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New Archaeobotanic Data for the Study of the Origins of Agriculture in China

by Zhijun Zhao

In the past 10 years, flotation techniques have been introduced and implemented in Chinese archaeology. As a result, a tremendous quantity of plant remains have been recovered from archaeological sites located all over China. These plant remains include crops that might have been domesticated in China—such as rice, foxtail millet, broomcorn millet, and soybean—as well as crops that were introduced into China from other parts of world—such as wheat and barley. The new archaeobotanic data provide direct archaeological evidence for the study of the origins and development of agriculture in China. This paper attempts a synthesis of these new archaeobotanic data while presenting some new ideas about the origins and development of ancient agriculture in China, including the rice agriculture tradition that originated around the middle and lower Yangtze River areas; the dry-land agriculture tradition, with millets as major crops, centered in North China; and the ancient tropical agriculture tradition located in the tropical parts of China, where the major crops seem to be roots and tubers, such as taro.

Introduction

China is one of the major centers for the origins of agriculture. In the past, intensive study of early Chinese agriculture made it clear that there were primarily two independent subcenters of origin within China (An 1989; Cohen 2011; Crawford 1992; Ho 1977; Jones and Liu 2009; Yan 1992; Zhao 2005*c*): one in the middle and lower Yangtze River areas, where rice agriculture was first developed, with rice (*Oryza sativa*) the major cultivar; and the other in North China along the Yellow River, where the origin of dry-land agriculture is centered, with foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) the most representative crops. However, the origin of domesticated rice and the beginning of rice farming in China remain uncertain and highly controversial, while the study of the origin of dry-land agriculture has lagged even farther behind. Apart from these two major areas central to the origin of agriculture, a third important area that deserves thorough investigation is the southernmost part of China, centered along the Zhujiang River, where the major crops of early farming seem to have been roots and tubers, probably including taro (*Colocasia* sp.; Zhao 2006). This investigation should be of great importance because it may reveal a third pathway of early Chinese agricultural development in a prehistoric context. There remain many unsolved questions in the study of the origins of agriculture in China that are partly due to the lack of reliable archaeological evidence.

Ancient agriculture is generally considered to be composed of two major elements: crop farming and animal husbandry, which relied on crops or by-products of farming for fodder. Thus, plant remains, especially crop remains, are the most important evidence in the study of origins of agriculture. However, plant remains are more often than not poorly preserved, fairly small in size, and consequently difficult to identify with the naked eye in the field. Thus, without special attention to their recovery, plant remains from the past may be easily underrepresented in archaeological excavations.

Well-preserved plant remains more frequently survive at archaeological sites where fire was used by the residents. Charred plant remains are chemically stable and relatively resistant to soil and water erosion, and they can be preserved for a long time in the sediments of archaeological sites. Charred plant remains are usually lighter in specific gravity than soil particles and water. This makes it possible to separate the plant remains from the soil matrix, as the charred remains will separate from sediment and float on the surface of water. Such is the widely used and recognized flotation technique, which has been commonly accepted as an effective way of extracting plant remains from soil samples.

In recent years, flotation work has been carried out at more than 80 archaeological sites throughout China. About 7,000 soil samples have been processed, and a tremendous quantity of charred plant remains have been recovered (Zhao 2005*a*).

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The charred plant material, especially the crop remains, obtained from the sites by flotation provide important new data for the study of the origins of agriculture. Identifiable domesticated taxa include rice, foxtail millet, broomcorn millet, wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), soybean (*Glycine max*), adzuki bean (*Vigna angularis*), oats (*Avena sativa*), buckwheat (*Fagopyrum esculentum*), and so on.

The plant remains recovered by flotation in China, considered together with plant remains from previous investigations, allow us to gain a number of new insights into the origins of agriculture in China. This paper presents a brief outline of this new scenario based mainly on quantitative analysis of the crop data derived from flotation samples collected at several major archaeological sites.

The Origin of Rice Agriculture in the Yangtze River Areas

Before we go into the details of the new flotation evidence of rice agriculture, it is necessary to clearly distinguish two terms for the study of the origin of rice agriculture: "domestication" and "cultivation." Benefiting from the discussion during the Wenner-Gren Temozon conference, I believe that there is no inevitable relationship between rice domestication and the beginning of rice cultivation.

Rice domestication was primarily an evolutionary process influenced by human activities that were by no means a deliberate effort aimed at changing the genetic or biological characteristics of plants but were simply intended to increase the yield of wild rice. People may have been unaware of the characteristics of a new species when it first appeared, and the plants were therefore not viewed as "domestic" at all. It is possible for domesticated rice to occur in a typical hunting-gathering adaptation, and the occurrence of domesticated rice might not immediately result in rice farming, which was characterized by intentional production and utilization of domesticated rice for food.

Also, the cultivation of rice might not be directly related to the domestication of rice. Cultivation is a series of intentional human activities—such as planting, protecting, and harvesting—for increasing the yield of plants that could be morphologically and genetically either wild or domesticated. Therefore, it is possible for early rice cultivation to be practiced without domesticated rice.

The flotation work at the Shangshan site has provided some clues for the study of early rice cultivation in China. The Shangshan site is an early Neolithic settlement located in the center of Zhejiang Province, which geologically belongs to the lower Yangtze River region (fig. 1). The cultural assemblage at the site can be clearly divided into two periods. The early period is named the Shangshan culture and is dated to around 10,000 cal BP by a number of radiocarbon dates, some of which have been published (Jiang and Li 2006:356). The later period belongs to the Kuahuqiao culture, which was distributed around Hangzhou Bay and is radiocarbon-dated to 8200–7000 cal BP (Zhejiang Institute of Archaeology and Xiaoshan Museum 2004:228).

Flotation work was conducted during the excavation in the Shangshan site in 2005. A diagnostic sampling strategy was employed by which soil samples were collected from each unambiguous archaeological feature found in every layer. A froth-flotation device with a 0.2-mm mesh screen was used. A total of 459 soil samples were collected and processed. Yet only a very small number of charred plant seeds were obtained from the samples. The most important result of the flotation work was the rice remains. A total of 33 charred rice grains (fig. 2) and 7 charred rice spikelet bases were found in the soil samples. However, most of these rice remains were recovered from the Kuahuqiao culture layers and only a few from the Shangshan culture layers.

Apart from flotation, other methods were also employed for obtaining rice remains. For example, heaps of rice husks were found in burnt soil blocks from the early-period layers of the site (Jiang and Li 2006, fig. 6). More significant evidence of rice used by humans was found in the temper of pottery. A large number of pottery sherds were excavated from the Shangshan site. It is possible to identify with the naked eye plant remains such as stems and leaves at the edge of these low-fired ceramic materials (Jiang and Li 2006, fig. 6). It is fairly interesting that in the two ash pits of the Shangshan culture period we examined, more than 80% of the pottery sherds were tempered with plant remains and that some rice husks were also observed in the temper. All this evidence indicates that the Shangshan people had a close relationship with rice and that rice, whether domesticated or wild, might have been one of the foods consumed by the Shangshan residents.

Some sort of rice cultivation activity might have taken place at the Shangshan site during the Shangshan period whether or not such rice remains belong to the domesticated species. Therefore, a complete study of the Shangshan site may possibly be used as a good case for the study of the beginning of rice cultivation in China. Future studies should take into account all factors, including the environmental setting of the site, the settlement pattern, pottery types, stone tools, and so forth.

As discussed at the Wenner-Gren Temozon conference, agriculture can be defined as a subsistence economy characterized by farming, although hunting and gathering continue. Therefore, the earliest archaeological site to date that clearly exhibits the characteristics of rice agriculture in China is the Jiahu site, which is located in the upper Huai River region in the center of China (fig. 1) and is dated to a period between 9000 and 7800 cal BP by 19 radiocarbon dates (Henan Institute of Archaeology 1999:515). The Jiahu site covers an area of 50,000 m^2, within which the living areas, manufacturing areas, and cemeteries were organized in an orderly fashion. The clear layout of the site documents a permanent village (Henan Institute of Archaeology 1999). The excavations in

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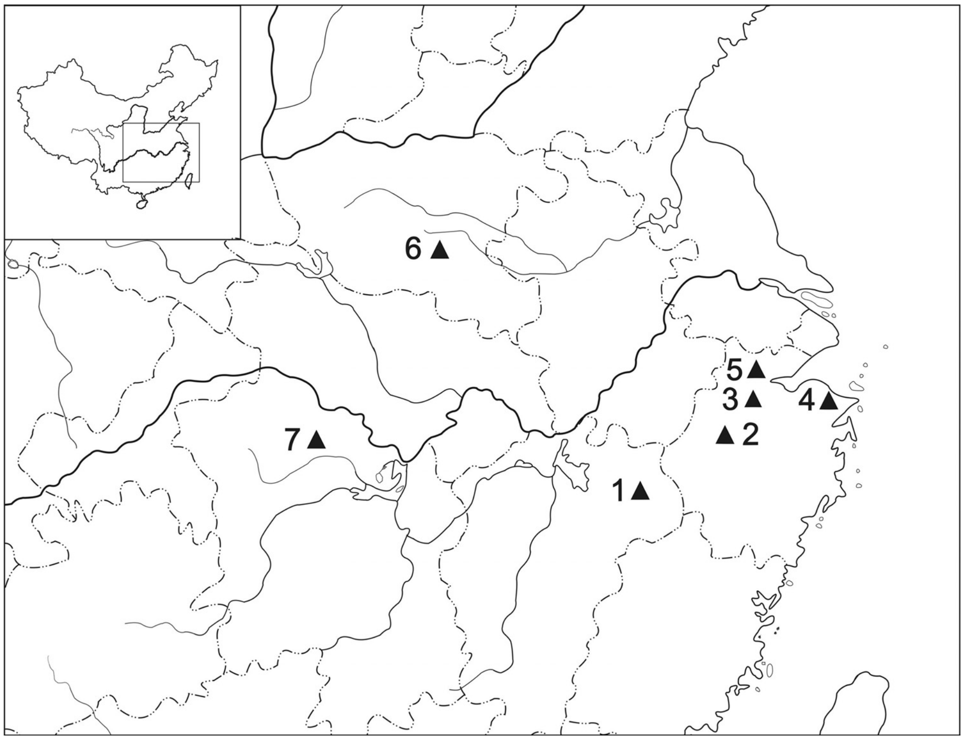

Figure 1. Locations of the sites with early rice remains in the Yangtze River areas: *1*, Xianrendong/Diaotonghuan; *2*, Shangshan; *3*, Kuahuqiao; *4*, Hemudu/Tianluoshan; *5*, Liangzhu; *6*, Jiahu; *7*, Chengtoushan.

the 1980s unearthed many charred grains that have been identified as domesticated rice (Zhang and Wang 1998).

Flotation work at the Jiahu site began in 2001. A diagnostic sampling strategy was employed. A simple bucket-flotation device was used, and plant remains were caught in a 0.2-mm mesh screen. A total of 125 soil samples were collected and processed. A large number of charred plant remains have been counted and identified, including about 4,100 seeds of 16 taxa (Zhao and Zhang 2009). They can be divided into two groups: edible plants and weedy grasses. The former embraces tubers (e.g., lotus roots *Nelumbo nucifera*), nuts (e.g., acorn and *trapa*), grains (e.g., rice and wild soybean *Glycine soja*), and so on. The latter includes such taxa as *Digitaria* and *Echinochloa*, among others.

More than 400 charred rice grains were found in the flotation samples (fig. 2). From analysis of the shape and size of the grains and the morphological characteristics of the embryos, and considering the fact that the Jiahu site is located far from the traditionally known distribution area of wild rice, we believe that the rice remains recovered at the Jiahu site are domesticated. Various quantitative measurements—such as absolute counts, total weight, and ubiquity—were employed to compare the plant remains recovered from the Jiahu site (Zhao and Zhang 2009). These data make it clear that wild plants derived from gathering practices accounted for the majority of food resources while domesticated rice might have played only a minor role in the subsistence of the Jiahu people.

A number of animal bones were unearthed during the excavation, and about 20 species were identified, among which dog is the only clearly domesticated animal. The identification of domestic pig from Jiahu has been controversial (Yuan 2001). A recent study suggests that the Jiahu pig was fully domesticated but was not significant for the meat supply (Luo and Zhang 2008). Nevertheless, zooarchaeological studies suggest that provisioning of animal feed was not an important part of Jiahu subsistence practices.

The abundance of fish bones and shells at the site is based not only on the absolute count but also on the fact that almost all trash pits contained fish bones. This is a strong indication that fishing played a very important role in the subsistence economy. Considering that water plants such as lotus and *trapa* are also abundant in the plant assemblage, aquatic species, both animal and plant, were a dominant food resource for the Jiahu residents.

We might conclude from the above analyses that the overall subsistence economy of the Jiahu people mainly relied on fishing, hunting, and gathering and that agricultural products produced by rice farming and animal husbandry were only supplements to their diet. Therefore, the Jiahu site is a good

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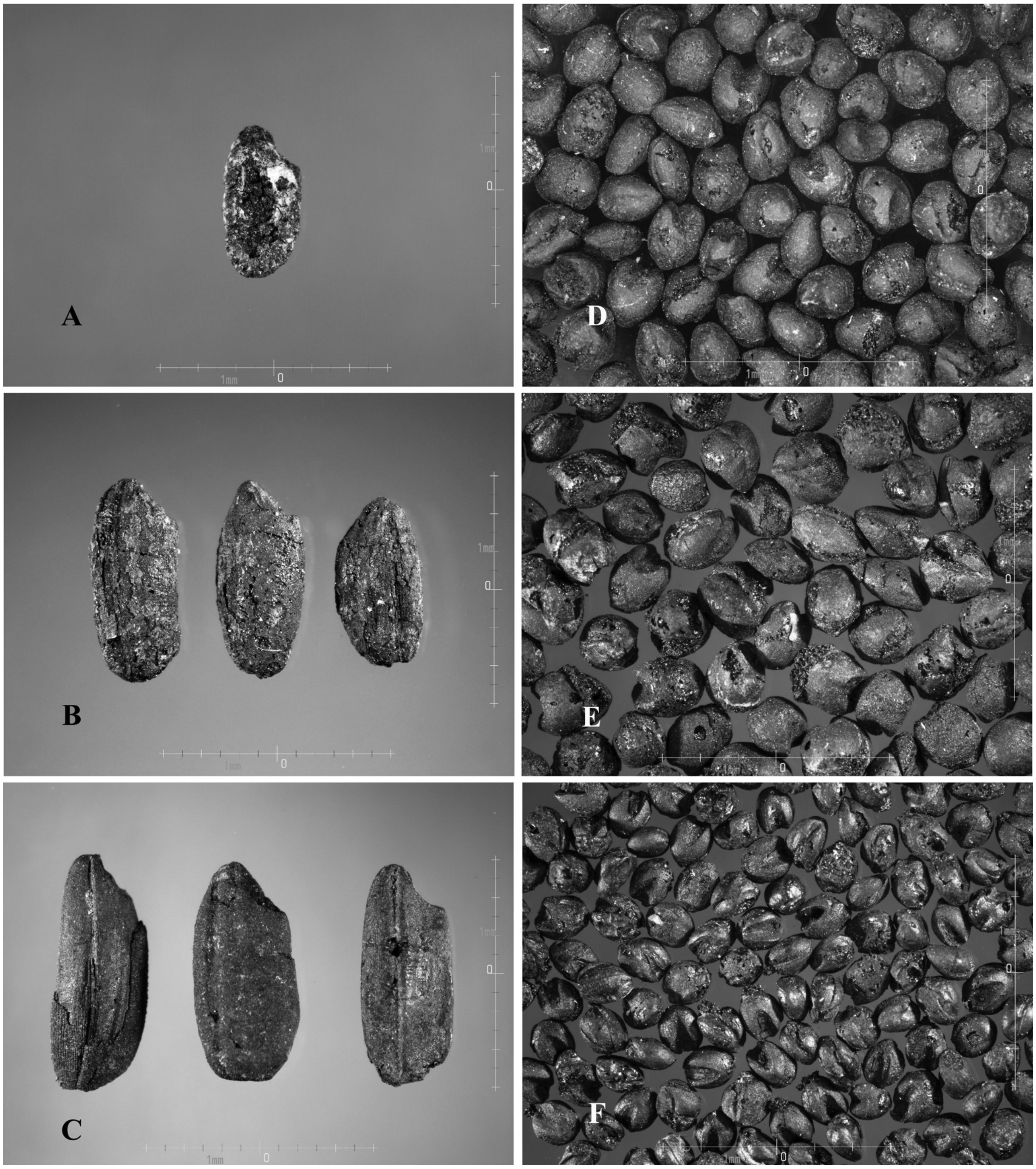

Figure 2. Charred crops recovered by flotation: *A*, Shangshan rice; *B*, Jiahu rice; *C*, Tianluoshan rice; *D*, Xinglonggou broomcorn millets; *E*, Yuhuazhai broomcorn millets; *F*, Yuhuazhai foxtail millets. A color version of this figure is available in the online edition of *Current Anthropology*.

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example for the study of an early stage in the transition to rice agriculture, and it thus shows that the transition from hunting and gathering to rice farming was a gradual evolutionary process rather than a revolutionary replacement.

The discovery of the Hemudu site in the 1970s resounded throughout the world. The site is located on the south bank of Hangzhou Bay, about 20 km from the present sea coast (fig. 1). Cultural assemblages have been divided into four phases dated to a period between 7000 and 5800 cal BP by 27 radiocarbon dates (Zhejiang Institute of Archaeology 2003: 411). Because of the waterlogged environment of the site, organic materials have been well preserved. Large numbers of plant remains have been recovered and identified, including rice, *trapa*, acorns, and other edible plants (Liu 2006). The most important result of the excavation was the discovery of large numbers of rice grains. Some scholars accordingly suggested that the Hemudu people might have had a very mature agricultural economy based on rice farming (Zhou 2002). Yet no quantitative analysis was carried out at that time, and it is therefore impossible to make comparisons between different plant taxa. For this reason, the importance of rice cultivation in the subsistence economy of the Hemudu society remained a question. However, the recent excavation of the Tianluoshan site, only 7 km from the Hemudu site, provides an opportunity to reexamine the unsolved questions about the Hemudu site.

The Hemudu and Tianluoshan sites are similar in size, environmental context, and the nature of the cultural deposits. Unlike at Hemudu, a systematic sampling strategy (i.e., a composite sampling strategy) was applied during the excavation of the Tianluoshan site. Both water screening and flotation techniques were employed to recover plant remains. A total of 222 soil samples were collected and processed, and a tremendous quantity of plant remains have been found by flotation as well as by water screening.

The identification and counting of plant remains are still in process because of the enormous quantities recovered by flotation. Nevertheless, abundant rice remains, including charred rice grains and rice spikelet bases, have been found in the treated samples (fig. 2). A detailed study of rice spikelet bases shows that the Tianluoshan rice consisted of a high proportion of the shattering wild type, which suggests that the process of rice domestication had not yet culminated in the Hemudu period, sometime about 6500 cal BP (Fuller et al. 2009).

Besides rice, plant remains recovered and identified from the processed samples of the Tianluoshan site include acorns, *Trapa* sp., *Diospyros* sp., *Gordon euryale*, *Ziziphus jujuba*, Chinese gooseberry seeds, bottle-gourd seeds, and seeds of various weedy grasses. The preliminary results of quantitative analysis suggest that rice farming, though important, was only part of more general subsistence activities of the Tianluoshan residents. The products of hunting and gathering, especially acorns, also made great contributions to the diet. Therefore, the importance of rice farming should not be overstated for the Hemudu culture, as seen at both the Tianluoshan site and the Hemudu site.

Thus, the above sites show that the transition to rice agriculture from hunting and gathering was not a clear-cut revolutionary change but a slow evolutionary process. During this long-term process, hunting and gathering gradually waned while rice agriculture slowly achieved a dominant position and finally became the major subsistence practice. On the basis of preliminary analysis of the flotation materials from the Tianluoshan site, the subsistence pattern of the Hemudu culture seems to be still in the transition to rice agriculture.

When was a hunting-and-gathering scenario completely replaced by rice-agriculture subsistence in the Yangtze River areas of China? We have no answer yet. More flotation work should be done in the future, especially at those sites important in the key stages of early agriculture. This is the only way that reliable evidence can be obtained.

However, on the basis of previous archaeological discoveries and studies, we believe that the overall subsistence economy of the Liangzhu culture, dated to a period between 5200 and 4300 cal BP in the lower Yangtze River region, already relied heavily on rice agriculture. Rice remains were occasionally found at some archaeological sites of the Liangzhu period in the past, but they cannot be used for a quantitative analysis because of the lack of systemic sampling strategies. In recent years, the flotation technique has been introduced, and new data has begun to emerge, but the results are not yet published. Nevertheless, some indirect evidence suggests the establishment of full rice agriculture in the Liangzhu period.

For example, a large walled town of the Liangzhu culture was unearthed near Hangzhou City recently (fig. 1), and it measures about 1,900 m in length and about 1,700 m in width, a total area of 3.23 km^2. The foundation of the wall is about 50 m in width and was consolidated by a layer of large pebbles (Liu 2007). It is difficult to imagine that this vast construction could be undertaken without the food support of fully developed rice agriculture.

Also, archaeological surveys indicate that the Liangzhu culture sites sharply increased in number in the lower Yangtze River region, especially in the Hangzhou Bay area, where the distribution of Liangzhu sites is even denser than that of modern villages. This clearly indicates a significant increase in human population, which is likely to have been correlated with a rapid development of rice agriculture. In other words, as late as about 5,000 years ago, rice agriculture had become the dominant food source in the lower Yangtze River region.

The development of rice agriculture in the middle Yangtze River region may have followed a pattern different from that in the lower Yangtze River region: full rice agriculture may have been established earlier. This hypothesis can be partly supported by studies of the Chengtoushan site, located in Lixian County of Hunan Province (fig. 1) in the middle Yangtze River region (Hunan Institute of Archaeology 1999). Water sieving was carried out during the excavation, and rice re-

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mains were recovered. Also, a possible rice field was identified by survey as well as by the phytolith technique, The site, dated to ca. 6000 cal BP by 14 radiocarbon dates (Hunan Institute of Archaeology and International Research Center of Japan Culture 2007:186), is one of the earliest walled towns in China and was possibly constructed and used as a central settlement in response to rapid population growth. Therefore, it is likely that the subsistence of the Chengtoushan society already relied on rice agriculture.

The Origin of Dry-Land Agriculture in North China

In the past, studies on the origin of dry-land agriculture in North China have focused on the middle Yellow River region of North China because this region is believed to be the motherland of ancient Chinese civilizations, where ancient millet farming was centered, and abundant prehistoric cultural remains have been recovered there (Lu 2002). However, new archaeological data suggest that the whole Yellow River area in North China had the potential to have been the place of origin of dry-land agriculture.

Millet remains have been reported in several early Neolithic sites distributed along the Yellow River. Those from the Cishan site draw the most attention. The Cishan site is located in the middle Yellow River region (fig. 3) and is radiocarbon-dated to 6856 ± 100 BP (charcoal), 7141 ± 100 BP (charcoal), and 7024 ± 105 BP (charcoal). (These dates were corrected from a 5,730- to a 5,568-year half-life by dividing by 1.03.) The calibrated age is ca. 7600–8100 cal BP (Institute of Archaeology CASS 1991:21). A large number of millet remains, identified as foxtail millet, were recovered during the excavations in the 1970s (Tong 1984). However, the taxonomic identification of the remains was problematic because all the so-called millet remains had already decayed to ash when they were discovered (CPAM, Hebei Province, and Handan Relics Preservation Station 1981). The identification had to rely on the spodogrammic technique, which is the same as the present-day phytolith technique. The work was based on a direct comparison between the morphological characteristics of phytoliths extracted from modern foxtail millet and the ash remains recovered from the Cishan site, and a conclusion was drawn when similarities were identified (Huang 1982). However, it is noteworthy that using phytoliths to identify plant species is not straightforward because of the redundancy of phytolith production; that is, similar phytolith types may be produced in widely divergent plant groups (Piperno 1988).

Recently, a new study was carried out on the Cishan millet by a research team, and the results indicate that the millet remains consist of both foxtail and broomcorn millet, but the

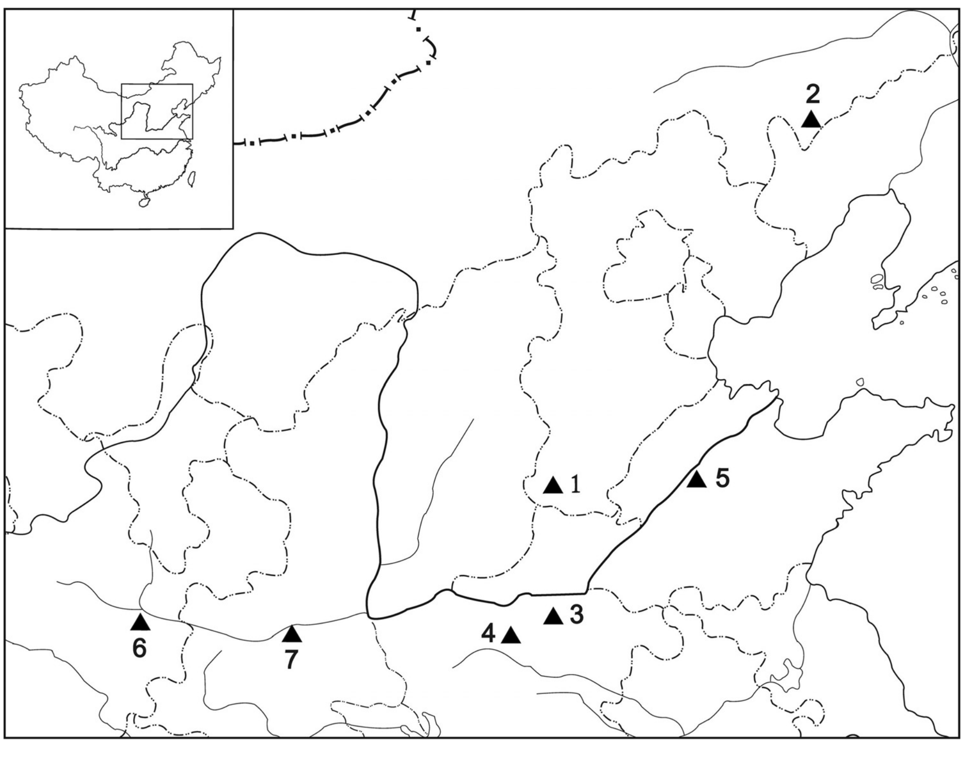

Figure 3. Locations of the sites with early millet remains in North China: *1*, Cishan; *2*, Xinglonggou; *3*, Shawoli; *4*, Peiligang; *5*, Yuezhuang; *6*, Dadiwan; *7*, Yuhuazhai.

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latter is more abundant (Lu et al. 2009*a*). The identification was done with the same technique (i.e., phytolith analysis), but this time it was based on a systemic comparative study with modern millets (Lu et al. 2009*b*), which makes the identification much more precise and believable.

New radiocarbon dates also have been obtained from Cishan, and some of them are much older than the original dates (Lu et al. 2009*a*). However, these new dates are highly suspect because of the ambiguous context of the materials used for the dating. For example, the term "newly excavated storage pits" in the report is misleading, because no excavation has been conducted at the Cishan site since the 1990s because of the stringent policy of the Chinese National Administration of Cultural Relics for its protection. Therefore, the samples likely had been collected from pits naturally exposed by erosion on the cliff. This is suggested from a photo shown in the report (Lu et al. 2009*a*, fig. 1*C*). The mention of materials of "millet grain crop" in the report is also confusing because the Cishan millet remains were already decayed to ashes mixed with soil when they were unearthed, according to the 1970s and 1980s reports and the materials now exhibited in the Cishan Museum. Note that it would not be necessary to use the complicated phytolith technique for the identification if actual millet grains had really been found, because it is quite straightforward and easy to identify and distinguish foxtail and broomcorn millet simply on the basis of morphological characteristics of the grains (Liu and Kong 2004). Therefore, the material used for dating likely consisted of the bulk samples rather than actual millet grains. It is interesting that one of the new dates came from sample CS-BWG, which had actually been collected during the 1970s excavation and stored in the Cishan Museum. Its date is 7671–7596 cal BP (Lu et al. 2009*a*; their fig. 3), which perfectly matches the original dates from the site.

An archaeological chronology relies not only on chronometric dating techniques but also on the classification and seriation of the cultural assemblages. A number of archaeological sites located in North China have been classified in the same cultural phase as the Cishan site (i.e., the early Neolithic period, 9000–7000 cal BP) on the basis of comparison of their cultural assemblages, including settlement patterns, burial traditions, pottery types, stone tools, and so forth (Zhao 2008). Millet remains were reported from some of these sites, for example, the Shawoli site (Wang 1984) and the Peiligang site (Institute of Archaeology CASS 1984) in the middle Yellow River region, the Yuezhuang site (Crawford, Chen, and Wang 2006) in the lower Yellow River region, the Dadiwan site (Gansu Museum 1982) in northwestern China, and the Xinglonggou site (Zhao 2005*b*) in northeastern China (fig. 3). Among these, the most important new data for millets come from the systematic flotation work at the Xinglonggou site.

The Xinglonggou site is located in the upper Liao River region in northeastern China, along the eastern edge of the Mongolian Grassland. The site consists of three independent localities that were fully investigated and excavated from 2001 to 2003 (Liu 2004). Locality 1 is a large village settlement site radiocarbon-dated to 8000–7500 cal BP. More than 150 house foundations were recovered from the site. The artifacts include pottery, stone tools, and bone and jade artifacts. Large-scale flotation work with a composite sampling strategy was carried out during the excavations. A froth-flotation device with a 0.2-mm mesh screen was used. More than 1,200 soil samples were collected and processed. Abundant charred plant remains were recovered. The most important result of the flotation work was the recovery of domesticated millets identified morphologically as broomcorn and foxtail millet. The broomcorn millet is more abundant, with about 1,400 charred grains found. Only about 60 grains of foxtail millet were recovered. Other plant remains recovered by flotation include *Astragalus*, *Chenopodium*, *Vitis*, and so forth. Nut fragments of acorns were also identified.

Morphologically different from the wild grasses, the millet grains recovered here exhibit the distinctive characteristics of domesticated species, being more spherical in shape and larger in size (fig. 2). As crops, the millet grains are generally not as compacted inside as is usually seen in other wild grass seeds, and therefore they are more readily expanded in the embryo portion when burned, exhibiting a popcornlike appearance. Such morphological characteristics have been found in the millet remains recovered from the Xinglonggou site.

The millet remains are directly dated by accelerator mass spectrometry to ca. 7670–7610 cal BP in three independent radiocarbon laboratories (Z. Zhao, L. Zhou, G. W. Crawford, G. Liu, Y. Li, K. Liu, X. Wu, and T. Nishimoto, unpublished manuscript). Therefore, the Xinglonggou millet remains recovered by flotation, with their precise dating and clear identification, are some of the earliest domesticated millets yet found in China.

Domesticated millets account for nearly 50% of the charred seeds recovered at the Xinglonggou site. However, the ubiquity of millet remains was as low as only 5% in the soil samples processed. A number of pig skulls were unearthed, and most of them were identified as wild, while a few exceptions show some characteristics of domesticated pig. Combining the results of studies of the plant remains, animal bones, and stone-tool use and wear, the subsistence of the Xinglonggou site still seems to have been dominated by hunting and gathering, although millet farming was already practiced and the pig was probably in the process of domestication. Therefore, the Xinglonggou site should be regarded as in an early stage of the transition from hunting and gathering to agriculture; that is, the Xinglonggou residents still relied on hunting and gathering for food, and agricultural products produced by millet farming and animal husbandry only supplemented their diet.

On the basis of flotation results from the Xinglonggou site and new data from other sites, we have found several significant characteristics of the early stage of the transition to millet agriculture in North China. First, morphologically, millets at this stage were already fully domesticated species. In other

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words, the emergence of millet domestication should be dated as earlier than the early Neolithic period. Second, millet grains recovered by flotation from these early Neolithic sites include both broomcorn and foxtail millet, but the former is always more abundant than the latter in this time period. Third, besides the middle Yellow River region, where ancient Chinese civilization and early dry-land agriculture were centered, new data on early millet remains are widely found farther north, along the Great Wall in North China, an economic area that combines farming and herding today.

The middle Neolithic period (7000–5000 cal BP) is a very important stage of cultural development in North China. This period is represented by the well-known Yangshao culture distributed all over North China. Thousands of archaeological sites of the Yangshao culture have been found in this broad area, especially along several important branches of the Yellow River, such as the Wei, Fen, Yi, and Luo rivers. Among these sites, the best known is the Banpo site in Xi'an City.

The Banpo site is a large village settlement enclosed by a moat inside of which house foundations, kilns, and ash pits were found arranged in an orderly fashion. Outside the settlement, a complete lineage cemetery was discovered. Excavations during the 1950s found large quantities of pottery and stone tools, among which stone hoes, spades, knives, and pestles and mortars are most likely to have been used as agricultural tools in relation to farming practices such as harvesting and grinding (Institute of Archaeology CASS and Banpo Museum 1963). Pigs and dogs are both identified as domesticated. Furthermore, a few charred millet remains were found inside a pottery jar. All this evidence suggests that agriculture was a compulsory element in the subsistence practice of the Yangshao culture. Unfortunately, flotation work was not practiced at the time of excavation, and we therefore have no reliable data for quantitative analysis regarding subsistence in the Yangshao culture.

However, the recent excavation of the Yuhuazhai site, only a couple of kilometers from the Banpo site, provided an opportunity to do more-detailed analysis about subsistence in the Yangshao culture. The Yuhuazhai site is also located in Xi'an City (fig. 3) and was excavated in 2002. It is almost a copy of the Banpo site. Both sites are large village settlements enclosed by moats and dated to 7000–6000 cal BP. The cultural remains are identical in these two sites, including features such as house foundations, kilns, pits, and artifacts such as pottery and stone tools.

During the 2002 excavation season, we carried out a flotation project at the Yuhuazhai site. A diagnostic sampling strategy was employed, and a froth-flotation device with a 0.2-mm mesh screen was used. A total of 106 soil samples were collected and processed. Very abundant plant remains were recovered, including about 55,000 seeds. On the basis of taxonomic identification, the seeds belong to the families of Poaceae, Leguminosae, Cruciferae, Chenopodiaceae, Polygonaceae, and Compositae, among others. Also, some economically important plant remains were found, such as *Brassica*, *Papaver*, *Vitis*, and, of course, crops that included foxtail millet, broomcorn millet, and rice.

The plant remains recovered from the Yuhuazhai site are obviously dominated by the millets (fig. 2), which account for nearly 90% of the total number of unearthed plant seeds. Only four charred rice grains were found. In absolute numbers, foxtail millet (about 36,000 grains) is much more abundant than broomcorn millet (about 14,000 grains), while in terms of ubiquity, the percentage of broomcorn millet (67%) is higher than that of foxtail millet (63%). The results of flotation at the Yuhuazhai site clearly indicate that millet farming was dominant in the food production of the Yangshao people. In other words, the overall subsistence of the Yangshao culture, including the Yuhuazhai, Banpo, and other related sites, mainly relied on millet farming and animal husbandry. Hunting and gathering might still play a role in economic practices but only a secondary one in subsistence. Therefore, the transition from hunting and gathering to agriculture seems to have been faster in North China than in the Yangtze River areas. As early as the Banpo phase of the Yangshao culture (i.e., 7000–6000 cal BP), full dry-land agriculture characterized by millet farming was already established in North China.

The Origin of Ancient Tropical Agriculture in South China

South China here refers to the region south of the Nanling Mountains, particularly in the Zhujiang (Pearl) River areas. The study of the origin of agriculture in these areas has mainly focused on the Zengpiyan site in the last century.

Zengpiyan is a cave site located in Guilin City, Guangxi Province (fig. 4). Cultural deposits at the Zengpiyan site can be divided into five phases, with the first phase dated to 12,000–11,000 cal BP and the last to 8000–7000 cal BP. Since its excavation in the 1970s, the site has attracted much academic attention throughout the world. Because the pig bones found there have been identified as possibly from domesticated pigs, the site was believed by some scholars to be the earliest archaeological site with rice farming, and therefore it has been cited as evidence for a hypothesis stating that South China was the center for the origin of rice agriculture. However, no plant remains were ever reported from the site to support this idea. Therefore, the question of the nature of subsistence at the Zengpiyan site has been vigorously debated.

In order to solve this problem, the Zengpiyan site was reexcavated in 2001 with a multidisciplinary approach, including archaeobotanic methods such as flotation and phytolith analysis (Institute of Archaeology CASS et al. 2003). The new excavation was limited to the reserved areas between the excavated squares of the 1970s. Therefore, a complete sampling strategy was used for collecting flotation soil samples: all cultural sediments from the excavation were floated to recover plant remains. More than 8,000 L of soil samples was processed by a froth-flotation device with a 0.2-mm mesh

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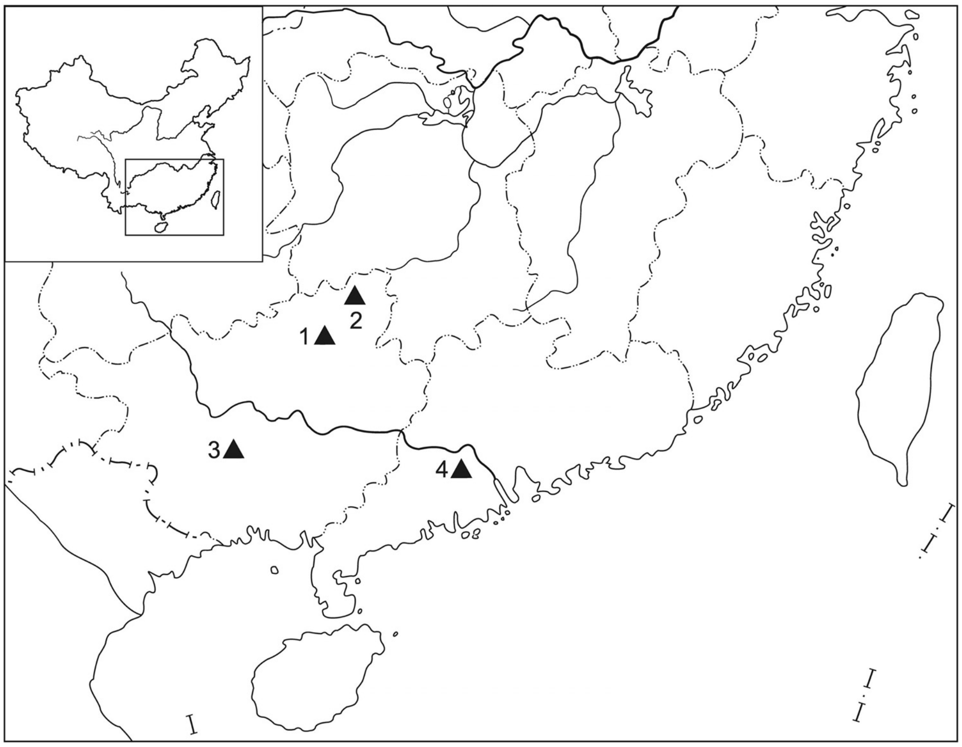

Figure 4. Locations of the sites related to the ancient tropical agriculture in South China: *1*, Zengpiyan; *2*, Xiaojing; *3*, Dingsishan; *4*, Guye.

screen. The charred plant remains obtained included wood, seeds, nuts, roots, and tubers. The seeds were identified as belonging to more than 16 plant species, but no rice was found. Soil samples were also collected from each layer for phytolith analysis, but no phytolith type of the *Oryza* genus, such as the double-peaked glume type or rice leaf types, was observed in the samples. Therefore, both flotation results and phytolith analysis clearly indicate that the Zengpiyan site had nothing to do with the origin of rice agriculture.

Information about local subsistence after 7000 cal BP can be obtained from the Xiaojing site. The Xiaojing site is located in Ziyuan County, Guangxi Province, about 100 km north of Zengpiyan (fig. 4). Cultural deposits of the Xiaojing site can be classified into three phases based on cultural remains and radiocarbon dates. Phase I was dated to 6500–6000 cal BP, phase II to 6000–4000 cal BP, and phase III to 4000–3000 cal BP (Guangxi Archaeological Team and Ziyuan Administration of Culture Relics 2004). Water sieving was applied to recover plant remains during the excavation at the Xiaojing site. A large number of charred rice grains, numbering in the tens of thousands, were recovered from phases II and III, but not a single rice grain was found in phase I. This stark contrast suggests that a rapid change to rice farming occurred at the Xiaojing site around 6,000 years ago. This rapid change can be interpreted only as the introduction of rice farming from another place. This was further corroborated by the excavations at the Dingsishan site.

The Dingsishan site is located in Yongning County, Guangxi Province (fig. 4). The site is a well-preserved shell midden, and the cultural deposits can be divided into four phases. Phase I (early Neolithic) was dated to 10,000 cal BP. The major part of the cultural deposits of the site is in phases II and III (8000–7000 cal BP). Phase IV was dated to 6000 cal BP. No systematic flotation work was conducted during the excavations in 1997, but soil samples were collected for phytolith study at that time.

The results of phytolith analysis of the Dingsishan site indicate that no rice phytoliths are present from phase I through phase III but that large numbers of rice phytoliths are found in phase IV (Zhao, Lu, and Fu 2005). Regarding the production of phytoliths, the Poaceae is the most productive family in the plant kingdom, while *Oryza* is one of the most productive genera in the grass family. Rice phytoliths are significant not only for their abundance but also because the large size of the phytoliths enables a more definitive morphological identification. From our experience, once rice has appeared in an archaeological site, it is relatively easy to discover rice phytoliths in the cultural deposits. For these reasons, the surprising abundance of rice phytoliths in phase IV

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indicates that rice was possibly introduced into this area about 6,000 years ago.

According to the above archaeobotanic studies, South China would have had nothing to do with the origin of rice agriculture. Rice agriculture was introduced into this area, probably from the middle Yangtze River region, later than 6,000 years ago, and then it rapidly became the major subsistence resource in South China. Therefore, the question becomes, what kind of subsistence pattern was present in South China before 6000 BP?

Abundant charred remains of roots and tubers recovered by flotation from the Zengpiyan site have attracted our attention. Most plants with edible roots or tubers feature vegetative propagation, and they should be easier to domesticate than seed-bearing plants. As early as the 1950s, Carl Sauer (1952) suggested that vegetative propagation should precede seed agriculture. He believed that the first domesticated plants in agricultural history were not seed plants such as wheat, rice, or corn but plants that lived in Southeast Asia, had edible tubers and roots, and reproduced asexually. Note that South China occupies the same climatic and environmental setting as, as well as sharing a similar Neolithic cultural tradition with, the northern part of Southeast Asia. Therefore, the flotation results of the Zengpiyan site remind us to reconsider Sauer's model of the origins of agriculture. At least we know that in the tropical area of Asia, there should be a type of subsistence pattern primarily based on vegetative propagation before rice agriculture was introduced.

Conclusions

From studying new archaeobotanic data obtained by flotation over the past 10 years or so, we now have greater insight into the origins of agriculture in China. These can be summarized as follows.

Three independent agricultures have centers of origin within China: (1) dry-land agriculture, represented by the major crops of foxtail and broomcorn millet, with a center located in a wide area of loess along the Yellow River between the southern border of the Mongolian steppe to the north and the Huai River to the south; (2) rice agriculture, with a center located in an area of wetland along the middle and lower Yangtze River between the Huai River to the north and the Nanling Mountains to the south; and (3) ancient tropical agriculture, characterized by crops that propagate vegetatively, often roots and tubers and with a center located in the area along the Zhujiang River south of the Nanling Mountains.

The history of the origin of rice agriculture can be divided into three periods. (1) About 10,000 cal BP, rice cultivation began in the Yangtze River areas. Although we need more research to clarify whether the rice cultivated at this period belongs to a domesticated species in morphological and genetic terms, we believe that the purpose of the beginning of rice cultivation was only to increase the production of wild rice, not for plant domestication. (2) The time between 9000 and 6500 cal BP was a transitional period from hunting and gathering to rice agriculture. This transition features a rather slow evolutionary process. The early stage of the transition is characterized by a mixed subsistence economy in which people still relied on hunting and gathering for their major food sources but began to practice rice farming and animal husbandry as a supplement. (3) During the time from 6500 to 4500 cal BP, rice agriculture–based subsistence was gradually established; that is, people began to rely on rice agriculture more and more as their major food source. Full rice agriculture was first established in the middle Yangtze River region about 6400–5300 BP, a period known as the Daxi culture, and then in the lower Yangtze River region about 5200–4300 BP, during the Liangzhu culture period.

The history of the origin of dry-land agriculture in North China can also be divided into three periods. (1) Cultivation of millet and millet domestication might have begun as early as 10,000 years ago, but this initial stage of dry-land agriculture is still vague. It is urgent to carry out thorough investigations and get more solid and reliable archaeobotanic data in future work. (2) From 9000 to 7000 cal BP, there was a transitional period from hunting and gathering to dry-land agriculture, evidenced by new data from several early Neolithic sites. The subsistence pattern in this time period relied on hunting and gathering, with millet farming as a supplement. (3) During the time from 7000 to 6000 cal BP, millet farming–based subsistence (i.e., full dry-land agriculture) was established in North China, represented by the Yangshao culture. However, it seems that the dry-land agriculture in North China developed faster than the rice agriculture in the Yangtze River areas. The data obtained by flotation indicate that agriculture accounted for a higher proportion of the subsistence at the Xinglonggou site in the north than at the contemporaneous Jiahu site in the south at ca. 8000 cal BP. Analysis of the plant remains recovered from the Yuhuazhai site also revealed that dry-land agriculture was already established in North China by 7000–6000 cal BP, earlier than the time when rice agriculture was fully adopted in the middle and lower Yangtze River areas.

Compared with the above two subcenters, the origins and early development of ancient agriculture based on vegetative propagation in South China are not yet clear. Further investigations are needed to deepen our understanding of this process.

From the discussion during the Wenner-Gren Temozon conference, it is clear that, from a worldwide perspective, there are many similarities between China and the other major centers for agricultural origins regarding the questions of when and how agriculture emerged in these centers. For example, new studies from the Near East suggest that the beginning of agriculture was indicated by the cultivation of wild plants such as wild barley and wild lentil. The archaeological evidence for the early cultivation has been dated to the Pre-Pottery Neolithic A sometime around 11,000 cal BP. The earliest domesticated plants, such as einkorn wheat and emmer

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wheat, were found from sites of the early Pre-Pottery Neolithic B, dated to about 10,000 cal BP (Weiss and Zohary 2011). Therefore, the origins of agriculture in both the Near East and China seem to follow the same pattern: they both began with plant cultivation. However, there is a slight difference in the timing between these two centers: the beginning of cultivation, as well as the occurrence of domestication, seems to be 1,000 years or so later in China than in the Near East. This might be due to inadequate archaeobotanic data in China at the moment, as flotation has been applied in the Near East for about 50 years but has been practiced in China for only 10 years.

Studies in other major centers, such as the Near East, also suggest that morphological change in crops may occur late in the domestication process not only for legumes but also for cereals (Zeder 2011). This pattern is also supported by new data from China, as can be seen in the study of rice spikelet bases from the Tianluoshan site (Fuller et al. 2009). This fact provides a challenge for the identification of domesticated plants recovered from archaeological sites because there are no generally recognized criteria to draw a line within this long, uninterrupted process in order to distinguish wild and domestic species. Also, it raises some new issues for the study of the origins of agriculture. For example, how long did it take to complete the process of plant domestication? Are there different rates in the domestication processes between different crops or between different areas? What are the factors that can affect the rate of the process of plant domestication? All of these issues need to be considered in our future research on the origins of agriculture in China as well as in the world.

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