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To eat like Liangzhu: isotopic investigation of diets in the Lower Yangtze area prior to and during the Liangzhu period (5300–4300 cal. BP)

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Abstract

This essay analyzes a robust body of C and N stable isotopes from human and animal collagen and plant remains ($n=423$) in the area of Lower Yangtze River dating to 8000–4300 cal. BP, combined with new isotopic data recovered from the Zhelin site in Shanghai, to explore the dietary differences between coastal region and the inland core area of the Liangzhu culture (5300–4300 cal. BP). Our findings suggest that the food variety of the peripheral inhabitants of the core area of the Liangzhu culture may became less diverse over time, while at the same time their reliance on a few domesticated species (rice and pigs) increased. It may be a result of the growing economic and cultural influence of the populations in the inland core Liangzhu area.

Keywords Diet, Stable isotope, Rice agriculture, Lower Yangtze area, Liangzhu

Introduction

In recent years, archaeologists have made significant discoveries at Liangzhu period sites, including China's earliest ancient city and water management technologies at Mojiaoshan and Maoshan [1, 2]. The Liangzhu culture, located in southern China near Shanghai, is arguably the first ancient society in the world to have relied on intensive rice agriculture [3–5]. After a thriving period of cultural development, the Liangzhu culture dissolved around 4200 cal. BP possibly due to the late Holocene climate event and widespread flooding [6–10]. Although the general chronology and some key accomplishments of the Liangzhu culture are widely known, many functional and ritual aspects of the Liangzhu economy remain poorly understood, partly because most archaeological investigations have focused on sites within the urban core at Liangzhu itself (Fig. 1). To counter this emphasis, we examine and compare sites within the municipal areas of Shanghai and Ningbo in coastal area of southeastern China, located on the coastal margin of the Liangzhu cultural sphere (Fig. 1).

Scholars have argued that diet can be a potential vector to examine people's conception of who they are and who they want to become [11]. Given that stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope analysis of human bones are widely accepted as indicators of dietary practices [12, 13], this study reexamines existing isotopic data from archaeological sites at the Lower Yangtze area in light of new evidence concerning the Liangzhu culture as well as a newly reported late Liangzhu cultural site, Zhelin (Fig. 1). Isotopic investigations of ancient diets over the past 30 years have made great progress in understanding

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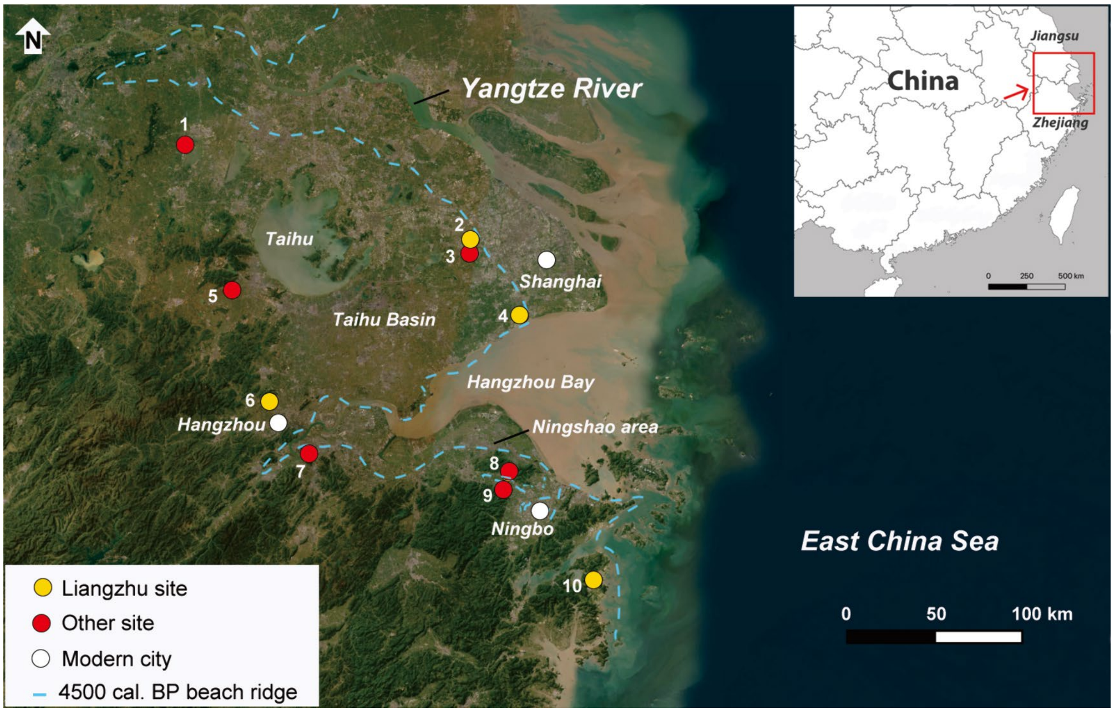

Fig. 1 Map of archaeological sites mentioned in the text, 1, Sanxingcun (6500–5500 cal. BP); 2, Fuquanshan (5300–4300 cal. BP); 3, Songze (6000–5300 cal. BP); 4, Zhelin (5300–4300 cal. BP); 5, Jiangjiashan (7000–6000 cal. BP); 6, Liangzhu (Meirendi site, 5300–4300 cal. BP); 7, Kuahuqiao (8000–7000 cal. BP); 8, Tianluoshan (7000–5300 cal. BP); 9, Hemudu (7000–6000 cal. BP); 10, Tashan (5300–4300 cal. BP), and beach ridge at Lower Yangtze area during around 4500 cal. BP [17]

dietary shifts in northern China, but major advances have been lacking in the area south of the Yangtze River, due to soil conditions and poor preservation of skeletal materials in this region [14, 15]. As such, we extracted collagen from human ($n=9$) and dog ($n=1$) bones recovered from the tombs and pits at the Zhelin site located in southern Shanghai for stable isotope analysis. This would allow us to examine the foodways of Zhelin residents living at this small coastal Liangzhu site dating to 5200–4900 cal. BP [16].

Furthermore, we collected extant isotopic data on human ($n=56$), animal ($n=361$) and plant ($n=3$) isotopic results from the Lower Yangtze area, published in Chinese and English, in order to summarize their findings and explore how the phenomenon of the Liangzhu culture led to adjustments in regional dietary diversity. By analyzing the δ^{13}C values of human collagen, together with other archaeological evidence, we can obtain information on the consumption of marine and terrestrial foods in prehistoric human diets [13]. In addition, since the δ^{15}N value of organisms increases by 3‰ to 5‰ as the trophic level rises, the δ^{15}N values of human bone collagen can investigate the role of proteins in ancient diets [12]. Here, using new stable C, N isotopic evidence from the Zhelin site and previous isotope evidence of human and different kinds of foodstuff remains recovered from the Lower Yangtze area during around 8000–4300 cal. BP, we aimed to examine how dietary practices and economic decisions differed between small coastal sites and core regions located further inland before and during the Liangzhu period (5300–4300 cal. BP). This study provides novel insights into how residents of these small coastal sites on the periphery of Liangzhu sphere made specialized economic decisions while participating within the broader Liangzhu culture.

Archaeological background

The Zhelin site (30.8261° N, 121.4705° E, and 4.1 m asl) is situated on the north bank of Hangzhou Bay, Fengxian District of Shanghai (Fig. 1). Archaeologists first discovered the site in 1973 (http://www.sanyamuseum.com/a/2/2022/0720/1079.html). The site is about 100 m long from east to west and 70 m wide from north to south and considered as a residential site of Liangzhu culture situated along the ancient Shanghai coastline 4500 cal. BP. In 2018 and 2020, archaeologists excavated the site, in order to better understand its size and type (Fig. 2). Excavations have already revealed at least twenty child and adult burials in varying states of preservation and some burial objects including jade, pottery and bone tools (Fig. 3A,

Fig. 2 **A** Map of the Zhelin site, **B** aerial photograph of the area around the Zhelin site, **C** excavation setting, **D** excavations in 2018

Fig. 3 **A** Burial with associated grave goods found at the Zhelin site, **B** Canine burial found in an excavated pit, **C** Profile of stratigraphy at Zhelin: note the two separate shell layers (ZL-1, ZL-2) with what the archaeologists interpret to be an earthen platform (ZL-3) built on top

B). The burials appear to be located within a slightly elevated platform near the prehistoric coastline (Fig. 3C).

Zhelin experienced a subtropical monsoon climate, with an average annual temperature of around 17.9 °C and an average annual precipitation of > 1500 mm [18]. Existing archaeobotanical and archaeological data suggests that ancient humans living at the eastern area of Taihu had developed rice-based farming and animal husbandry since around the Majiabang cultural period (7000–6000 cal. BP) [19, 20]. Moreover, paleoenvironmental evidence shows that the marshification process of shallow wetlands may have contributed to the expansion of prehistoric rice-farming societies in the Taihu Basin during the Liangzhu cultural period (5300–4300 cal. BP) [21].

Recent physical anthropological research on human bones from Zhelin has revealed dental calculus and metatarsal-phalangeal joint osteoarthritis among some Zhelin residents [22]. In addition, we have found similarities between pottery excavated from burial contexts at Zhelin and similar contexts at Fuquanshan site (Fig. 1), a high ranking Liangzhu burial mound at modern Qingpu District, Shanghai (Fig. 4A, B). These common grave goods include the double-nosed *hu-jar* (Fig. 4C, D). Pending further archaeological evidence from Zhelin and Fuquanshan, archaeologists believe that Zhelin may have been a part of an extended sub-center of Liangzhu society that accommodated both sides [3]. In addition, unlike the north–south oriented burials found at Fanshan in Liangzhu City [23], the burials at the Zhelin site are all oriented east–west.

Fig. 4 **A** Map of the Fuquanshan site, **B** pottery double-nosed *hu*-flask found at Zhelin, Fuquanshan and Tashan, respectively

Materials and methods

Stable C, N isotope analysis

The procedure for stable C, N isotope analysis used in this study is the same as described in Jay and Richards [24]. Detailed information on archaeological contexts is listed in the online Table S1. We modified the protocol slightly to include a final stage of ultrafiltration prior to lyophilization, as described in Brown et al. [25]. Bone (~ 0.5 g) was cleaned by ultrasonic in water and then demineralized in a 0.5 M HCl solution at 4 °C for 1–2 weeks. In the process, we replaced the HCl solution every 48 h. The remains were rinsed with deionized water to neutrality, and reinsed in 0.125 mol/L cold sodium hydroxide for 20 h, and washed again with deionized water. The residues were rinsed in 0.001 mol/L HCl, then gelatinized at 70 °C in a pH = 3 solution for 2 days. The heated solution was filtered into tube and frozen, then freeze dried for 48 h.

The purified collagen was measured at the Environmental Stable Isotope Laboratory (ESIL), Institute of Environment and Sustainable Development of Agriculture, Chinese Academy of Agricultural Sciences, using an Isoprime 100 IRMS (Elementar, UK) coupled with an Elementar Vario (Elementar, UK), and calibrated with USGS 40 ($\delta^{13}C_{VPDB} = -26.39 \pm 0.04‰$, $\delta^{15}N_{air} = -4.52 \pm 0.06‰$) and USGS41a ($\delta^{13}C_{VPDB} = +36.55 \pm 0.08‰$, $\delta^{15}N_{air} = +47.55 \pm 0.15‰$) reference materials (https://www.usgs.gov/publications/two-new-organic-reference-materials-d13c-and-d15n-measurements-and-new-value-d13c-nbs). For every 12 samples, a laboratory reference-Gelatin from bovine skin ($\delta^{13}C_{VPDB} = -14.7 \pm 0.2‰$; $\delta^{15}N_{air} = +7.1 \pm 0.2‰$) was inserted for calibration and to monitor stability. The isotope results were analyzed as the ratio of the heavier isotope to the lighter isotope ($^{13}C/^{12}C$ or $^{15}N/^{14}N$) and expressed as 'δ' in parts per 1000 or per mil (‰) relative to internationally defined standards [26] for carbon (Vienna Pee Dee Belemnite, VPDB) and air nitrogen. The equation is, for example, $\delta^{13}C\ (‰) = [(^{13}C/^{12}C)_{sample}/(^{13}C/^{12}C)_{std}]/(^{13}C/^{12}C)_{std} \times 1000$. The measurement errors were less than ± 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$ values.

Additionally, a considerable number of $\delta^{13}C$ and $\delta^{15}N$ isotopic data from archaeological sites from the Lower Yangtze area around Shanghai before and during the Liangzhu period (5300–4300 cal. BP) (regional chronology of cultures and the development of rice agriculture shown in Fig. 5), were collected to assess differences in

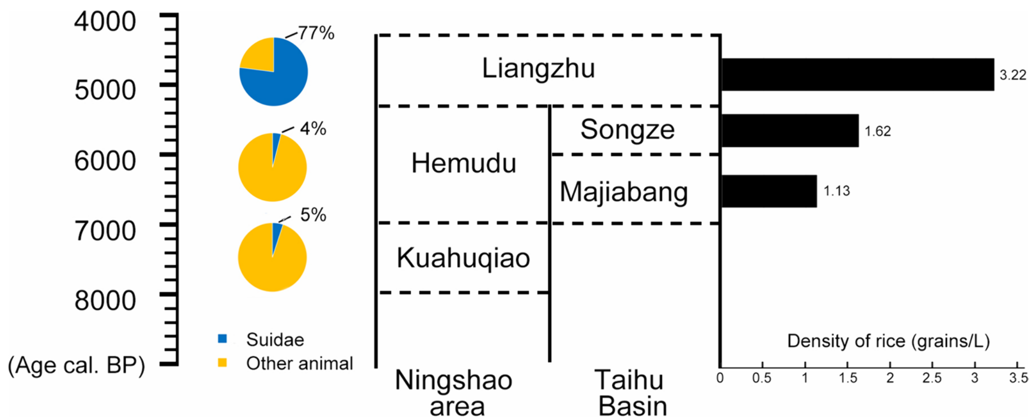

Fig. 5 Chronology of major cultures mentioned in this study and the pig NISP percentage from the sites around Liangzhu during 8000–4300 cal BP (raw data from [20, 27, 28]), as well as the density of rice seeds recovered from the sites at the eastern Taihu Basin (redrawn after [21])

dietary pattern between these peripheral populations and core communities living in the Lower Yangtze area (Fig. 1). We surveyed relevant publications reporting stable isotopic data of C and N in the Neolithic period and synthesized the data. Since some researchers only published scatter plots of stable carbon and nitrogen isotope values, we used software of GetData Graph Digitizer to capture the C, N isotopic values. The detailed information of these sites and data are listed in Table S2 and Table S3. Statistical data analysis was performed using the Student's *t*-test using the Microsoft Office Excel (2021 for Windows), with the significance level set at $P<0.05$, to test the statistical hypothesis.

Results

Isotopic evidence of dietary patterns

New isotope data for Zhelin's human and dog specimens ($n=10$) is listed in Table S1. Due to the humid environment and acidic soils in Shanghai area, only two human specimens and one dog specimen produced collagen of suitable quality, with C:N ratios ranging between 2.9 to 3.6 for further analysis [29, 30]. Our δ^{13}C values for the human and dog samples ($n=3$) from Zhelin are −19.2‰, −19.4‰ and −19.6‰ (mean ± SD: −19.4 ± 0.2‰), respectively, indicative of similar diets significantly influenced by C_3-based foods. The δ^{15}N values of these three specimens were +9.1‰, +11.3‰ and +8.6‰ (mean ± SD: +9.7 ± 1.2‰), respectively, suggesting they consumed foods at different trophic levels. All new and existing stable C, N isotope data analyzed in the present study are listed in Table S2 and Table S3.

Previous studies have suggested that human δ^{15}N values are about 3–5‰ heavier than the food they consume [31]. As can be seen Fig. 6 and detailed in Table S3, carbon and nitrogen isotope values of charred plant samples ($n=3$) including the rice grains and acorns from the Tianluoshan site (7000–5300 cal. BP), located on the south bank of Hangzhou Bay, range from −28.4 to −25.4‰ (mean ± SD: −27.1 ± 1.6‰) and +4.1‰ to +7.4‰ (mean ± SD: +5.3 ± 1.9‰), which are the lowest C and N isotopic values [32], establishing an isotope baseline for primary producers in surrounding area. On the contrary, the highest δ^{13}C (mean ± SD: −13.4 ± 1.1‰) and δ^{15}N values (mean ± SD: +13.0 ± 1.6‰) derived tuna and whale bones (marine fish/mammal) from the Tianluoshan site [33, 34], revealing the highest enriched ^{13}C and ^{15}N isotopic signals for marine animals in this coastal area.

Additionally, the largest amount of previously published isotopic data derived from terrestrial herbivores ($n=194$) including several kinds of deer and bovid (including water buffalo) from the sites (Fig. 6) of Kuahuqiao (8000–7000 cal. BP), Tianluoshan and Meirendi (5300–4300 cal. BP), which ranges from −24.8 to −10.7‰ (mean ± SD: −17.8 ± 3.9‰) and +3.3‰ to +11.8‰ (mean ± SD: +7.4 ± 2.1‰), suggesting that these likely enjoyed a broad spectrum of diets derive from ^{13}C-enriched plant foods [33–38]. The second most abundant animal isotopic results belonged to terrestrial omnivores ($n=139$) dominated by pig and dog samples from Kuahuqiao, Jiangjiashan (7000–6000 cal. BP), Tianluoshan, Meirendi and our study site of Zhelin. The mean δ^{13}C and δ^{15}N values of these animals are −20.6 ± 1.2‰ and +6.4 ± 1.5‰, indicating that omnivore diet in the studied area was largely influenced by low-protein C_3 terrestrial grasses and shrubs [33–38]. The δ^{13}C and δ^{15}N values of freshwater animals including freshwater fish, frog, alligator, and turtle from Kuahuqiao, Tianluoshan and Meirendi ranged from −23.5 to −18.8‰ (mean ± SD: −20.9 ± 1.4‰) and +5.6‰ to +12.3‰ (mean ± SD: +8.0 ± 1.7‰), the highest level for protein C_3 foods inland [33–36].

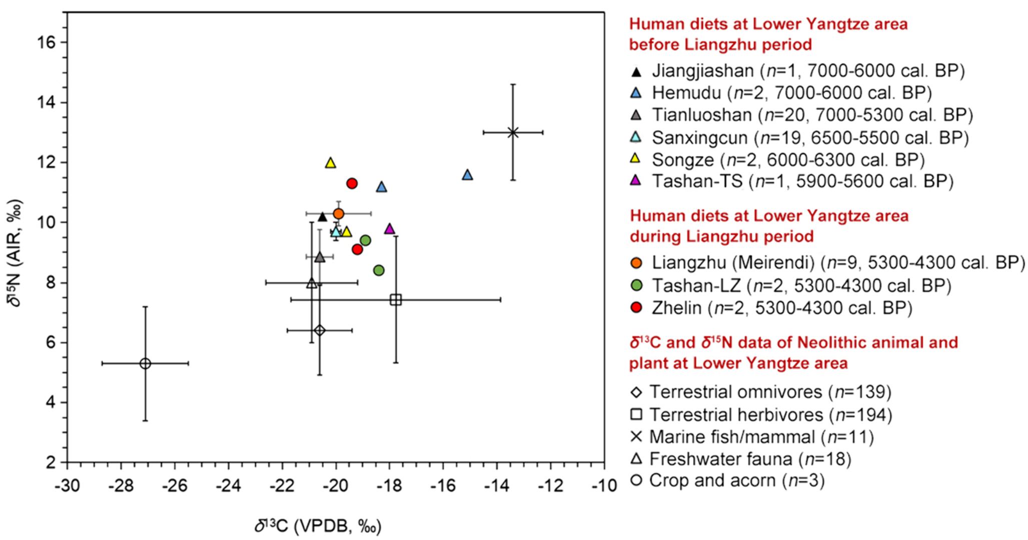

Fig. 6 $\delta^{13}C$ and $\delta^{15}N$ data of human, animal and plant samples recovered from archaeological sites at the Lower Yangtze area before and during the Liangzhu period (detailed information of these sites and isotopic data detailed in Table S2 and S3)

As for the isotopic data of human beings, plotted in Fig. 6, in the coastal area around Shanghai, the Songze human bone samples ($n=2$) during Songze culture period (6000–5300 cal. BP) exhibited $\delta^{13}C$ values of −20.2‰ and −19.6‰ (mean ± SD: −19.9 ± 0.3‰) and $\delta^{15}N$ values of +9.7‰ and +12.0‰ (+10.9 ± 1.2‰) during 6000–5300 cal. BP [39]. This reveals that individuals largely relied on C_3-based diets with varying trophic levels. In another small coastal settlement in the Ningshao area (Fig. 1), Tashan site, the mean carbon and nitrogen isotope values of humans during Liangzhu period ($n=2$) are −18.7 ± 0.3‰ and +8.9 ± 0.5‰ during 5300–4300 cal. BP [40]. Dating before that time, one individual from the Tashan site during 5900–5600 cal. BP before Liangzhu culture period yielded ^{13}C and ^{15}N-enriched results ($\delta^{13}C=-18.0$‰ and $\delta^{15}N=+9.8$‰). Similarly, in the same area of Ningshao, the mean carbon and nitrogen isotope values of the Hemudu sample ($n=2$) during 7000–6000 cal. BP were −16.7 ± 1.6‰ and +11.4 ± 0.2‰, respectively [39]. However, the $\delta^{13}C$ and $\delta^{15}N$ values of human bone samples ($n=20$) from another Hemudu culture site of Tianluoshan ranged from −21.9 to −20.1‰ (mean ± SD: −20.6 ± 0.5‰) and +7.2‰ to +10.7‰ (mean ± SD: +8.9 ± 0.9‰) during 7000–5300 cal. BP [33, 37].

As for the isotopic evidence for diets in these inland sites at Lower Yangtze area prior to and during the Liangzhu period (5300–4300 cal. BP), carbon and nitrogen isotope values of Jiangjiashan people ($n=1$) living on the southwestern bank of Taihu during 7000–6000 cal. BP (Fig. 1), were −20.5‰ and +10.2‰, respectively (Fig. 6). According to Hu et al. [41], the carbon and nitrogen isotope values of Sanxingcun peoples ($n=19$) ranges from −20.4 to −19.6‰ (mean ± SD: −20.0 ± 0.2‰) and +8.9‰ to +10.3‰ (mean ± SD: +9.7 ± 0.3‰), indicative of a diet ate by these individuals largely influenced by C_3 foods. Given that the Sanxingcun site is located in the north of Taihu at the Lower Yangtze area, where rice agriculture had been practiced since early-mid Holocene period [4, 42], combined with the isotopic evidence of Sanxingcun people's trophic level, it is safe to believe that the humans of Sanxingcun mainly fed on rice and terrestrial omnivores as well as a small number of terrestrial herbivores during the 6500–5500 cal. BP. In addition, during the Liangzhu period (5300–4300 cal. BP), Liangzhu resident ($n=9$) $\delta^{13}C$ and $\delta^{15}N$ values recovered from the Liangzhu City area (Meirendi site) ranged from −22.2 to −17.4‰ (mean ± SD: −19.9 ± 1.2‰) and +9.7‰ to +11.0‰ (mean ± SD: +10.3 ± 0.4‰), which is indicative of a C_3-based diet with relatively high trophic levels.

Discussion

Just as at Liangzhu [1], archaeological work around the world often prioritizes the great sites. However, to better understand the past and the role that these large sites had to play in shaping neighboring settlements, archaeologists should obviously also pay attention to these smaller sites. We argue that the recent studies at core inland Liangzhu sites can only be comprehensively understood within a broader regional context and with regard to peripheral coastal sites at Lower Yangtze area. Previous work by Dong and Yuan has suggested that existing zooarchaeological findings at the Liangzhu cultural area reveal different animal husbandry practices between the urban center of Mojiaoshan and small sized sites during Liangzhu period (5300–4300 cal. BP) [20]. In the present study, we provide new isotopic data from Zhelin in an attempt to fill the gap in the study of dietary practices of Liangzhu cultural human societies at Shanghai area, as a geographic periphery of the Liangzhu core. More importantly, by integrating new and existing C, N isotopic data of humans ($n=58$), animals ($n=362$) and plants ($n=3$) recovered from sites around the Lower Yangtze area during 8000–4300 cal. BP, we provided a broad picture of the dynamic changes of diets and economic decisions of these coastal communities living at Shanghai and Ningshao areas before and during the Liangzhu phenomenon.

Archaeological evidence suggests that rice agricultural production in the Lower Yangtze area developed over thousands of years until before becoming more stabilized during the middle Songze culture through Liangzhu periods (5600–4300 cal. BP) [43]. Specifically, as illustrated in Fig. 5, it shows that the number of charred rice seeds found in 1 L of flotation soil samples from the study area (the density of rice grains) remarkably increased from 1.13 and 1.62 during the Majiabang and Songze periods to 3.22 during the Liangzhu period. Research has suggested that, prior to the Liangzhu period, ancient humans may have consumed more wild animals (see Fig. 5) and nuts for survival [44]. In Fig. 6, in the coastal area of Ningshao before Liangzhu time, stable carbon and nitrogen isotope evidence from the Hemudu site and Tianluoshan site also suggests that diversified human subsistence, like exploitation of wild plants and hunting games, sustained a continuous parallel development with low-level rice farming for millennia. In another coastal area of Shanghai, δ^{15}N results for human bones recovered from the Songze site, 6000–5300 cal. BP, yield a visible increase in δ^{15}N values compared to the inland residents of Jiangjiashan (7000–6000 cal. BP) and Sanxingcun (6500–5500 cal. BP). ^{15}N enrichment levels in Songze people (6000–5300 cal. BP), who lived in the coastal area of Shanghai during the same period, may be related to a higher intake of freshwater foods. One important finding is that although different groups of Neolithic populations in Lower Yangtze region from 7000–5300 cal. BP have similar C_3-based diets which were probably attributed to low-level rice farming and foraging of wild food resources at large, according to varies of stable nitrogen values and zooarchaeological evidence from the study area (see Fig. 5) [20], there are significant differences in foodways between the populations who lived in the inland area (Sanxingcun, Jiangjiashan) and other coastal (Hemudu, Tianluoshan, Songze, Tashan) settlements (Figs. 1, 6). This also shows that the food-related differentiation had appeared in inland and coastal societies at the Lower Yangtze River area during 7000–5300 cal. BP.

According to previous archaeobotanical studies and archaeological finding of complex water management systems at ancient Liangzhu City [2], during the Liangzhu period rice agriculture rapidly developed and rice foods eventually became a staple food incorporated into diets across the Lower Yangtze area [4, 10]. At this time, more sophisticated water management and farming techniques allowed the majority of individuals in the core of the Liangzhu area had a relatively balanced diet including a large number of domesticated rice, and meat from domesticates like pigs and some wild freshwater fauna as well (see Fig. 5) [20]. We had compared the δ^{13}C and δ^{15}N values of human samples from the sites of Sanxingcun and Liangzhu City (Meirendi site). Our analysis reveals that both inland communities shared a similar C_3-based dietary pattern, while the core Liangzhu culture humans from the Meirendi site had relatively high trophic levels than Sanxingcun peoples based on N isotopic evidence (student's t-test, $P<0.05$).

As for the foodways of human beings living at the peripheral coastal areas during Liangzhu period (5300–4300 cal. BP), previous work by Zhang et al. [40], for example, has reported that Tashan people, occupying a small East China Sea coastal settlement in the period 5300–4300 cal. BP (Fig. 1), likely exploited more foods from rice and terrestrial animals but less marine food resources than the residents of the same site for the period 5900–5600 cal. BP (see Fig. 6). Also, it can be seen that the Hemudu residents living in the Ningshao area during 7000–6000 cal. BP (Fig. 1) had higher stable nitrogen isotopic values than Tashan peoples during 5300–4300 cal. BP (student's t-test, $P<0.05$). Considering that large-scale rice paddies have been found at the Shiao site (30.030998° N, 121.389251° E) in Ningshao area dating to the Hemudu and Liangzhu cultural periods [45], we believe that the changes of diets and consumption habits of these peripheral populations at Tashan during the Liangzhu period were likely influenced by the expansion of massive rice cultivation in the Lower Yangtze area from the Hemudu culture to Liangzhu culture periods (7000–4300 cal. BP). Nevertheless, we have also found that the δ^{15}N values of humans of Tashan lower than those of the Liangzhu City during the same period (student's t-test, $P<0.05$) (Fig. 6). This suggests that despite communication with the core Liangzhu culture, the Tashan societies likely reorganized their own sense of cultural identity along dietary lines and made specialized economic decisions to participate in a new social network, influenced by inland Liangzhu culture.

Moreover, as can be seen in Fig. 6, our new isotopic data suggests that the dietary lifestyle of the Zhelin people, living on a small Liangzhu site in the coastal area of the Lower Yangtze (Fig. 1), was more similar to that of people from the core area of the Liangzhu culture compared to human beings from the Tashan site at Ningshao area during the Liangzhu period. Specifically, from Fig. 6, the δ^{13}C (student's t-test, $P>0.05$) and the δ^{15}N (student's t-test, $P>0.05$) values of humans at the Zhelin site and the inland Liangzhu core (Meirendi site) express no clear differentiation. Mean δ^{15}N values at Zhelin are, however, higher than those of the Tashan individuals during the same period (Fig. 6). The diet of Zhelin remains largely consistent to previous dietary pattern of humans at the Songze site during 6000–5200 cal. BP (δ^{13}C: student's t-test, $P>0.05$ δ^{15}N: student's t-test, $P>0.05$). However, the mean δ^{15}N value of Zhelin humans decreased compared to inhabitants of Songze in nearby region prior to Liangzhu period, perhaps suggesting a decrease in the consumption of high-protein foods, as subsistence economies became more agrarian during the Liangzhu period (5300–4300 cal. BP). In these cases, we argue that the economic decisions of the Zhelin people may be more dominated by Liangzhu core concerns, expressing a recognition of inland dietary lifestyle of the core area of Liangzhu culture.

Previous studies have suggested that intensive rice agriculture has underpinned increased human populations and massive social evolution at the Lower Yangtze area during the Liangzhu period (5300–4300 cal. BP) through a rapid expansion of wetland under rice cultivation and a greater reliance on domesticated foods like rice crops and pigs (see Fig. 5) [3, 4, 20, 21, 46, 47]. As such, we believe that the diets and consumption habits of these peripheral Liangzhu populations at Zhelin and Tashan, perhaps influenced, to some extent, by their desired food choices under the rapid development of early urbanized and intensive agricultural lifestyle originating in the inland core Liangzhu area. The differentiation in dietary practices between the populations from the coastal Zhelin and Tashan sites, further suggests that the two societies living at the periphery of the Liangzhu cultural sphere may have taken on different roles to integrated into a new social network of Liangzhu culture. In the long run, this transition to a more standardized man-made agricultural economic choice may have inadvertently locked Liangzhu society into a system that depended on a limited range of "taxable" domesticated species [48], which may have been significantly affected by rapid climate changes around 4200 cal. BP.

Conclusion

By integrating new C, N isotopes from Zhelin, Shanghai, with previous isotopic studies done in the Taihu Basin and Ningshao area during 8000–4300 cal. BP, we used the isotopic evidence to gain a better understanding of the dietary and culinary changes at the Lower Yangtze area prior to and during the Liangzhu cultural period (5300–4300 cal. BP). Our findings suggest that the dietary differences between the coastal periphery and more inland core cultural area of Lower Yangtze area likely existed through the Liangzhu period. Moreover, our study shows that the Liangzhu dependence on limited domesticated victuals became much more widespread around Lower Yangtze area, and more socially integrated economic decisions (based on rice agriculture) appeared along with the development of Liangzhu cultural phenomenon in this coastal region. This study provides essential data for understanding the development of the Liangzhu cultural phenomenon at Lower Yangtze area in a more comprehensive manner. However, more stable C, N isotopic research is necessary for more robust comparisons between the developmental trajectory of foodways across different societies in the coastal reaches of Neolithic southeastern China.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40494-024-01374-3.

Supplementary Material 1.

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Author contributions

Conceptualization: P.S., E.A., M.S.; methodology: P.S., M.S.; Investigation: P.S., X.Z., X.H., M.S.; Funding Acquisition: P.S.; Project Administration: P.S.; Writing—original draft: P.S., E.A., M.S.; Writing—review & editing: P.S., E.A., M.S. All authors contributed to the article and approved the submitted version.

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Data Availability

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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