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ORIGINAL PAPER

The first discovery of Neolithic rice remains in eastern Taiwan: phytolith evidence from the Chaolaiqiao site

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Abstract Located in the key junction between mainland China and Island Southeast Asia, Taiwan is of great significance for our understanding of the southeastward dispersal of rice agriculture in the prehistoric period. Until now, quite limited archaeobotanical work has been done in this region. In eastern Taiwan, no archaeological evidence of rice agriculture has been obtained, probably owing to the poor preservation conditions for plant macroremains. Here, we report a new discovery of 4200-year-old domesticated rice remains at the Chaolaiqiao site, which for the first time in detail demonstrates the ancient practice of rice agriculture in this area. Based on a combination of factors that include a rice-based plant subsistence strategy, the mid-Holocene limits to available farmland and the fast-growing Taiwan Neolithic population from settlement pattern data, we infer that this contradiction in eastern Taiwan between land-dependent agriculture and limited suitable farmland encouraged a population movement out of Taiwan during the Middle Neolithic period.

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Introduction

As one of the most important staple foods in the world, rice has played a significant role in the development of the ancient societies of monsoon Asia. With the accumulation of sites bearing archaeobotanical data in South, Southeast, and East Asia, great progress has been made just within the last decade on the origin and dispersal of rice farming (Fuller et al. 2009; Fuller 2011; Silva et al. 2015; Stevens et al. 2016). Nevertheless, limited evidence has been obtained on the southeastward spread of rice into the island regions of Taiwan, the Philippines, and Indonesia, where rice is the major daily food today. It is generally accepted that rice spread from mainland southern China into Taiwan and then into other islands (Bellwood 2005; Zhang and Hung 2010; Fuller 2011). However, chronologies suffer from a scarcity of hard evidence. Taiwan, located in the pivotal junction of rice spreading from mainland China into the island areas, is of crucial significance for our understanding of this agricultural dispersal process.

So far, more than ten sites in Taiwan have been stated to contain ancient rice remains (Fig. 1), yet most lack systematic analysis and direct dating. Even for the earliest rice grains from Nanguanli and Nanguanlidong, which are claimed to be 4800 years old, no detailed data have been published and no direct dating has been acquired on the actual crop remains (Tsang 2005; Tsang et al. 2006; Hsieh et al. 2011). So far, except for the Chikan and Suogang sites in the Penghu Islands (Tsang 1992), all reported sites with ancient rice in Taiwan are located close to the western coast. No ancient rice grains have yet been reported in eastern Taiwan owing to poor

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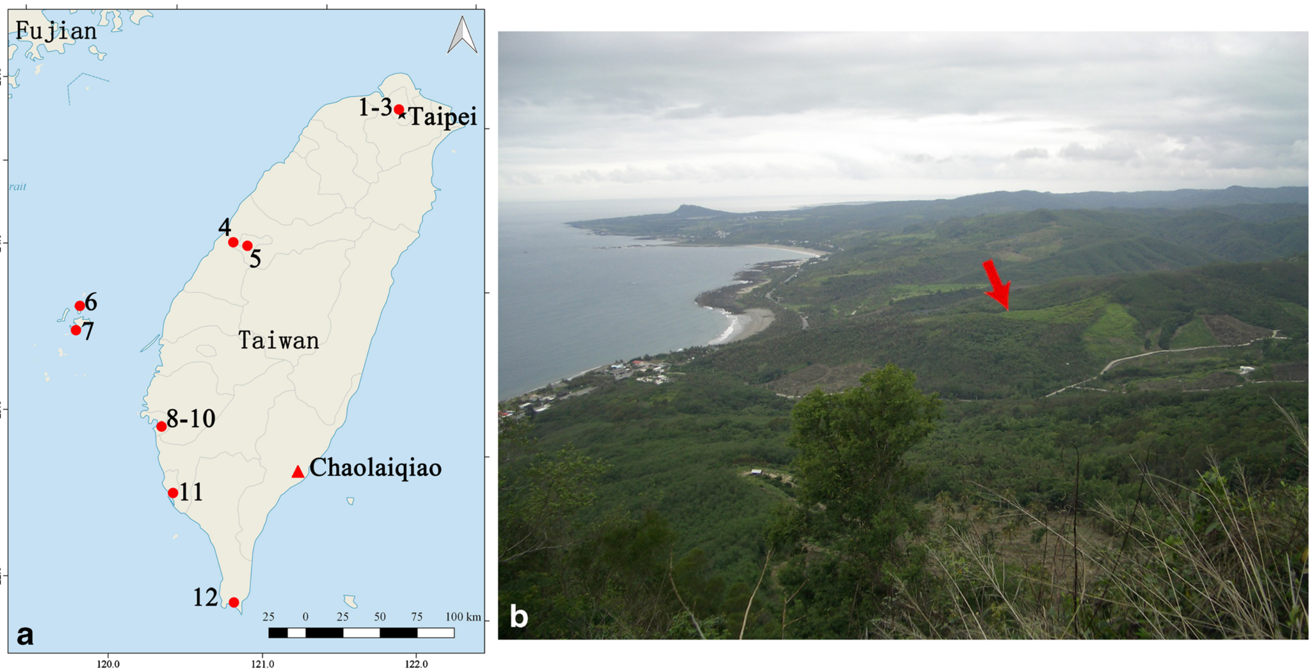


Fig. 1 **a** Location of Chaolaiqiao and other sites with rice remains in Taiwan: *1–3* Zhishanyan, Yuanshan, and Dalongdong; *4* Yingpu; *5* Anhelu; *6* Chikan; *7* Suogang; *8–10*. Nanguanli, Nanguanlidong, and Youxianfang; *11* Fengbitou; *12* Kending (base map converted by QGIS 2.14.3 http://www.qgis.org/ from free vector and raster map data at naturalearthdata.com). **b** The modern environs of Chaolaiqiao (*red arrow* indicates the 2005 excavation, on a raised coral reef terrace 50 m above sea level)

preservation, but phytolith analysis is a potential method to resolve this problem as phytoliths can be preserved in a wide range of environmental conditions. Accordingly, they have been increasingly extracted and identified for global investigation of agricultural origins and dispersals (Ball et al. 2015).

The present work offers the first systematic study of rice phytoliths in eastern Taiwan, at the Middle Neolithic site of Chaolaiqiao (Fig. 1). This site was occupied ca. 4200 years BP, at a time when Neolithic cultures of Taiwan origin first made an appearance in the northern Philippines (Hung 2005, 2008).

Material and methods

Chaolaiqiao (22° 50′ 50″ N, 121° 11′ 10.75″ E) is situated on an uplifted coastal terrace in eastern Taiwan, approximately 50 m above current sea level, between two creeks that drain the foothills of the Coastal Mountain Range (Fig. 1). The site was discovered in 2000 (Liu et al. 2000), and a 2 × 1.5 m^2 excavation was conducted in 2005 (Hung 2008). Chaolaiqiao has four stratigraphic layers (Fig. 2), of which layers I and II are recent non-archaeological colluvium and IV is natural underlying alluvium. Only layer III contains archaeological material, with large quantities of potsherds and stone artifacts. Two accelerator mass spectrometry (AMS) radiocarbon dates on charcoal from layer III confirm site occupation at 4200–4000 BP (Table 1).

Seven soil samples (see Fig. 2) were extracted at 10-cm intervals from basal layer III to the top of layer I in the profile of Chaolaiqiao Pit 1. For each sample, three sub-samples (about 1.5 g each) were processed to extract phytoliths according to previous studies (Piperno 1988; Pearsall 2000; Lu et al. 2006) but with a slight modification. The procedures consisted of sample treatment with 30% hydrogen peroxide (H_2O_2) and cold 15% hydrochloric acid (HCl), separation of phytoliths with zinc bromide ($ZnBr_2$, density 2.35 g/cm^3) heavy liquid, and mounting on a slide with Canada Balsam. Phytolith identification and counting were performed using a Leica microscope with phase contrast at 400× magnification.

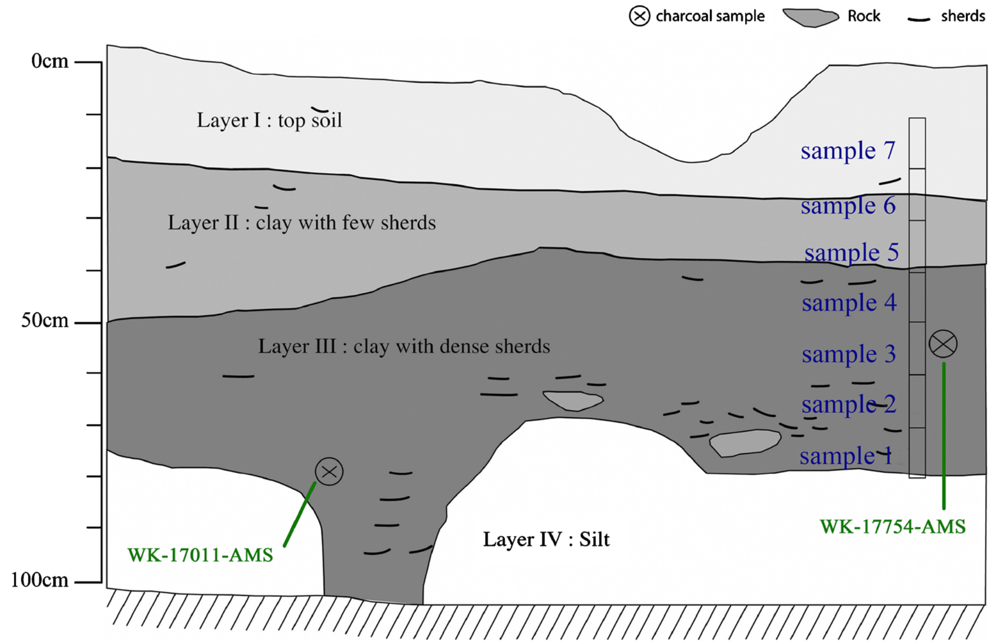
For each sample, at least 500 phytoliths were identified and recorded. For the purpose of distinguishing domesticated and wild rice, the number of scale-like ornamentations of all well-preserved rice bulliform phytoliths in every slide were counted and recorded using a Leica microscope with phase contrast at 630× magnification, according to an established criterion (Lu et al. 2002; Huan et al. 2015). Heavily eroded or non-planar phytoliths were excluded from the analysis (Fig. 3).

Results

Phytoliths from the Chaolaiqiao site

All samples from Chaolaiqiao produced sufficient phytoliths for identification, although some phytoliths were slightly

Fig. 2 The stratigraphy of Pit 1 at Chaolaiqiao with the locations of phytolith samples 1 to 7 and charcoal samples for radiocarbon dating



eroded. Each sample yielded a similar range of phytolith types (Figs. 4 and 5) in that trapeziform and bulliform shapes were the most common, constituting over 52 and 20%, respectively, of every sample. Considerable numbers of elongate smooth, elongate echinate, and acicular hair cell forms were found. Bilobate, saddle, and rondel shapes appeared occasionally in most samples. Sponge spicules were found in the four samples from layer III (40–80 cm), indicating a wet environment during the occupation of the site.

Although a small proportion of phytoliths like reed-type bulliform (Fig. 4l) and rondel (Fig. 4m) types indicate the presence of reed and Pooideae plants, most phytoliths are not identifiable into genera or family. Rice is the only identifiable crop plant recognizable in the Chaolaiqiao samples, through double-peaked glume cells and scooped bilobate phytoliths as well as a large number of rice bulliform phytoliths. Notably, the percentages of rice bulliform phytoliths compared to the total number of phytoliths in samples 2, 3, and 4 from layer III is over 2.2%, much higher than from the other samples (Fig. 5), indicating an *in situ* preservation of Neolithic rice remains. Given the numbers of rice bulliform phytoliths found at Chaolaiqiao, well-preserved specimens were sufficient in quantity to be further studied to distinguish whether they were domesticated or wild.

Analysis of the rice bulliform phytoliths

Bulliform phytoliths form a very common type in the genus *Oryza* and are characterized by the distinctive scale-like ornamentations around the convex ends of their profiles, a characteristic rarely found in other similar grasses (Fujiwara 1976; Fujiwara and Sasaki 1978; Wang and Lu 1993). A comparison of the number of these ornamentations on the bulliform phytoliths of seven wild and six domesticated rice species has shown that those of wild rice usually have fewer than nine, indicating that this statistic can be used to distinguish between the bulliform phytoliths of wild and domesticated rice (Lu et al. 2002).

A new comparative phytolith analysis of 59 soil samples collected from fields of both wild and domesticated paddy rice in south China has revealed that bulliform phytoliths with at least nine scale-like ornamentations form only 17.86 ± 8.29% of the bulliform phytoliths in the wild rice soil samples, compared to 63.7 ± 9.22% in the domesticated samples (Huan et al. 2015). This criterion has been applied to several Neolithic sites with evidence for early rice cultivation in the Lower Yangtze region, with results corresponding to those on the course of rice domestication derived from macroremains (Luo et al. 2016; Ma et al. 2016).

Table 1 AMS radiocarbon dates from Chaolaiqiao (calibrated using OxCal v4.2.4; locations of samples are shown in Fig. 2)

Laboratory code	Material dated	Conventional radiocarbon age (years BP)	Calibrated date (years BP)	
			1σ (68.2%)	2σ (95.4%)
WK-17011-AMS	Charcoal	3736 ± 43	4151–3992	4236–3974
WK-17754-AMS	Charcoal	3704 ± 32	4088–3985	4149–3931

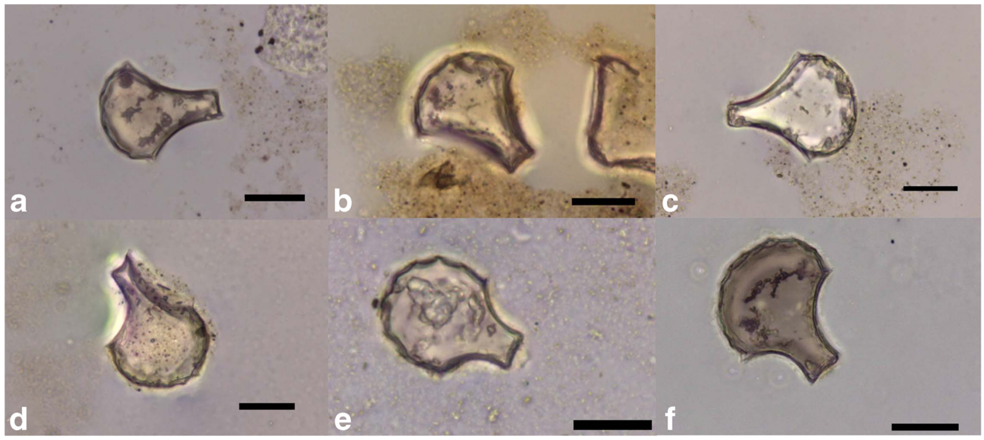


Fig. 3 Different types of rice bulliform phytoliths from Chaolaiqiao. **a**, **b** Rice bulliform phytoliths with fewer than nine scale-like ornamentations (counted). **c**, **d** Eroded rice bulliform phytoliths (excluded). **e**, **f** Rice bulliform phytoliths with nine or more scale-like ornamentations (counted). All *scale bars* are 20 μm

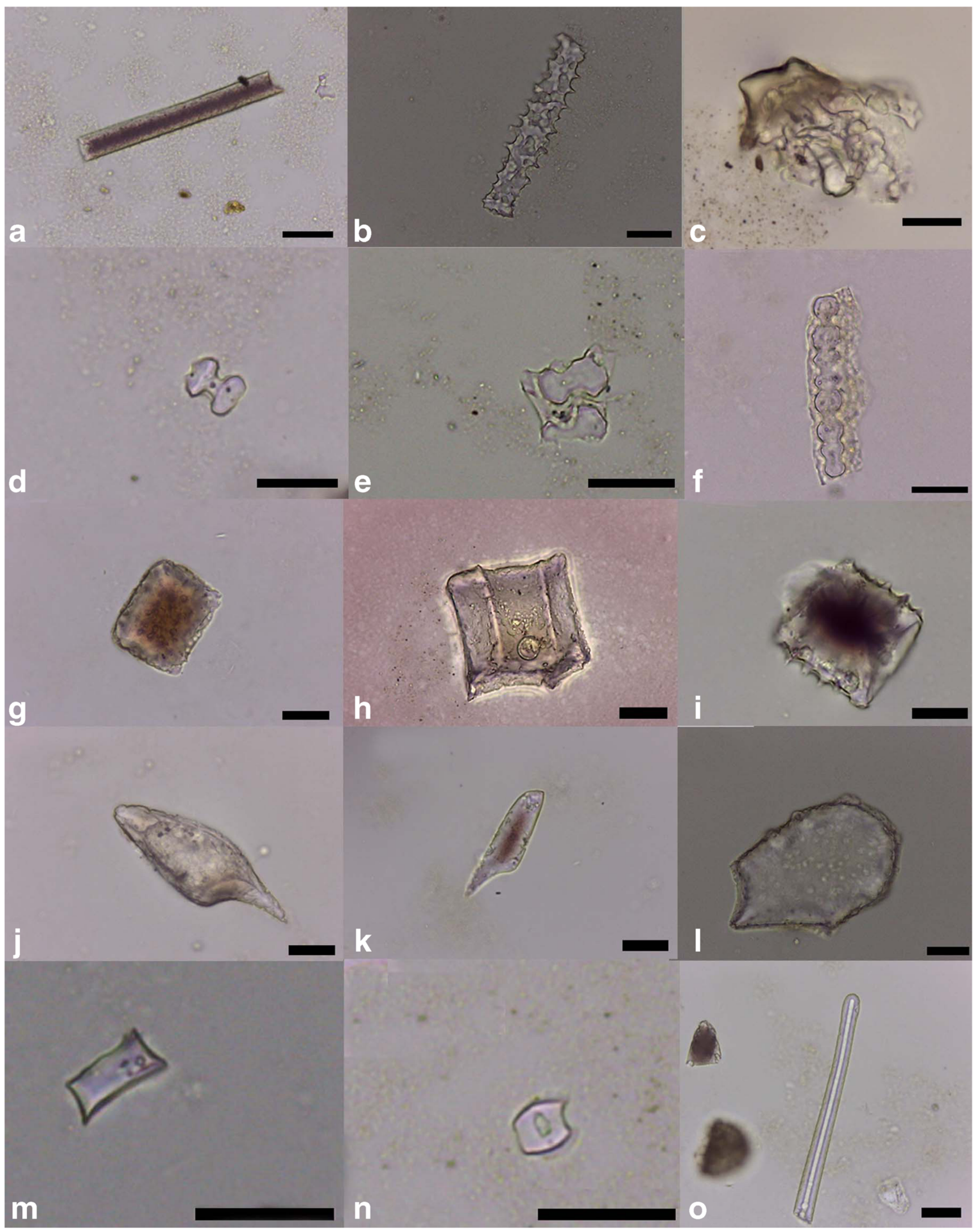


Fig. 4 Phytoliths found at Chaolaiqiao. **a** Elongate smooth. **b** Elongate echinate. **c** *Oryza* double-peaked glume cell. **d** Bilobate. **e** Scooped bilobate. **f** Cylindrical polylobate. **g**–**i** Trapeziform. **j**, **k** Acicular hair cells. **l** Reed bulliform. **m** Rondel. **n** Saddle. **o** Sponge spicule. All *scale bars* are 20 μm

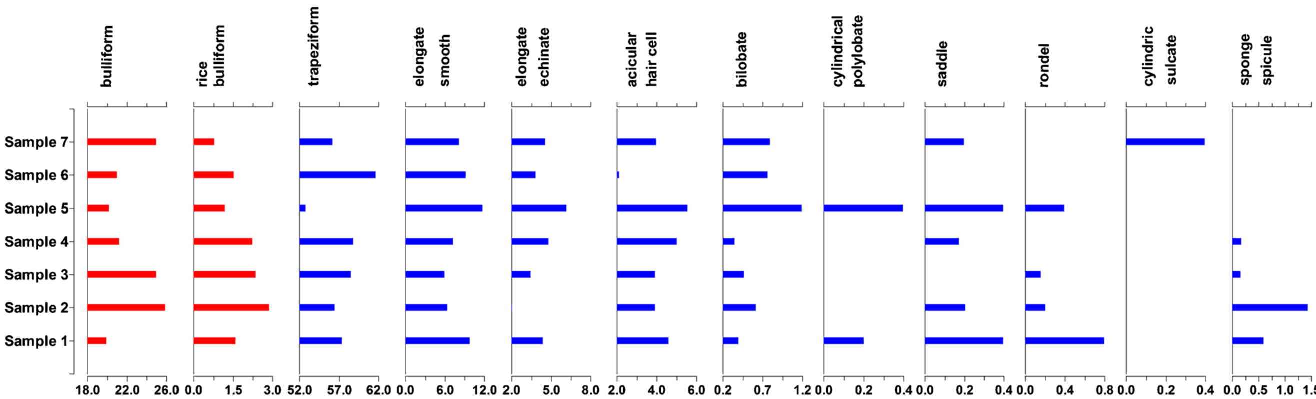


Fig. 5 The proportions of different types of phytolith in the seven Chaolaiqiao samples

In total, the Chaolaiqiao samples included 127 well-preserved rice bulliform phytoliths, with 71.7% coming from samples 2 and 3 in archaeological layer III. In all four samples from layer III, 67.2% of the 119 well-preserved rice bulliform phytoliths had at least nine scale-like ornamentations, with the separate proportions for samples 2 and 3 being 60.4 and 69.8%, respectively (Fig. 6). Therefore, it can be speculated that the rice consumed during the deposition of archaeological layer III at Chaolaiqiao was domesticated.

Moreover, both the number of rice bulliform phytoliths and the proportions that are well preserved are much higher in layer III than in the upper non-cultural layers I and II (Fig. 4). This suggests a close relationship between the rice remains and the human activity around 4200 BP.

Discussion

Rice farming and subsistence strategies in the Middle Neolithic Taiwan

Taiwan contains the earliest evidence for rice cultivation off the East Asian mainland, dated to a time of diversification and expansion amongst the Neolithic populations of the island. After 4500 BP, Taiwan's archaeological assemblages became increasingly differentiated from the more homogenous Dabenkeng (TPK) assemblages that preceded them. These post-4500 BP cultures comprised Xuntangpu in the northwest, Niumatou in the central west, Niuchouzi in the southwest, and Fushan in the southeast (Hung 2008). These regional cultures,

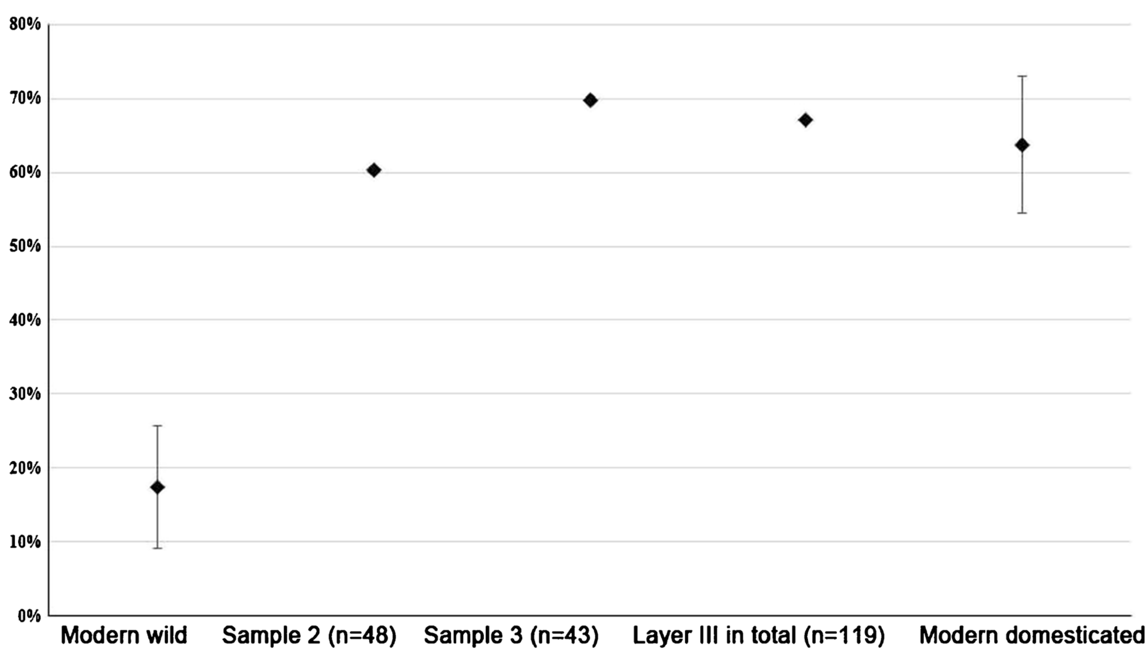


Fig. 6 Proportions of rice bulliform phytoliths with at least nine convex edge scale-like ornamentations

especially those in the north and west of the island, were associated with rapidly growing populations in terms of site sizes and numbers, presumably reflecting a reliable food supply. A few sites show clear macroscopic plant evidence for cultivation of both rice and millets (likely both broomcorn and foxtail, according to the millet photographs shown by Hsieh et al. 2011), possibly from ca. 4800 BP onwards (Tsang 2005; Tsang et al. 2006; Hsieh et al. 2011).

Botanical evidence relevant for this time period has until now been very elusive in eastern Taiwan. The eastern coast sites, such as Chaolaiqiao and others, have yielded pottery and other artifacts of the Fushan assemblage, linked most strongly with the spread of pottery making moving into Island Southeast Asia by 4000 years BP. Therefore, the discovery of 4200-year-old domesticated rice remains from Chaolaiqiao, for the first time, provides solid confirmation of ancient rice agriculture in this area. Unlike sites on the west coast of Taiwan, however, we have so far no evidence for the cultivation of foxtail or common millet at Chaolaiqiao. This might reflect differential conditions for phytolith preservation, or it could suggest that the eastern Taiwan populations had a different farming strategy from their contemporaries in the west. To resolve this question, more archaeobotanical research will be needed.

Besides rice agriculture, hunting of wild pig and deer was still an indispensable component of subsistence according to information excavated from the Fushan site in eastern Taiwan (Li and Ye 1995). Evidence for marine resource exploitation is so far limited but should be expected given the former locations of these sites near the seashore and also the importance of shark, mullet, and parrotfish in the diet at the contemporary Eluanbi II site on the south tip of Taiwan (Li 1997).

Possible motivations for the Middle Neolithic people to migrate beyond Taiwan

With the development of rice agriculture and an associated sedentary lifestyle, communities expanded rapidly in population size after 4500 BP in eastern Taiwan. A total of 43 sites were dated between 4500 and 3500 BP, almost seven times the number attributed to the preceding millennium (Hung 2005; Carson and Hung 2014). Additionally, the sites dated 4500–3500 BP were much larger than their predecessors, suggesting a possible 20 to 30 times increase in population size.

At the time of this population increase, geomorphological observations suggest that the coastal plain of eastern Taiwan was much narrower than at present (Carson and Hung 2014), partly due to rapid tectonic uplift (Wang and Burnett 1990; Liew et al. 1993). Sites of this period were originally located within low hilly formations close to sea level, but since then they have been uplifted to elevations of 40–50 m and stranded some kilometers inland from today's coastline. The tectonic history is indicated by dated coral limestone at measured elevations, such as immediately beneath the cultural layer at the Fushan site (Hung 2008). The modern alluvial plain in eastern Taiwan is devoid of sites predating 3500 BP, and geologically, this landform was not available for extensive farmland during the time when people lived at Chaolaiqiao, Fushan, and other sites at 4500–4000 years BP.

It can be inferred that flat alluvial and coastal terrain suitable for growing wetland rice was very limited around 4500–4000 BP, and instead, people at that time must have farmed in low formations and adjacent naturally wet zones at the base of those hillslopes. Therefore, there was a potential contradiction between limited land area and a land-dependent subsistence strategy that perhaps reached a crisis swiftly after 4500 BP, such that some people might have been forced to leave their homeland and search for new habitation areas.

Further congruent with the hypothesis that limited croplands stimulated migration from eastern Taiwan into the northern Philippines at around 4000 BP, cross-regional parallels in the artifacts illustrate the same cultural context and association, consistent with a population expansion from eastern Taiwan into northern Luzon at precisely this time. In Island Southeast Asia, the oldest pottery-bearing horizon may be linked with the artifact assemblages as seen at Chaolaiqiao and other sites of eastern Taiwan, found in northern Luzon of the Philippines, about 4000 BP and post-dating the region's archaeological layers of hunter-gatherer campsites lacking pottery (Bellwood et al. 2011; Hung 2005, 2008). The diagnostic red-slipped pottery, along with spindle whorls, Taiwan nephrite ornaments, and stone adzes first appeared in eastern Taiwan around 4200 BP and then in the Batanes Islands (Bellwood and Dizon 2013) and the Cagayan Valley of northern Luzon soon afterwards (Hung 2005, 2008). Hence, the discovery of rice remains around 4200 BP in eastern Taiwan is crucial for understanding the economic foundation for the Neolithic settlement of these first Neolithic people moving into northern Luzon.

There is still insufficient archaeobotanical evidence predating 3500 BP from northern Luzon, but younger sites indicate similar subsistence and land use strategies as in the Middle Neolithic eastern Taiwan. For instance, a rice spikelet found in a sherd from Andarayan suggests local production of rice around 3500 BP (Snow et al. 1986). Our new discovery of charred rice grains and one spikelet base from Magapit provides more conclusive evidence of local production of rice in the Cagayan Valley, directly dated by AMS radiocarbon to ca.3000 BP (Deng et al., unpublished data). As in Taiwan, Cagayan sites such as Nagsabaran also relied on deer and pigs for the meat diet (Piper et al. 2009a; 2009b). In total, the evidence from Neolithic northern Luzon suggests a very similar subsistence pattern as in eastern Taiwan.

Conclusion

The findings at Chaolaiqiao constitute the first direct evidence for prehistoric agriculture in eastern Taiwan, with rice confirmed so far as the only crop. Based on the number of ornamentations on rice bulliform phytoliths, the 4200-year-old rice was fully domesticated. Taking both plant and terrestrial animal evidence into account, a lifestyle heavily reliant on terrestrial resources can be inferred. At the time in question, eastern Taiwan was subject to very rapid tectonic uplift and a consequent contradiction between subsistence and available cropland might have persuaded Neolithic groups to leave eastern Taiwan in search of new territories overseas.

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