14}C data in this study. The figure is modified from Table 1 and Table S1 (online). All the data were calibrated with the IntCal 13 atmosphere curve [31] through OxCal v4.3.2 [32].

the timeframe of the late phase of Shixia Culture. During this time, rice apparently was popular in this hilly area of Guangdong (Fig. 4).

Regarding other areas of Guandong, the dates of oldest rice farming have been unclear. The Pearl River Delta, south of Guangdong, undoubtedly was an attractive place for settlement concentrations and a likely area for early rice farming. Despite this overall framework, direct evidence has been rare and unclear about ancient rice farming in this area. According to a study of the macroplant remains, the waterlogged rice seeds from the Guye Site had occurred as later-aged intrusions [27]. The one identified charred rice seed from the Neolithic layer of the Shaxia Site in Hong Kong (cal 4,500 a BP) has not been radiocarbon dated directly [47,48]. From phytolith analysis, some phytoliths extracted from the Shaxia Site and the Haoyong Site in Sai Kung, Hong Kong, were identified as Oryzoideae [47–49]. Based on the cultivated phytoliths of Cucurbitaceae found at the Shaxia Site, Lu [48] interpreted that the cultivation practices had emerged around 4,000 a BP in Sai Kung, Hong Kong, but no report so far has clarified if rice was included.

The domesticated rice phytoliths recovered from the Chaling Site provide new evidence for the early cultivated plant package in the Pearl River Delta. The results may confirm that rice farming had been introduced into this region by 4,000 cal a BP. The conclusion is also clarified by environmental changes. Pollen, sediment facies, and isotope analysis of several cores from the Pearl River Delta show that the spatial foundation had been built by the extended fresh mash gradually since 7,000 cal a BP [50–52] and the fishing-gathering declined as the result of the marine regression, which pushed the prehistoric communities during that period attempted rice cultivation, a new subsistence practice responding to local horticulture [53].

4.3. Possible routes of rice southward dispersal

Rivers can be viewed as having played crucial roles in the rice introduction process. The Shixia Site was occupied along the Maba River, one of the branches of the North River. The Laoyuan Site was situated along the branches of the East River. As these rivers flowed southward to the South China Sea, people could follow these conduits to the deltaic region where the Chaling and Gancaoling Sites were located. A similar situation can be seen in Fujian. The Nanshan Site was close to a brook, Yutang, flowing to the Shaxi Brook, the largest tributary of the Min River, through which ancient people could reach the Tanshishan Site efficiently. Although the river corridors are believed to be helpful for entrance of rice farming into South China, it cannot be denied the existence of other routes, for example, the ocean one. This hypothesis is supported by recent discovery, namely, the combination of carbonized rice seeds (dating around 7,500 cal a BP) and carbon-tempered pottery adulterated with rice husks, unearthed from Dapingding site, which is similar to that from lower Yangtze River region in the same or earlier period [54].

5. Conclusion

We dated the charred rice seeds and analyzed the phytoliths from archaeological sites excavated in recent years in south China. Our new results conclude that as early as 5,000 cal a BP, rice farming had reached the east piedmont of the Wuyi Mountain (Nanshan Site) and south piedmont of the Nanling (Shixia Site and Laoyuan Site). Subsequent to those events, people followed the flows of rivers toward the coastal zones, resulting in the introduction of rice farming into sites along the lower rivers and coastal areas in both Guangdong and Fujian Province by 4,000 cal a BP. Now for the first time, the newest discoveries here demonstrate a rough image of early attempt of rice cultivation in the south China during late Neolithic period and provide the evidence for identifying the dates and routes of the southward rice dispersal and the southward margin routes.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2018.10.011.

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Xiaoyan Yang is a professor of the Institute of Tibetan Plateau Research of Chinese Academy of Sciences. Her research interests are environmental change and human adaptation.

Yongchao Ma is a doctoral candidate at Peking University. His research interests are archaeobotany and Neolithic archaeology.