ARTICLE IN PRESS

Quaternary International xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Investigating the late neolithic millet agriculture in Southeast China: New multidisciplinary evidences

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ARTICLE INFO

Keywords:
Southeast China
Late neolithic
Millet
Pig
Isotope analysis

ABSTRACT

The spread of millet agriculture to southeast (SE) China is critical to understanding the region's economic pattern and its potential impact on the proposed initial expansion of proto-Austronesians. In this study, we present new multidisciplinary evidence for the development of millet agriculture from three Neolithic sites in Fujian Province, China: Hulushan, Pingfengshan and Huangguashan. The carbonized seeds from Hulushan indicate the existence of millet agriculture around 3842-3649 cal. BP. Meanwhile, we tested stable carbon and nitrogen isotope ratios of faunal remains (n = 22) from Pingfengshan and Huangguashan shell midden sites in a coastal area of Fujian. The stable isotope results for pigs ($\delta^{15}N$ values range from 4.9 to 11.2‰, and $\delta^{13}C$ values range from −24.1 to −11.2‰) show significant variations, suggesting that these pigs were fed different foods, including C_3 plants, C_4 plants and marine resources. Specifically, two samples of pig collagen with strong millet signals were directly dated to about 4000-3600 cal. BP. These new findings provide substantial evidence for a new understanding of the development of millet agriculture in SE China.

1. Introduction

The spread of millet agriculture from its northern China center to coastal SE China and the offshore islands has increasingly received attention over the past decade. Evidence has been used to support possible population migrations, particularly the expansions of the proposed ancestors of Austronesians across the Taiwan Strait (Deng et al., 2017; Hung and Carson, 2014; Hsieh et al., 2011). Some even proposed a possible trade of millet-consuming pigs across long-distance ocean gaps from mainland China to the Ryukyu islands (Minagawa et al., 2005). Yet along this possible expansion route, critical evidence of the presence of millet agriculture in coastal SE China, particularly modern Fujian Province, has been missing until very recently. While the recent finds of a small amount of carbonized millet grains from two Neolithic sites (Huangguashan and Pingfengshan) have filled this gap (Deng et al., 2017), the intensity of millet cultivation and consumption is still unknown.

Located on the western side of the Taiwan Strait, modern Fujian province has been regarded as one of the most important regions for studying the spread of agriculture and proto-Austronesian people from mainland China to the Pacific islands. Recent studies on pollen and charcoal records suggest that there was progressively increased human pressure on the forest vegetation in Fujian province since 5500 cal. BP. (Zhao et al., 2017). This find is in line with the archaeological records of the increasing number of Neolithic sites in Fujian around the same time. However, it is not clear whether this kind of deforestation was a result of agricultural activities. At least in the coastal area, archaeological evidence suggests that even if there was farming in the Neolithic period, it was likely low-level production, a minor subsistence pattern in comparison with the exploitation of marine resources (Jiao, 2016; Wu et al., 2016).

Over the past few years, we have carried out flotation work and isotope analyses on three Neolithic sites in Fujian. We found both direct and indirect evidence of millet consumption at these sites, providing new data for investigating the spread of millet agriculture in SE China. This paper introduces these new finds and offers a new interpretation of

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https://doi.org/10.1016/j.quaint.2019.01.007
Received 24 August 2018; Received in revised form 20 December 2018; Accepted 4 January 2019

Please cite this article as: Ge, W., Quaternary International, https://doi.org/10.1016/j.quaint.2019.01.007

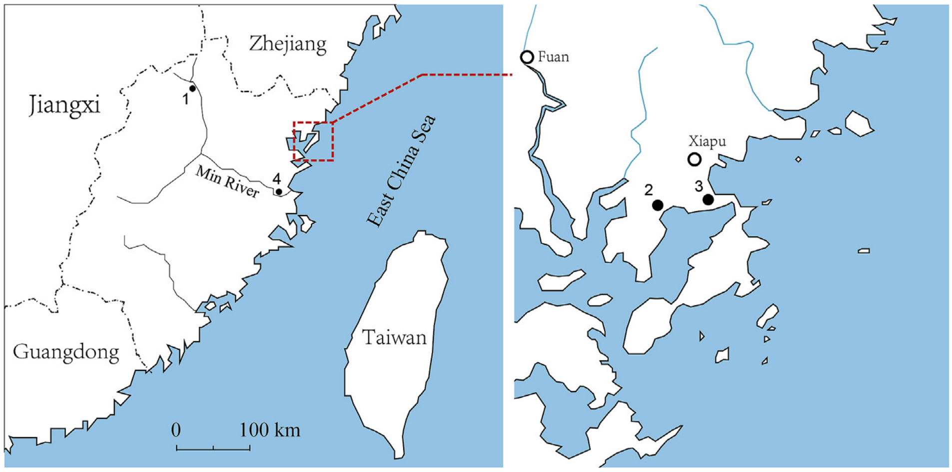

Fig. 1. Map showing Fujian Archaeological sites mentioned in the text. 1) Hulushan; 2) Huangguashan; 3) Pingfengshan; 4) Tanshishan.

the increased significance of millet consumption in late Neolithic and early Bronze Age SE China.

2. Material and methods

2.1. Flotation at Hulushan site

Located on a hill slope in the mountainous Wuyi County, Fujian Province, the Hulushan site (HLS, 27°31′ 3″N, 118°1′ 44″E) has attracted academic attentions since the 1990s (Fig. 1). In particular, the kilns have been frequently referred to as evidence of changing firing technology of prehistoric ceramics in the region. The distinct ceramic styles and decorations were also regarded as representations of a new archaeological culture (Jiao and Fan, 2010). More recent excavations at this site further demonstrate that it is a late Neolithic and early Bronze site in the region's chronological sequence (Fujian Museum et al., 2016). Our flotation focuses on the soil samples collected in the excavation season of 2014. Due to the high soil acidity, no human or animal bones were found. The soil samples were mostly from ash pits. Carbonized light fractions were examined under an Olympus SZ61 stereo microscope, equipped with a MS60 camera (MSHOT Company, China) for taking photos.

2.2. Carbon and nitrogen stable isotope analyses on HGS and PFS animal bones

2.2.1. Huangguashan site (c. 4300-3500 cal. BP)

Huangguashan (HGS, 26°47′50"N, 119°55′24"E) is another representative late Neolithic and early Bronze Age site in coastal Fujian Province. Situated on a small hill to the west of Xiaoma village in Xiapu County (Fig. 1), Huangguashan is about 1 km away from an ocean bay. Excavations were carried out by Fujian Museum in 1989 and 2002 (Fujian Museum, 1994; Jiao, 2013). A large quantity of shells, pottery, stone tools and fauna were recovered. The main cultural traits of HGS seems to have descended from Tanshishan culture (middle and lower layer of the Tanshishan site) which was distributed in the lower Min River valley (Fig. 1).

2.2.2. Pingfengshan site (c. 3700-3400 cal. BP)

Pingfengshan (PFS, 26°48′37″N, 119°59′44″E) is another shell midden site in Xiapu County, about 5 km away from the Huangguashan site (Fig. 1). The site is on an independent hill with steep slopes, covering a total area of about 4000 m^2. In 2016, Fujian Museum and collaborators excavated about 15 m^2 at the site, revealing a great amount of fauna and pottery. The fauna includes pig, deer, dog and other small size carnivores. Shell remains largely consist of oyster and *Anadara granosa* (Fujian Museum and Xiapu county Museum, 2017). In terms of the pottery assemblage, the painted sherds of the early phase are similar to those at HGS, but they differ in other aspects of the assemblage, indicating there might be regional difference in the area.

2.2.3. Collagen extraction and testing

Twenty-two bone specimens from the HGS and PFS sites were analyzed for this study. Eighteen of them are from HGS, and four from PFS (Table 1). A small chunk of bone sample (about 1 × 1 cm) was cut off from each specimen and cleaned mechanically and rinsed with deionized water in an ultrasonic cleaner to remove dirt particles and dust. Collagen was extracted using a modified protocol following Richards et al. (Richards and Hedges, 1999; Jay and Richards, 2006). All collagen samples underwent carbon and nitrogen stable isotope testing using a Delta V ™ Advantage Isotope-ratio Mass Spectrometer (IRMS) equipped with a Vario El III elemental analyzer (Elementar, Germany) at the IRMS laboratory, the Third Institute of Oceanography of State Oceanic Administration. Stable isotope concentrations are measured on the basis of international standards, V-PDB for carbon and AIR for nitrogen, respectively. The analytical precision of the instrument is 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$.

2.3. Isotope analyses of modern marine references

Due to the diffusion effects of air CO_2 and N_2 in water, the flora in the sea show relatively higher values of $\delta^{13}C$ and $\delta^{15}N$ than terrestrial plants (Boutton, 1991; Ambrose et al., 1997; Schoeninger and DeNiro, 1984). Although some modern marine flora and fauna data have been published in other areas (Dunton, 2001), specific references from the Chinese coast are still rare. Considering that the regional environment may impact the isotope ratio of local life (Heaton et al., 1986), we collected four marine animals and one plant for stable isotope test from a seaside mudflat near the PFS site as background references, including oyster (*Ostrea* sp.), mudskipper (*Periophthalmidae* sp.), crab (*Portunus* sp.), conch (*Batillaria zonalis*) and one kind of seaweed (*Enteromorpha* sp.). The fauna samples are all common in the area, and the seaweed was one of the resources to feed pigs in the past, according to the local farmers. All samples were cleaned with deionized water in an ultrasonic cleaner. For the faunal specimens, 0.001 M HCl was used to dissolve the protein. The solution of protein with the cleaned seaweed plant was freeze-dried and tested with the same instruments as in part 2.2.3.

2.4. Radiocarbon dating

We selected three pig collagen samples, one human collagen sample and one carbonized rice grain for AMS radiocarbon dating. These

Table 1
Results of stable carbon and nitrogen isotope analyses of archaeological skeletal specimens from HGS and PFS sites and modern references.

Lab No.	Provenience	Taxon	Element	δ^{13}C	δ^{15}N	%C	%N	C/N
HGS samples								
HGSP01	Layer 4B	pig	radius	−22.9	3.8	13.3	2.4	6.3
HGSP02	Layer 4B	pig	ulna	−16.4	8.2	41.0	14.7	3.3
HGSP3A	Layer 6	pig	femur	−20.6	7.8	37.4	13.1	3.3
HGSP3B	Layer 6	pig	ulna	−12.7	8.0	41.9	15.6	3.1
HGSP3C	Layer 6	pig	humerus	−19.3	8.8	39.0	14.5	3.1
HGSP4A	Layer 7	pig	scapula	−20.6	8.8	40.7	15.0	3.3
HGSP4B	Layer 7	pig	humerus	−24.1	5.7	38.3	13.9	3.2
HGSP4C	Layer 7	pig	radius	−19.4	11.2	38.7	14.2	3.2
HGSP05	Layer 9	pig	tibia	−18.6	8.1	36.2	13.2	3.2
HGSP06	Layer 9	pig	femur	−17.5	8.6	38.4	14.1	3.2
HGSP08	Layer 10	pig	humerus	−18.6	9.6	39.8	14.5	3.2
HGSD01	Layer 5	dog	mandible	−18.0	12.5	38.1	13.3	3.3
HGSD02	Layer 6	dog	ulna	−22.6	4.6	39.2	14.0	3.3
HGSD03	Layer 8	dog	mandible	−18.3	8.5	35.1	13.1	3.1
HGSD04	Layer 9	dog	femur	−23.9	7.6	36.1	11.7	3.6
HGSM02	Layer 7	deer	femur	−13.2	11.3	40.3	14.3	3.3
HGSM04	Layer 6	deer	tibia	−22.6	6.3	31.0	10.8	3.4
HGSM07	Layer 9	tiger	metatarsus	−20.3	9.5	35.5	12.6	3.3
PFS samples								
PFSP01	layer 5	pig	limb	−12.2	4.9	42.8	15.8	3.2
PFSP02	layer 5	pig	mandible	−14.6	8.3	39.1	13.0	3.5
PFSP03	layer 5	pig	mandible	−15.7	10.0	37.7	13.4	3.3
PFSP04	layer 5	pig	scapula	−20.6	5.4	40.9	14.7	3.2
Modern references								
Xp01	mudflat, Xiapu	oyster	whole protein	−18.3	8	32.9	8.6	4.5
Xp02	mudflat, Xiapu	mudskipper	whole protein	−13.1	20.5	39.4	12.23	3.8
Xp03	mudflat, Xiapu	crab	whole protein	−13.7	11.1	35.0	7.4	5.5
Xp04	mudflat, Xiapu	Conch	whole protein	−13.7	9.8	32.3	6.1	6.2
Xp05	mudflat, Xiapu	seaweed	part of plant	−19.7	9	38.7	5.4	8.4

samples were analyzed by Beta Analytic Inc. Two of the three pig samples were selected because both have signals of C_4-based food consumption. The third one was selected because it was from the lowest layer. The rice sample is from the same phase as the millets recovered from the HLS site. The human sample from the Tanshishan site (TSS) was extracted from a sample in a previous study carried out by Wu et al. (2016), which has been preserved in −20 °C condition. All dates were calibrated using the OxCal 4.2 program, with the calibration curve of INTCAL13 (Ramsey, 2009; Reimer et al., 2013).

3. Results

3.1. Carbonized botanical remains from HLS

The carbonized remains from the Hulushan site include charcoal, charred seeds and unidentifiable tuber pieces. A total of 511 seeds were identified, including rice (*Oryza sativa*, n = 26), foxtail millet (*Setaria italica*, n = 2), Chinese tallow (*Sapium sebiferum*, n = 480), purple perilla (*Perilla frutescens*, n = 1), *Acalypha australis* (n = 1) and Rosaceae sp. (n = 1). In addition, 97 rice spikelet bases were identified. The length/width ratios of the rice grains are between 1.62 and 1.98, a standard range of japonica (Cheng et al., 1984) (Fig. 2: A). One of the two foxtail millet grains is relatively full-bodied, 1.22 mm in length by 1.24 mm in width (Fig. 2: B). The other one is much smaller and distorted severely, indicating it was probably an immature grain (Fig. 2: C).

3.2. Modern references from the mudflat

Our results show large variability in the carbon and nitrogen isotopic composition of faunal samples collected from the mudflat in Xiapu: δ^{13}C ranged from −18.3 to −13.1‰, and δ^{15}N ranged from 8 to 20.5‰ (Table 1, Fig. 3). This may indicate the complexity of the local food web. In general, the results are consistent with the previous knowledge that marine animals produce relatively higher carbon and

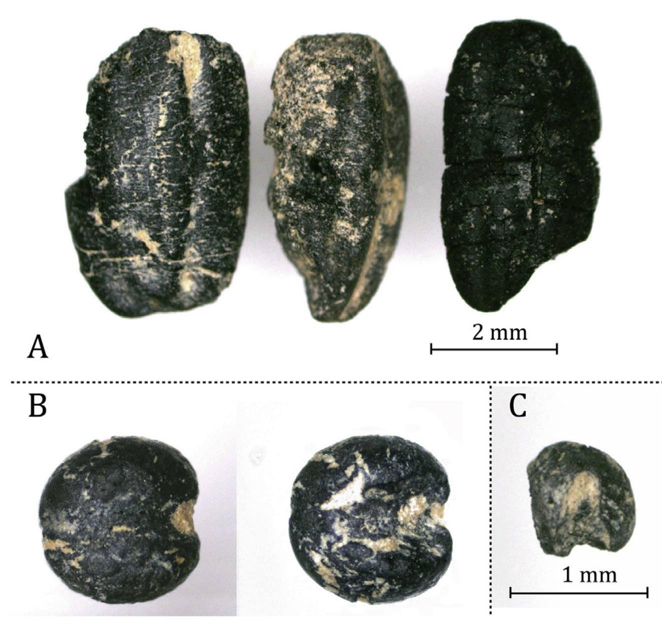

Fig. 2. Crop remains recovered from HLS site. A. *Oryza sativa* B. *Setaria italica* (Left: scar side; Right: embryo side) C. *Setaria italica* (immature). B, C share the same scale bar.

nitrogen isotope ratios than terrestrial ones (Ambrose et al., 1997). As for the seaweed, the δ^{13}C and δ^{15}N come out to be −19.7‰ and 9‰, respectively. Both values are much higher than the published values of terrestrial C_3 plants (O'Leary, 1981; Cloern et al., 2002). Dunton (2001) has reported one species of the same genera of *Enteromorpha* with different carbon and nitrogen values (δ^{13}C = −13.2‰, δ^{15}N = 6.7‰). The differences could be the consequences of interspecies variation, effects of temperature, concentration of CO_2 and other unknown environmental factors (O'Leary, 1981; Amundson et al., 2003; Schubert

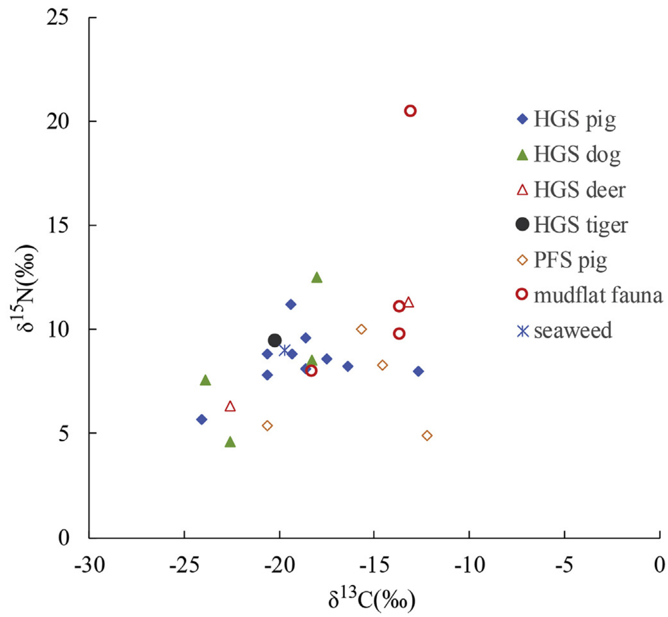

Fig. 3. Stable carbon and nitrogen isotope ratios of animal bone collagen from HGS and PFS sites with modern references collected from local coastal area.

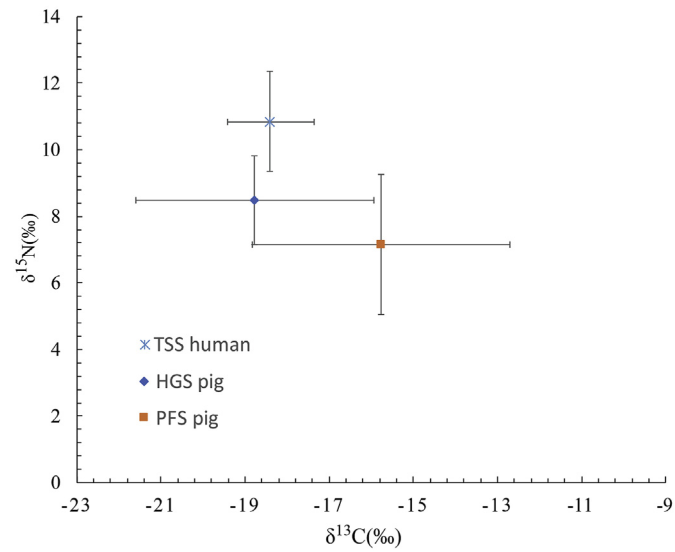

Fig. 4. Mean isotopic analysis for data from TSS, HGS and PFS sites.

and Jahren, 2012).

3.3. HGS faunal isotope data

Among the HGS samples, the majority yielded an atomic C/N ratio of 3.1–3.6, with high carbon and nitrogen concentrations in collagen (Table 1). One sample (HGSP01), with a C/N ratio outside the acceptable range of 2.9–3.6 together with low carbon and nitrogen percentage, was excluded from further analyses (DeNiro, 1985). Pig carbon isotope values are between −24.1 and −12.7‰, and the nitrogen isotopic values are between 5.7 and 11.2‰. Some of the pig samples have $\delta^{15}N$ values higher than 9‰ (HGSP4C and HGSP08), suggesting significant consumption of marine food. Among these pigs, HGSP3B possesses the highest $\delta^{13}C$ value (−12.7‰), while its $\delta^{15}N$ is in the middle level (8.0‰), which may be interpreted as an indicator of C_4 plants. If the high carbon value was a result of marine food intake, its nitrogen value should also have been elevated. However, we did not find this signal in our data. The $\delta^{15}N$ values of HGS dog samples show high variability, ranging from 4.6 to 12.5‰, with $\delta^{13}C$ values based on C_3 plants (Table 1, Fig. 3). The two dog individuals with high $\delta^{15}N$ values also have higher $\delta^{13}C$ values than the others, which may indicate a diet containing a certain amount of marine resources. One of the two deer samples (HGSM02) shows remarkably higher nitrogen and carbon values than the wild herbivores (Bocherens et al., 1994), reflecting an unusual predominantly marine-based diet. The data of the tiger shows typical isotopic values of a carnivore on the top of a terrestrial food web.

3.4. PFS pig isotope data

The four pig samples from PFS all exhibited acceptable data, of which the C/N ratios fall in the 3.2–3.5 range with relatively high carbon and nitrogen percentages. The isotope values among these samples show a high degree of variation (Table 1, Fig. 3, Fig. 4). PFSP01 has a high $\delta^{13}C$ value (−12.2‰ and a quite low level of $\delta^{15}N$ (4.9‰), which clearly indicates a significant dietary intake of C_4 plants. PFSP02 and PFSP03 have similarly high levels of nitrogen values and middle levels of carbon values, which may be interpreted as the results of consuming marine resources and mixed C_3 and C_4 plants. The $\delta^{13}C$ value of PFSP04 shows obviously heavy reliance on C_3 plants. Meanwhile, the low level of its nitrogen value also demonstrates negligible marine dietary intake. Overall, the wide range of these data may reflect either a complicated source of the pigs, or the diversity of foddering strategies.

4. Discussion

4.1. Linking C_4 signals with millets

In the modern natural environment, only about 1% of terrestrial plants are C_4 species, while 4% are CAM, and nearly 95% use the C_3 pathway (Bowes, 1993). Although the latitude and water stress may affect the distribution of C_4 plants, the general low ratio is relatively stable worldwide, and wild terrestrial animals mostly rely on the C_3 food chain (Kelly, 2000). In this study, the low $\delta^{13}C$ value (−20.3‰) of the individual tiger HGSM07 clearly suggests that it occupied a C_3-based food web, therefore suggesting that the natural vegetation of Neolithic PFS and HGS was also dominated by C_3 plants. Meanwhile, carbon stable analyses on modern and ancient wild boar from West Asia, Europe and East Asia have all revealed distinct C_3 significance (Lösch et al., 2006., Dürrwächter et al., 2006., Minagawa et al., 2005., Hu et al., 2009). So, it is reasonable to infer that the C_4 diet for those individuals with C_4 signal in HGS and PFS pigs was unlikely from the nature environment but should be from leftover crops provided by humans. Given the fact that carbonized millet grains have been found at both HGS and PFS (Deng et al., 2017), these crop leftovers are most likely millets, as discussed by Rowley-Conwy et al. (2012) in similar cases.

It must be pointed out that the difference in $\delta^{13}C$ between the pigs with strong C_4 signals (HGSP3B and PFSP01) and the other individuals at HGS and PFS is statistically significant ($t = 3.381$, $p < 0.05$). This kind of high degree of variation in the carbon values of HGS and PFS pigs demands further interpretations. It might indicate diverse strategies for pig feeding. Nevertheless, the significant consumption of millet by the pigs clearly indicates that millet cultivation must have been developed to such a scale that there were enough leftovers for raising animals (Liu et al., 2012).

4.2. The spread of millet cultivation in SE China

Recent archaeobotanical work has recovered millet remains from a number of Neolithic sites in SE China. One of them is the Shangshan site, Zhejiang province, where two grains of foxtail millet were

Table 2
Radiocarbon ages and calibrations for the samples from the studied sites.

Lab No.	Site and Material	Sample	^{14}C date (BP)	Calibrated age (BP)	
				1σ(68.2%)	2σ(95.4%)
Beta-463024	TSS human Collagen	TSS07(Wu et al., 2016)	4140 ± 30	4813–4782(14.0%) 4768–4755(5.5%) 4708–4666(19.6%) 4661–4609(23.2%) 4599–4584(5.9%)	4823–4570(95.4%)
Beta-411758	HLS Carbonized seeds	Chinese tallow	3580 ± 30	3914–3838(68.2%)	3977–3827(94.2%) 3788–3777(1.2%)
Beta-411759		rice	3490 ± 30	3827–3788(26.8%) 3778–3718(41.4%)	3842–3690(93.4%) 3660–3649(2.0%)
Beta-463022	HGS Pig collagen	HGSP08	3700 ± 30	4086–4062(18.1%) 4050–3985(50.1%)	4148–4113(8.7%) 4100–3966(84.5%) 3944–3930(2.2%)
Beta-463023		HGSP3B	3600 ± 30	3965–3945(14.0%) 3930–3862(54.2%)	3980–3834(95.4%)
Beta-463021	PFS Pig Collagen	PFSP01	3430 ± 30	3807–3804(1.0%) 3720–3635(67.2%)	3825–3790(10.2%) 3770–3746(4.4%) 3731–3592(80.8%)

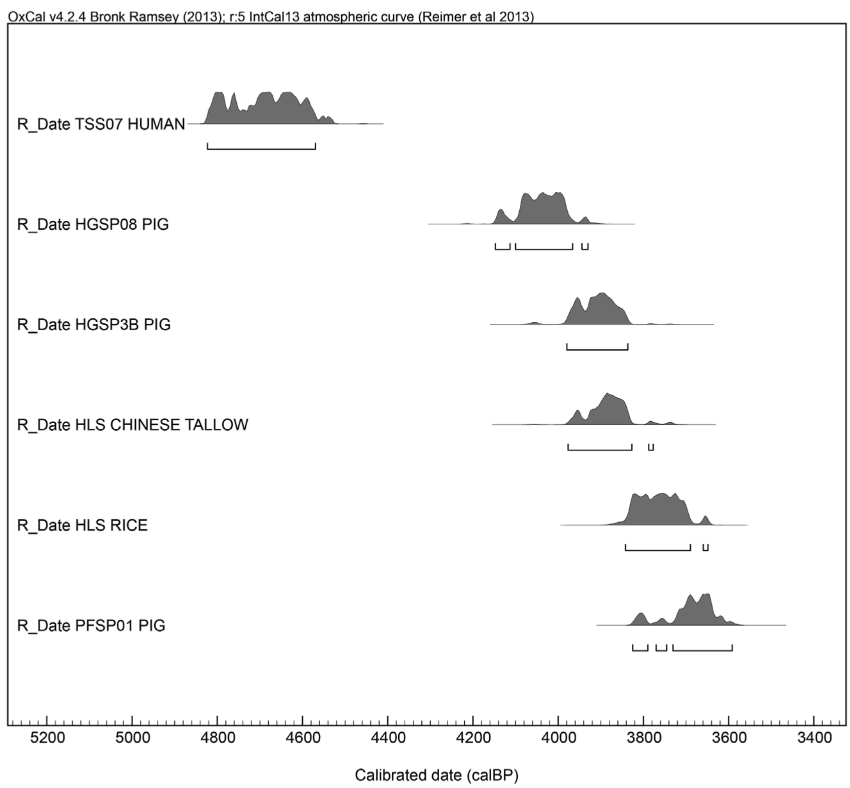

Fig. 5. Calibrated radiocarbon dates of samples selected from sites mentioned in the text.

recovered from its Hemudu culture period (about 6500 BP) (Zhao and Jiang, 2016). These are the earliest millet remains in SE China, suggesting at least around 6500 BP, millet agriculture was also practiced in SE China. As indicated above, both HGS and PFS have produced carbonized millet grains. Because of their small quantity, the seeds were not sent for direct ^{14}C dating. However, the date of the contemporaneous rice grains (3980–3846 cal. BP) suggest that at least around 4000 BP, millet was also cultivated on the coast of Fujian (Deng et al., 2017). The strong C_4 signal of pigs from HGS and PFS can be regarded as additional evidence for the consumption of millets. The pig with C_4 signal from HGS (HGSP3B) was directly dated to 3980–3834 cal. BP (2σ range, the same as the following date, see details in Table 2 and Fig. 5), which is almost the same as the age of rice recovered from the same layer (Deng et al., 2017). The pig with C_4 signal from PFS (PFSP01) was dated to 3825–3592 cal. BP, which overlaps with the date of rice (3684–3494 cal. BP) at PFS. The rice grain from HLS was dated to 3842–3649 cal. BP. In summary, the isotope data and the flotation results provide consistent evidence for the co-existence of rice and millet consumption in coastal and inland north Fujian at about 4000-3600 BP. Our findings are consistent with palaeoecology studies based on pollen and charcoal records around the studied areas, which revealed that intensive human activities only happened after about 4000-3600 cal. BP (Ma et al., 2016; Yue et al., 2012).

Studies show that the isotope signal of the input of a cultigen into the diet of human and animals often falls behind its first emergence in an area. For example, charred millet seeds were documented as early as 5000-3000 BC in Europe, while the isotopic signals of C_4 were not detected in human and fauna remains until 2000-1000 BC (Hunt et al., 2008; Tafuri et al., 2009). Research by Liu et al. (2012) in Inner Mongolia also indicates that the time of the first cultivation of millet was much earlier than the time of detectable isotopic signals in domestic animals. Therefore, we can expect an earlier date for the first introduction of millet in Fujian.

Our analysis of a sample from the Tanshishan site offers further evidence of a possible earlier date of millet consumption in Fujian. In a previous isotope study on the TSS human skeleton, Wu et al. (2016) suggested significant marine resources and C_3 plants in the diet, yet the contribution of C_4 plants could not be excluded. Among the samples, TSS07 has the highest $\delta^{13}C$ value (−16.5‰) with a $\delta^{15}N$ value of 9.6‰. Although the nitrogen value shows some intake of marine food, the notable high carbon ratio suggests that it was not simply enriched by marine resources. Excessive reliance on marine food may lead to even higher nitrogen value, while this value of TSS07 is relatively not high, taking the mean value 10.9 ± 1.5‰ into consideration. Similar human data at *Olmo di Nogara* in Italy was attributed to millet consumption (Tafuri et al., 2009). AMS dating of collagen from TSS07 gave a result of 4823-4570 cal. BP, which is close to the reported date of TSS culture as 4820-4290 cal. BP, based on charcoal recovered from ash pits (Fujian Museum and Tanshishan Site Museum, 2010). This result indicates that millet was possibly cultivated in Fujian as early as 4800 BP. Nevertheless, this hypothesis is subject to the test of future archaeobotanical finds.

In Fig. 4, the mean isotope values of humans from TSS and pigs from HGS and PFS are plotted with error bars. Because of the enrichment of $\delta^{13}C$ values, there is likely an increasing consumption of millets from the late Neolithic to the Bronze Age. Meanwhile, the diachronically decline of Nitrogen values from TSS to PFS may indicate a decreasing reliance on marine resources in the diets of humans and pigs over time.

5. Conclusion

Our analysis of the materials from three sites in Fujian Province for the first time demonstrates that millet consumption by human and pigs was substantial around 4000-3600 cal. BP. The millet agriculture in late Neolithic Fujian most likely came from the nearby lower Yangtze River valley after about 6500 BP. Considering that the presence of a crop in an area may precede its entry into the diet of domestic animals, it is plausible to assume millet spread to Fujian from that area in a much earlier date.

Given the fact that both the Huangguashan and Pingfengshan sites are coastal shell midden sites, the result of our analysis allows us to reexamine the food diversity of these coastal settlements. Although marine resources continued to be important, millet and rice were increasingly consumed by both people and pigs around 4000 BP. To feed pigs with millet is an indicator that the cultivation of millets had reached a scale sufficient to produce surplus beyond human needs. It also suggests that food production had become more important in the subsistence pattern in coastal Fujian around 4000 BP. Interestingly, starting from this period, the density of archaeological sites also increased in the coastal area. The development of food production likely played a crucial role in the increasing population density, an important change in the prehistory of southeast coastal China.

Acknowledgements

This research was supported by the National Social Science Foundation of China (No.18BKG002). We thank Xinyi Liu from the Department of Anthropology of Washington University in St. Louis for valuable discussions. We are truly grateful to two anonymous reviewers for their constructive comments and Dr. Maureece J. Levin from Stanford Archaeology Center for helping with language improvements.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2019.01.007.

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