

Presumed domestication? Evidence for wild rice cultivation and domestication in the fifth millennium BC of the Lower Yangtze region

Dorian Q Fuller¹, Emma Harvey¹ & Ling Qin²

*Prompted by a recent article by Jiang and Liu in *Antiquity* (80, 2006), Dorian Fuller and his co-authors return to the question of rice cultivation and consider some of the difficulties involved in identifying the transition from wild to domesticated rice. Using data from Eastern China, they propose that, at least for the Lower Yangtze region, the advent of rice domestication around 4000 BC was preceded by a phase of pre-domestication cultivation that began around 5000 BC. This rice, together with other subsistence foods like nuts, acorns and waterchestnuts, was gathered by sedentary hunter-gatherer-foragers. The implications for sedentism and the spread of agriculture as a long term process are discussed.*

Keywords: East Asia, China, Yangtze region, sixth millennium BC, fifth millennium BC, rice, foraging, cultivation, origins of agriculture

Presumed domestication

In some legal traditions, people are presumed innocent until proven guilty. In the study of agricultural origins it is perhaps prudent to presume plants are *wild* until evidence can be found to indicate domestication. This has not, however, been the convention in the archaeology of East Asia, where domestication is taken for granted, unproven and unquestioned. The recent research report by Jiang and Liu (*Antiquity* 80: 355-61), unfortunately continues this tradition. It seems a curious fact that little discussion has ever been devoted to wild rice foraging in Asia, which logically must have preceded agriculture, or how this might appear archaeologically. We believe that the rice chaff that was used to temper Shangshan pottery will most likely turn out to be a product of foraging, and we would like to take this opportunity to consider a larger body of available evidence from the Lower Yangtze area (Figure 1) that suggests the process of rice domestication came to an end (full domestication) closer to 4000 BC after an extended period, of a millennium or more, of pre-domestication cultivation and presumably a much longer period of wild rice use by foragers.

¹ *Institute of Archaeology, University College London, UK*

² *School of Archaeology and Museology, Peking University, Beijing, China*

Received: 15 June 2006; Accepted: 7 September 2006; Revised: 15 September 2006

ANTIQUITY 81 (2007): 316–331

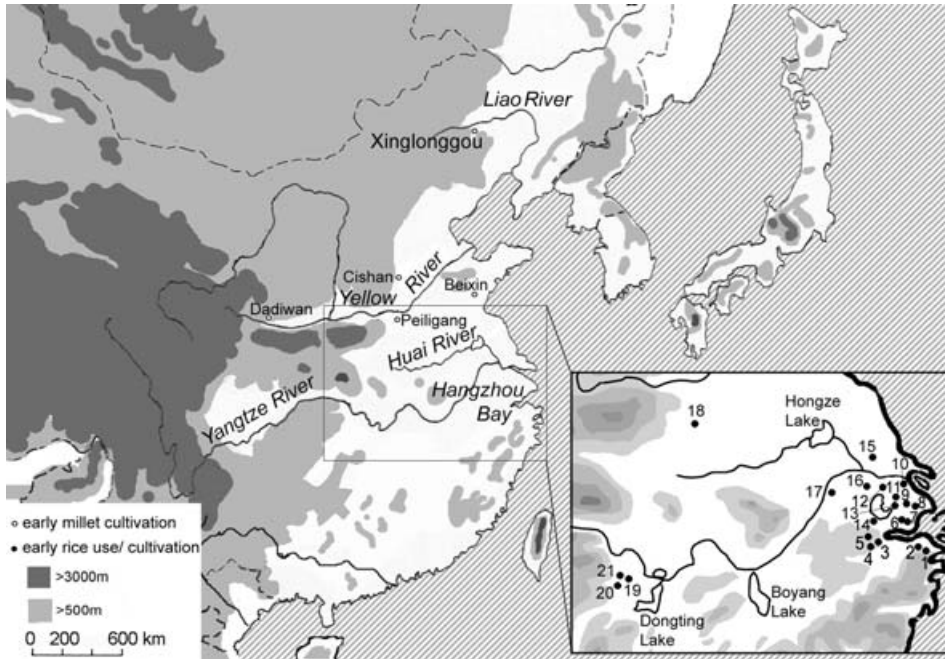


Figure 1. Map of East Asia with inset of Yangtze region, showing archaeological sites mentioned in this article: 1. Hemudu; 2. Tianluoshan; 3. Kuahuqiao; 4. Shangshan; 5. Liangzhu; 6. Majiabang area, including Nanzhuangqiao, Luojujiao and Pu'anqiao; 7. Nanhebang; 8. Maqiao; 9. Songze; 10. Xujiawan; 11. Chuodun; 12. Weidun; 13. Longnan and Caoxieshan; 14. Qiucheng; 15. Longqiuzhuang; 16. Sanxingcun; 17. Lingjiatan; 18. Jiabu; 19. Bashidang; 20. Pengtoushan; 21. Chengtoushan.

Writings on rice in the Lower Yangtze contain a paradox. It has been suggested that rice assemblages contain a mixture of *indica* and *japonica* cultivars, or just *indica* or just *japonica*, or intermediate 'ancient' forms of rice (e.g. You 1976; Zhou 1981; 2003; Li 1985; Zhao & Wu 1987; Oka 1988; Bellwood 1997; 2006; Zhang 2002), but such claims are riddled with contradictions between different scholars looking at the same material, and all such claims are predicated on a now disproven theory of rice origins. In the 1980s prominent botanists, especially Oka (1988) but also T. Chang (1989), favoured a single origin for rice followed by differentiation into *indica* and *japonica* subspecies under cultivation. This scenario, however, is no longer tenable as data accumulated through newer genetic techniques indicates that *indica* and *japonica* are phylogenetically distinct, and represent separate domestication events from distinct progenitor species, *Oryza nivara* for *indica* and *Oryza rufipogon* (*sensu stricto*) for *japonica* (e.g. Sato *et al.* 1990; Sano & Morishima 1992; Chen *et al.* 1993; Wan & Ikehashi 1997; Cheng *et al.* 2003; Vaughan *et al.* 2003; Li *et al.* 2004; for nomenclature, see Vaughan 1994). Indeed, the most comprehensive study to date indicates two separate domestication events for *japonica* rice, in the South China region, and two domestications of *indica* rices in South Asia or western Southeast Asia (Londo *et al.* 2006). This evidence has only begun to be considered in the archaeological literature recently (e.g. Crawford & Shen 1998; Jones & Brown 2001; Fuller 2002: 297; Sato 2002). It should be noted that this genetic evidence overturns the assumption of a single Asian rice origin, which remains

prominent in many textbooks (e.g. Bellwood 1997; Higham 2005). While this alone should call into question older archaeobotanical descriptions, since the dominance of '*indica*' in early China should be impossible, in fact the attribution of these early finds to *indica* or *japonica* domesticated rice is not supported by available morphometric evidence.

Traditional identification ratios do not work unless the presence of wild species can be excluded. Attributions of ancient rice material has been made on the basis of grain or spikelet length-to-width ratios, with ratios of greater than 2.5 attributed to *indica* and ratios of less than 2.3 attributed to *japonica*. Recent morphometric data collected on modern rice species indicates that this does not work if wild species, including both the wild progenitors and other *Oryza* spp. are included (Figure 2). There is much variation in the size and proportions of domesticated and wild rice species today, making it difficult to assign one or a few grains to any given population (Thompson 1996: 176; Harvey 2006). Nevertheless, we would encourage the use of scatter-plots of actual measurements (Figure 3) as a more useful way to look at grain characters and suggest that some species distinctions can be made on an assemblage level. Also changes over time can be more easily tracked. A further problem is the issue of grain maturity, as immature grains will have exaggerated length-to-width ratios. We return to this problem below after considering what is expected in identifying the transition from wild to domesticated rice.

An evolutionary model of the rice domestication syndrome

There is an essential distinction between cultivation (human activity) and domestication (change in the plant). We should expect there to have been a phase, however brief, of pre-domestication cultivation (Helbaek 1960; Wilke *et al.* 1972; Hillman & Davies 1990; Harris 1996; Gepts 2004), and we should seek this archaeologically. In the Near East evidence suggests that pre-domestication cultivation was not brief, but lasted for one to two millennia (Tanno & Willcox 2006; Weiss *et al.* 2006). The domestication syndrome consists of traits that evolved under cultivation, but they are unlikely to have evolved entirely simultaneously. In rice we can consider three traits that should be recoverable through archaeology:

1. Relaxation of selection for natural dispersal aids, i.e. the reduction in awns and hairs which help the shed spikelet grip the soil. As humans start to plant seeds this should relax natural selection in favour of maintaining these characters. As others have remarked, many domesticated rices are awnless, and those with awns have many fewer awn hairs (Sato 2002). But there are also awnless wild rices such as *Oryza meyeriana* or *O. granulata*. (Vaughan 1994).
2. Increase in grain size, or grain weight. This character in cultivated cereals is related to increased efficiency and competitiveness in germination and early growth in open, heavily disturbed soils and with deeper burial of seeds, which is expected under tillage (see e.g. Harlan *et al.* 1973).
3. Finally, and perhaps most important, is selection against wild-type dispersal, i.e. the development of a non-shattering spikelet base, allowing plants to be efficiently harvested, as by uprooting or by sickle (Hillman & Davies 1990). It is this change which is most often taken as the key trait of domesticated cereals (see e.g. Zohary & Hopf 2000). This

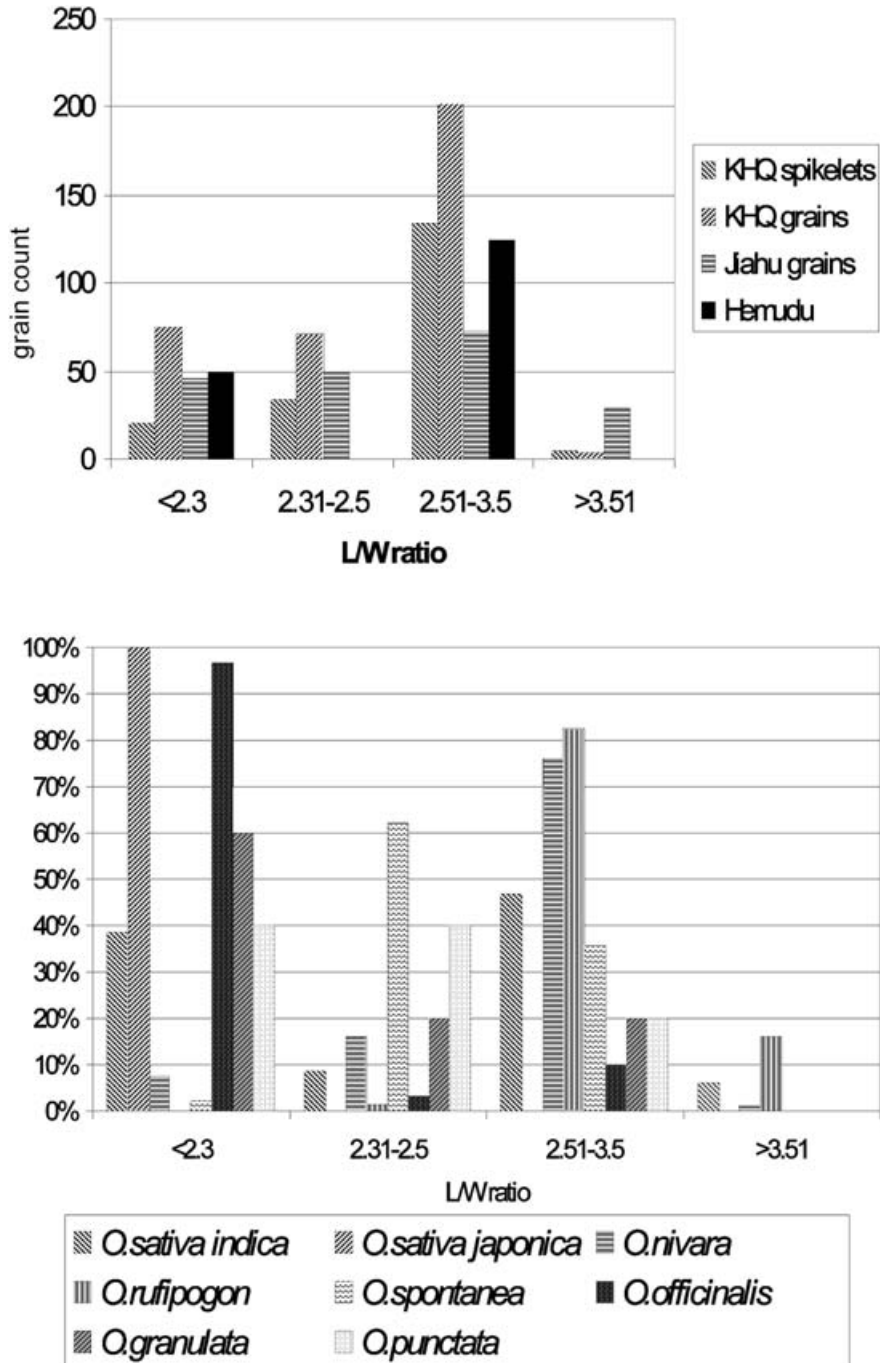


Figure 2. The proportions of rice grains and spikelets within given shape ranges based on length-to-width ratios, from Kuahuqiao (KHQ), Jiahu and Hemudu (data from Henan Provincial Institute of Archaeology 1999; Zhejiang Provincial Institute of Archaeology 2003; Zheng et al. 2004a), and from modern measured rice populations (from Harvey 2006). While such data have traditionally been used to arrive at the mix of indica and japonica grains on Neolithic sites, this can only have validity if the presence of any wild rice species can be ruled out, and ancient grains are assumed to be fully mature.

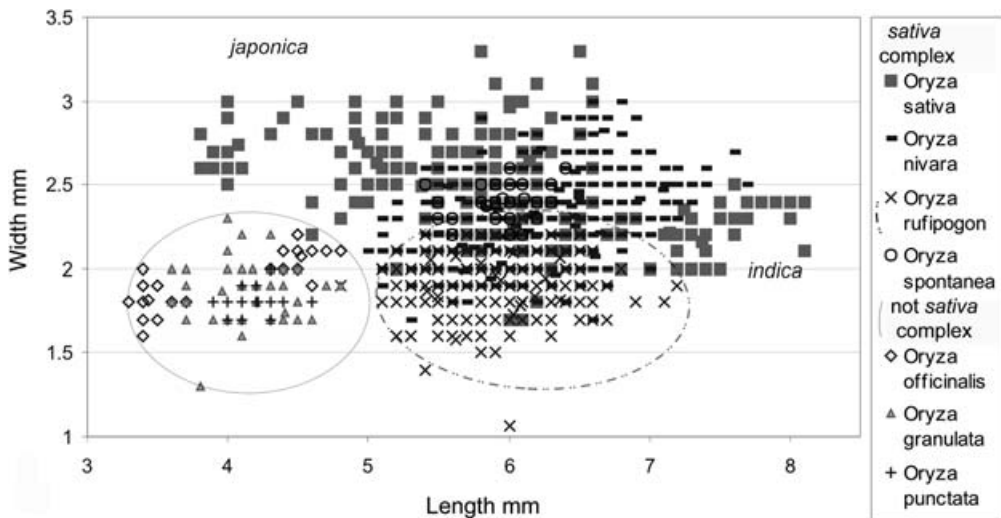


Figure 3. A scatter plot of length and width of grains measured in modern populations (72 populations, 15 grains each, in the Institute of Archaeology, University College London reference collection: Harvey 2006). Ovoid boundaries emphasise the distribution of *Oryza rufipogon* the East Asian wild progenitor, and wild species that are not connected with domesticated rice.

trait however, evolves in response to human harvesting practices and may evolve later than some of the other traits. The non-shedding trait occurs in rice by a toughening of the attachment of the spikelet base to the rachilla, and as shown by Thompson (1996; 1997), this is accompanied by a subtle change in the cross section of the rachilla attachment scar (also Sato 2002).

Of particular importance is that this last trait allows plants to retain all their grains at maturity, as opposed to wild plants that lose grain progressively as they come into maturity. This issue is particularly important because we expect foragers to have targeted rice for harvest when substantial number of grains were immature (as known amongst grass-using foragers, cf. Harris 1984). Immature spikelet bases may mimic those of domesticated types.

The challenge of rice foraging and grain immaturity

The challenge for hunter-gatherers targeting rice is that as grains mature they are shed into the water and mud where wild rice grows. Because rice panicles mature over an extended period, of 15-16 days, the number of grains available at one time on a plant changes. In order to maximise grain recovery it is necessary to target plants early in their grain production cycle, which means that a large proportion of immature spikelets will also be recovered (Figure 4). This has two important implications, first that it will reduce selection pressure for the evolution of domesticated (non-shattering) plants, and second it can be expected to produce assemblages with proportions of immature spikelets, including those without significant grain formation and those in which grains are long and skinny as a product of how rice grains fill out during maturation (Figure 5). This means that pre-domesticated assemblages will contain grains with exaggerated length:width ratios due to immaturity.

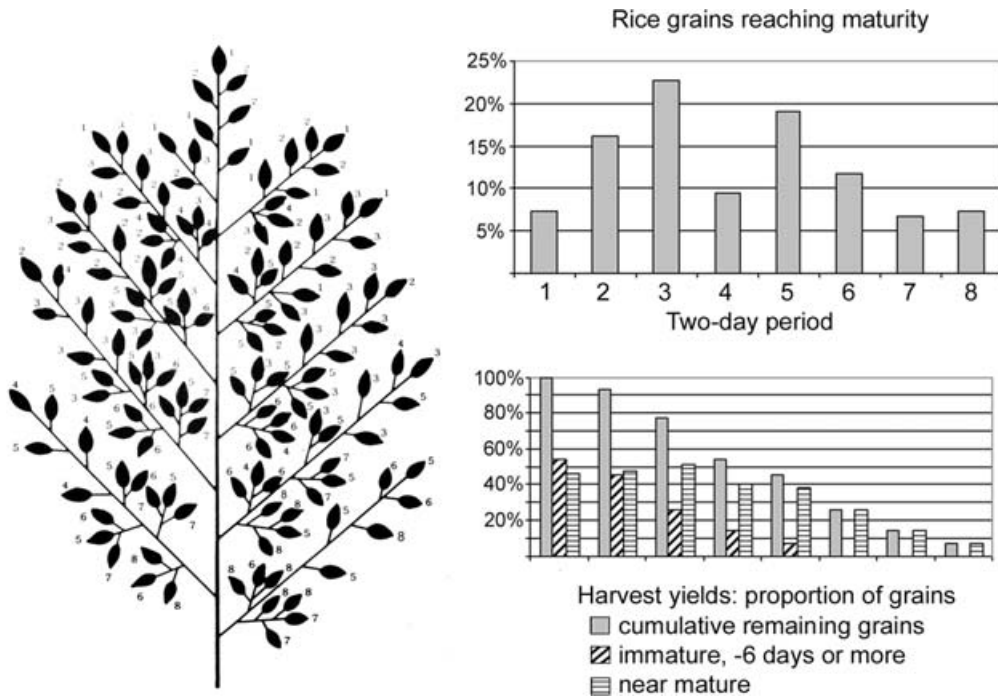


Figure 4. Rice panicle maturation and harvest yields assuming wild type grain shedding. The diagram on the left indicates the stage of pollen shed, and by extension grain initiation on an individual rice plant (after Hoshikawa 1993). From this we have derived the graph at top right which shows the proportions of grains that are expected to come into maturity at each of these stages, approximately two days each, i.e. a total of 16 days for the grains of an entire plant to mature. The graph at lower right indicates the total number of grains remaining on the plant at each stage and the proportions that are near mature and substantially immature (by six days or more).

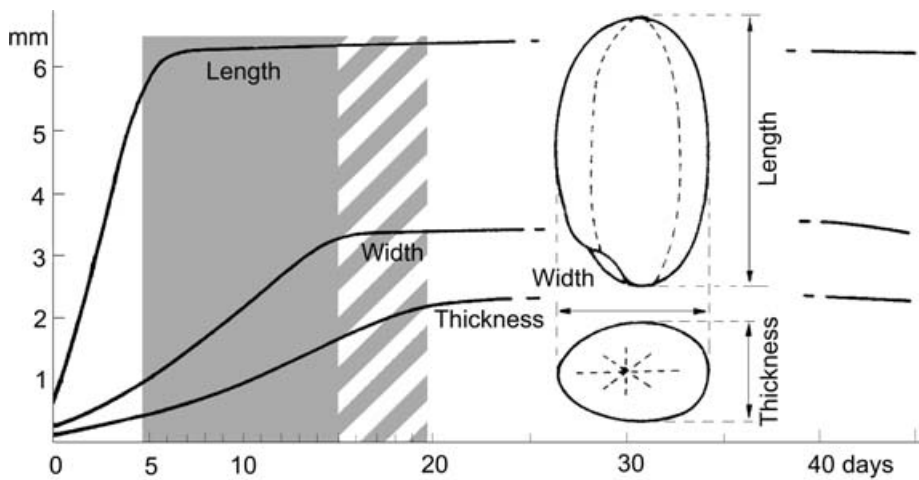


Figure 5. Chart of japonica rice grain metrical development in terms of length, width and thickness measures (after Hoshikawa 1993), on which is shaded the period of grain immaturity in which grain proportions differ from those of standards based on the mature grain. Shown in solid grey is an approximate 10-day window during which immature grain proportions will be biased towards length, and thus closer to indica or rufipogon, rather than japonica.

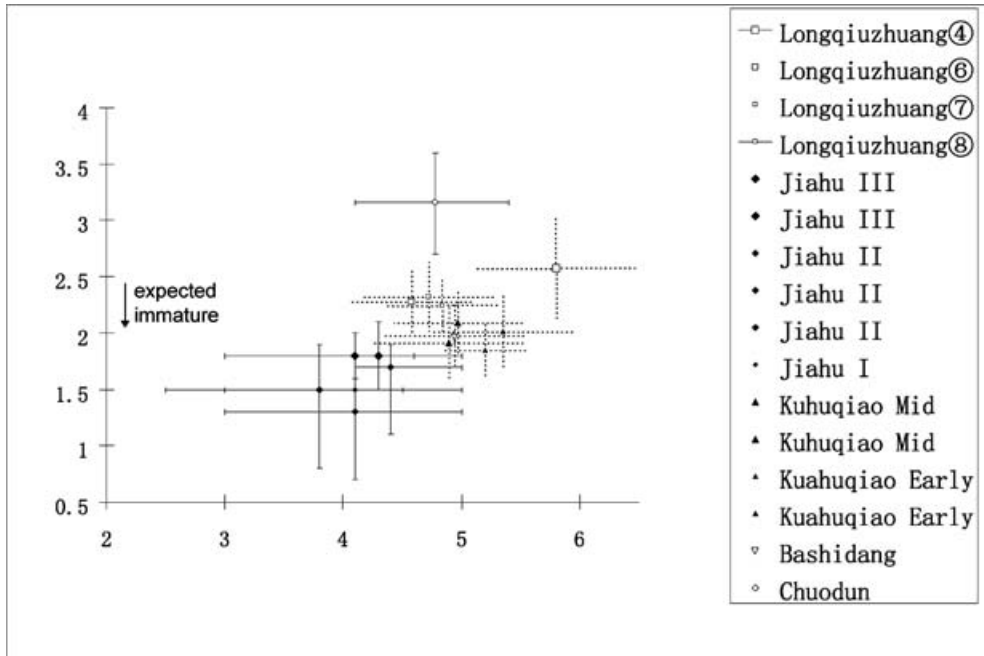


Figure 6. A scatter plot of grain measurements from selected Neolithic sites, showing maximum and minimum measured ranges with solid lines and statistical standard deviations with dashed lines (as reported). Notice that grains from Kuahuqiao, Bashidang and the lower (Majiabang period) levels (8-6) at Longqiuzhuang fall largely or entirely in the expected immature grain proportions (compare Figure 9), while the latest grains from Longqiuzhuang, Songze period (level 4) indicate a clear shift towards longer and fatter grains that can be regarded as fully mature, and thus domesticated. Chuodun (Late Majiabang) also indicates a shift towards mature japonica type grains, but suggests local population differences from the domesticated rice at Longqiuzhuang. The small grains from Jiahu are suggestive of wild rice not in the sativa complex, such as *O. officinalis* (compare Figure 5). Sources: Kuahuqiao (Zheng et al. 2004b), Longqiuzhuang (Huang & Zhang 2000), Jiahu (Henan Provincial Institute of Archaeology 1999), Chuodun (Tang 2003), and Middle Yangzte Bashidang (Pei 1998).

The combination of increasingly mature harvesting, allowed by loss of wild shedding, and selection for larger grains under cultivation will both contribute to morphometric change in archaeobotanical assemblages.

The assemblages from Hemudu (5000-4000 BC, i.e. layers 4 & 3) and Kuahuqiao (6000-5400 BC) contained significant proportions of immature harvested spikelets, indicated both by spikelet/chaff remains and by grain morphometrics. At Hemudu finds included 'abundant empty husks of immature spikelets' (Zhou 2003: 430 [Chinese original]). Similarly at Kuahuqiao, quantified rice remains included about 18 per cent grains, 47 per cent empty (dehusked) spikelets and 35 per cent intact spikelets (immature grains without full grain formation) (Zheng et al. 2004a). A reassessment of published grain measurements from the region, including Kuahuqiao and the Majiabang culture site of Longqiuzhuang (4800-4000 BC) indicate that grains fall into the immature and/or wild progenitor range, but that a marked shift in grain size occurred by the later levels at Longqiuzhuang (Songze culture, after 4000 BC), at which time grains appear longer, wider and presumably represent predominantly mature-harvested grains (Figure 6). In addition the site of Chuodun (late Majiabang period site, just before 4000 BC), shows a marked distinction from earlier sites in having

wider grains. This suggests that the process of morphological domestication took place during the Majiabang/Hemudu period. Quantitative data from the Middle Yangtze region is more limited, but data from Bashidang (7000-6000 BC), a site often associated with early rice agriculture, has markedly thin rice, comparable to those from Kuahuqiao, which we interpret as immature and morphologically wild. Also of note are measurements from Jiahu (Henan Province Institute 1999), which are remarkably small, and more suggestive of a different wild rice, such as *Oryza officinalis*, which did not contribute to later domesticated populations but is a prolific wild seed producer.

An additional source of evidence that suggests a shift from immature to mature harvesting during the Majiabang period comes from bulliform phytoliths. While some of the variation in shape amongst bulliforms appears to be under genetic control and therefore reflects phylogenetics (Zheng *et al.* 2003; 2004a; 2004b; cf. Pearsall *et al.* 1995), there remains much to be understood about such phylogenetic variation in the past. However, some aspects of variation relate to plant maturity, especially horizontal length (HL) and vertical length (VL) show a strong correlation with plant maturity (Zheng *et al.* 2003: 1217). In other words more mature plants produce larger bulliforms. Recent metrical data on bulliforms from sites in the Lower Yangtze indicate a significant shift towards larger bulliforms through time (Figure 7). These data therefore agree with the evidence of grain morphometrics that earlier rice, e.g. of the Majiabang period, was being harvested substantially less mature than later, presumably domesticated rice of the Songze and Liangzhu phases.

Other evidence argues for pre-domestication cultivation during the Hemudu/Majiabang period. As is well-known, Hemudu yielded a great many hafted or haftable bone scapula artefacts, which are regarded as spades or hoes, as well as some wooden spade blades (Chang 1986: 212; Zhejiang Provincial Institute 2003). This suggests manipulation of the soil through tillage. Coupled with the evidence that rice grains were largely immature we regard this as a strong case for wild plant food production. At the earlier Kuahuqiao, only four possible bone 'spades' were recovered, and these had poor hafting features suggesting they would not be suited to heavy tillage (Zhejiang Provincial Institute 2004: 176-7). This argues for the development of cultivation with systematic tillage sometime between Kuahuqiao and Hemudu, or during Hemudu.

In addition, a study of a small sample of rice spikelets from Hemudu, indicated a mixture of domesticated, wild and intermediate characters (Sato 2002). Studies of awn remains had hair densities between those of modern wild and domesticated rices, thus suggesting that natural selection to maintain spikelet dispersal aids had been relaxed by cultivation. In addition spikelet bases included both smooth, wild types and torn types (although these may include immature wild as well as domesticated individuals).

From the later Majiabang period the first preserved field system, interpreted as small rice paddies, has been recovered from the sites of Caoxieshan (Jiangshu province) (Zou *et al.* 2000) and Choudun (Zhejiang Province) (Gu 2003). This development would have an important effect in terms of separating the cultivated wild rice from cross-pollination with free-growing populations, thus accelerating evolution. In the context of these small plots, experimentation with new harvesting methods, like uprooting, may also have played a role in domestication.

Evidence for wild rice cultivation and domestication

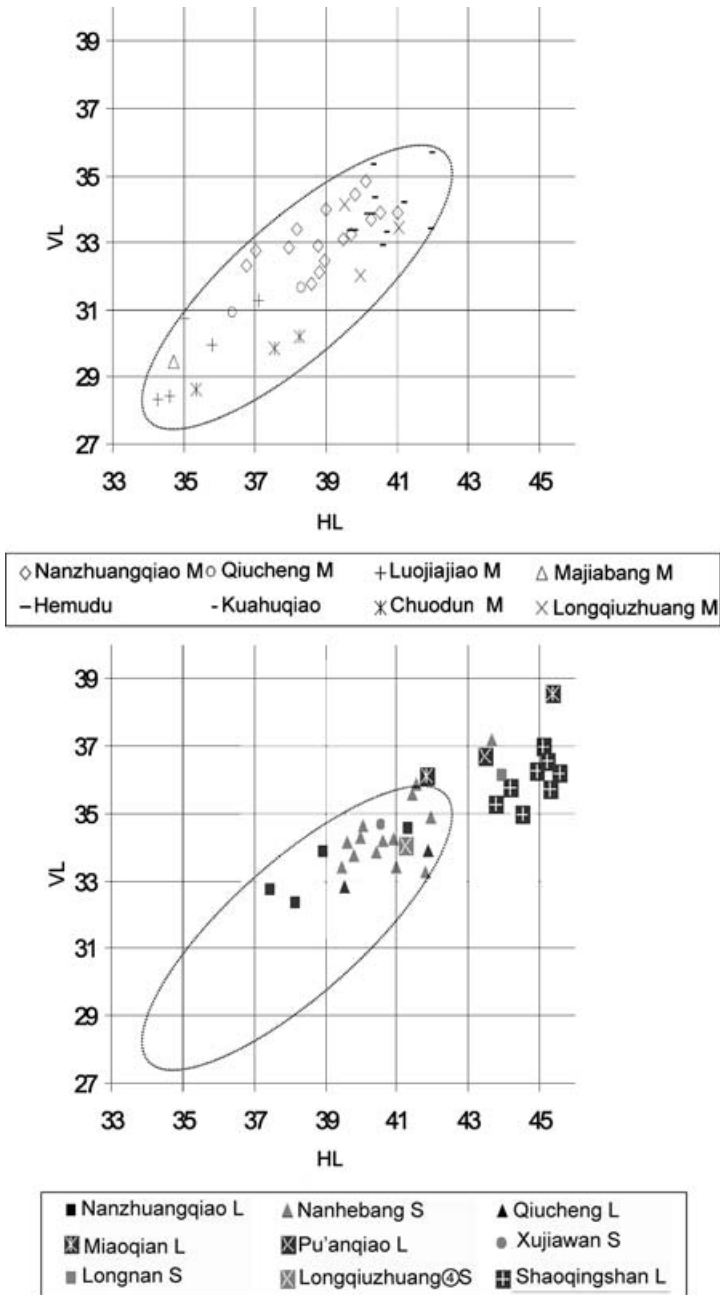


Figure 7. Size increase in Lower Yangtze rice phytoliths. The upper graph shows measured horizontal length (HL) and vertical length (VL) of rice bulliform phytoliths from Majiabang period samples (M), while the lower graph shows measurements from samples of the subsequent Songze (S) and Liangzhu (L) phases. The dashed oval represents the distribution of the Majiabang measurements. Data re-plotted, from Zheng et al. 1994; 2004a; 2004b; Wang & Ding 2000).

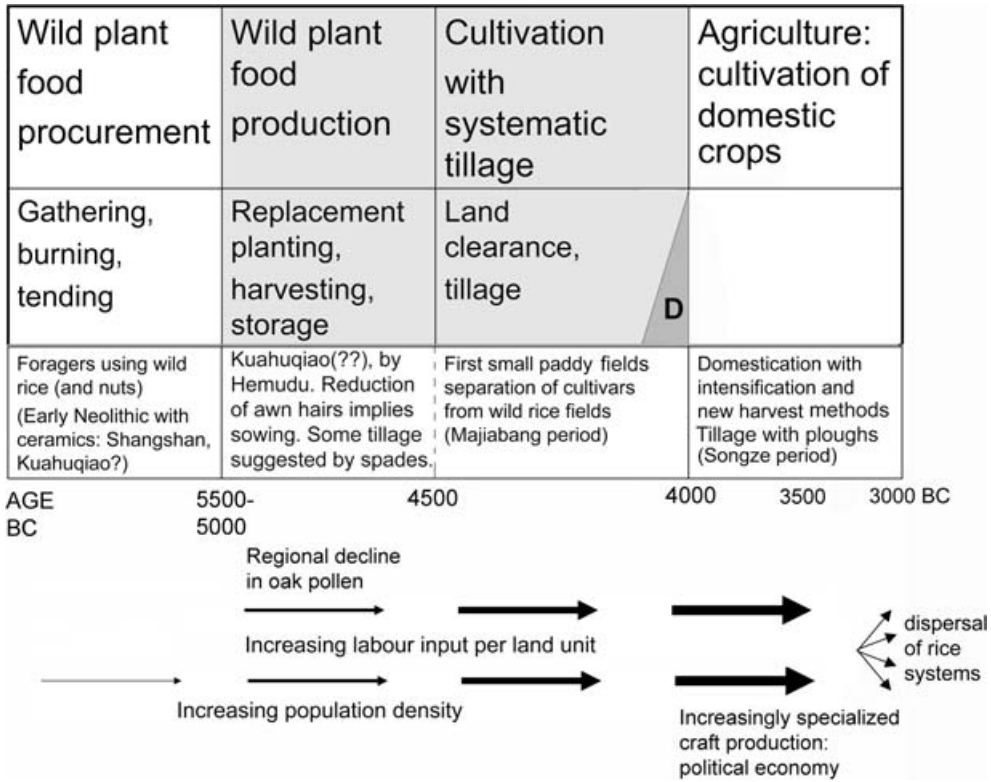


Figure 8. The idealised evolutionary spectrum from pure foraging to agriculture based on domesticated crops, indicating the significant stages of wild plant food production and pre-domestication cultivation (after Harris 1990). On the row at the base of the chart the inferred presence of these stages in the Lower Yangtze river area. Also noted is the regional decline in oaks indicated in pollen data (Tao et al. 2006).

On the grounds of the above data, we suggest that wild plant food production began by or during the Hemudu phase (i.e. by c. 5000 BC) and that domesticated rice had evolved by c. 4000 BC (Figure 8). This implies that earlier finds of rice, such as Kuahuqiao and probably Shangshan represent wild rice gathered by foragers (with some cultivation perhaps beginning before the end of Kuahuqiao). It should be noted that this scenario implies an evolutionary process to evolve non-shattering rice plants with a duration of the order 1000-1500 years. Data from the Near East indicate an equivalent period in the evolution from early cultivation to domesticated wheat and barley (Colledge 1998; Willcox 2004; Tanno & Willcox 2006; Weiss et al. 2006).

Wider implications for early East Asian agriculture

Our hypothesis has wider repercussions for understanding the origins and spread of agriculture in East Asia. Clearly, pottery developed in East Asia well in advance of agriculture, as is true in many other parts of the world (Rice 1999; Kuzmin 2006). It would also imply that sedentary hunter-gatherers preceded agriculture, rather than sedentism being driven by agriculture. In recent years, the orthodoxy has been that rice agriculture began early,

perhaps at the start of the Holocene or late Pleistocene, in the Middle Yangtze, perhaps amongst seasonally inhabited cave-sites (e.g. Cohen 1998; Yasuda 2002; Higham 2005). The archaeobotanical basis for these inferences, however, has remained very limited (see Lu 1999; Crawford 2006). One site of the Pengtoushan culture, Bashidang, produced quantities of rice, but as indicated above this fits clearly with wild rice. Other criteria which have been used to suggest domestication include husk patterns (Zhang & Wang 1998) and husk phytoliths (Zhao 1998), although the relationship between these and evolution under cultivation (the domestication syndrome) remain unclear. Recent tests of these criteria on modern rice species fail to support their utility for inferring domestication (Harvey 2006). Nevertheless, some average grain 'types', reported from later Chengtoushan (Pei 1998), suggest the presence of both wild as well as mature/domestic types by the mid-fifth millennium BC and the Daxi Culture period.

The delayed domestication of rice in the Yangtze implies that millet domestication in northern China developed first. The earliest well-documented millets are from *c.* 6000 BC at Xinglonggou, in Eastern Inner Mongolia (Zhao 2005), while millet cultivation is regarded generally as established in the Yellow River basin by 5500 BC (the Beixin, Cishan, Peiligang and Dadiwan cultures). Rice from the south was added to this agricultural system only in the third millennium BC, with a few rice finds from Late Yangshao contexts (3000-2500 BC) and many more from the Longshan period (2500-2000 BC) (Crawford *et al.* 2005). This would suggest that within 1000-1500 years of fully domesticated rice in the South it had spread to Central China. The spread of rice southwards, to Taiwan and Vietnam, has a similar time frame with the earliest finds dating to *c.* 2500 BC (Higham 2005; Tsang 2005). The southward dispersal is often linked to migration and demographic expansion. Indeed the revised time frame makes this dispersal comparable in rate to the spread of crops from Greece through much of Europe, to the western *Linearbandkeramik* of Belgium and the Cardial Ware related pottery of Mediterranean France and Iberia. An earlier development of rice agriculture leaves unexplained a long latent period with little evidence for demographic growth and expansion.

Concluding remarks: nut foragers and rice domestication

At Hemudu the presence of rice has been emphasised whereas the quantities of nuts, especially acorns, has been mainly ignored. Both Hemudu and Kuahuqiao produced substantial quantities of waterlogged plant remains. Rice was a small component of a broader subsistence base with a focus on nuts. Table 1 summarises the species present at these sites (Zhejiang Provincial Institute 2003; 2004). What is striking about this list of taxa is the wide range of nuts, in particular acorns, which were found in large quantities in storage pits. The authors have recently begun a collaboration with the Zhejiang Provincial Institute of Archaeology and Chinese Academy of Social Sciences on the archaeobotany of Tian Luo Shan, a site of the Hemudu culture. Here, large quantities of acorns and waterchestnuts are preserved in water-logged samples and storage pits, in addition to rice spikelet bases and other wild (weed?) seeds. Nut remains substantially outnumber those of rice, which was probably also true at Hemudu although the remains were never quantified and the acorns were ignored in publications on the site. The ongoing investigation of new material will

Table 1. Plant species identified from Hemudu (H) and Kuahuqiao (K) from fruit remains, and their possible uses, taken from the final reports (Zhejiang Provincial Institute of Archaeology 2003; 2004). Ethnographically documented uses based on Usher 1974; Menninger 1977; Notes: 1. Acorn identifications are difficult, but judging by illustrated and examined acorn receptacles the East Asian ‘qinggang oaks’ *Cyclobalanopsis* spp., appear to dominate. 2. Not recorded in report, but included amongst unidentified fruit seeds, examined by the authors at the Hemudu museum; this species was identified in the report of the basis of leaf remains; 3. On the specific identity and domestication status of rice, see discussion in text.

Taxa; Common names (English, Chinese)		Probable use
<i>Lagenaria siceraria</i>	HK	Containers, fishing net floats, seeds can be processed for oily kernal
Eng. Bottle gourd, Ch. 葫芦 <i>Hu lu</i>		
<i>Quercus</i> spp. (<i>sensu lato</i>)	HK	Potential carbohydrate staple (storable)
Eng. Oaks, acorns, Ch. 橡子 <i>Xiang zi</i> (probably mainly <i>Lithocarpus</i> and <i>Cyclobalanopsis</i> oaks) ¹		
<i>Choerospondias axillaris</i>	HK	Edible fruits, rich in vitamin C; also medicinal
Eng. “Southern Sour Jujube”, Ch. 南酸枣 <i>Nan suan zao</i>		
<i>Amygdalus davidiana</i> (syn <i>Prunus davidiana</i>) ²	H	Edible seasonal fruits, seeds can be eaten roasted (like almonds), and stored in stone
Eng. Chinese mountain peach, Ch. 山桃 <i>shan tao</i>		
<i>Amygdalus (Prunus) persica</i> [Rosaceae],	K	As above.
Eng. True peach, Ch. 毛桃 <i>Mao tao</i>		
<i>Prunus mume</i>	K	Edible seasonal fruits, seeds can be eaten roasted (like almonds), and stored in stone
Eng. Mume apricot; Ch. 酸梅 <i>Suan mei</i>		
<i>Prunus armeniaca</i>	K	Edible seasonal fruits, seeds can be eaten roasted (like almonds), and stored in stone
Eng. Apricot, Ch. 杏 <i>Xing</i>		
<i>Euryale ferox</i>	HK	Seeds dried to make starchy flour (storable); stems and roots eaten as vegetable
Eng. Foxnut, “gorgon seeds”; Ch. 芡实 <i>qian shi</i>		
<i>Sophora</i> sp.	H	Leaves or roots used medicinally (<i>Sophora</i> spp.); pods used as a yellow dyestuff (<i>S. japonica</i>)
Eng. Sophora, Ch. 槐 <i>Huai</i>		
<i>Coix lachryma-jobi</i>	H	Grains edible as cereal (storable)
Eng. Job’s tears, 薏苡 <i>Yi yi</i>		
<i>Trapa bispinosa</i>	HK	Edible nut, storable, potential staple(?)
Eng. Water chestnut, Ch. 菱角 <i>Ling jiao</i>		
Polygonaceae,	K	Edible with roasting; species in this family known to have been used in aboriginal North America and Jomon Japan
Eng. Knotweed (family), Ch. 蓼科		
<i>Oryza rufipogon/sativa</i> ³ [Poaceae],	HK	Potential carbohydrate staple (storable)
Eng. Rice, Ch. 稻 <i>Dao</i>		

provide an opportunity to check the model for a late evolution of domesticated rice. Jiahu also produced large quantities of acorns (Henan Provincial Institute of Archaeology 1999; Zhao Zhijun, personal communication), suggesting that these were a significant, if not the staple, resource.

Our hypothesis of a late rice domestication not only provides a coherent integration of archaeobotanical evidence with expectations from botany and genetics, but suggests an explanatory framework for the origins of rice agriculture. Regional pollen evidence indicates a marked decline in oaks at the end of the sixth millennium BC (Tao *et al.* 2006), which could suggest an important 'push' factor that encouraged the development of rice cultivation. Models of agricultural origins drawn from evolutionary ecology (the 'diet breadth model'), suggest that many early crops were secondary resources, but were reliable sources of subsistence risk-buffering which became increasingly important when primary resources (such as nuts) declined, whether due to over exploitation or climatic factors (e.g. Winterhalder & Goland 1993; Keeley 1995; Piperno & Pearsall 1998). A social pull factor can also be suggested. Specialised craft production, and potential status artefacts (such as jades and fine ground axes), began to be produced during the Kuahuqiao through Majiabang horizon, and emerged as key status symbols in the Songze (4000-3300 BC) and subsequent Liangzhu periods (3300-2200 BC). The cultivation of wild rice in small wetland plots could also have provided a source of wealth production, as its surplus could have been more reliably produced and controlled than foraged resources. Our evolutionary model for rice also makes sense in terms of what is known from archaeology of settlement patterns and inferred social organisation (Qin 2000; 2003; Fuller *et al.* in press), as it is only after the Majiabang period (during the Songze and subsequent Liangzhu periods) that evidence suggests a demographic filling in of the landscape, social differentiation and specialised craft production. A post-4000 BC demographic explosion therefore becomes explicable.

The available data clearly indicate the need for archaeologists to cease and desist in presuming that all rice finds are domesticated and equate to agriculture. Rather we need to look for the long-term processes, by which nut collectors became rice farmers, and one of many wild marsh grasses in the genus *Oryza* became the world's most productive crop.

Acknowledgements

The authors would like to thank our colleagues at Zhejiang Provincial Institute of Cultural Relics and Archaeology, especially Sun Guoping and Zheng Yunfei, who first introduced Dorian to the material at the Hemudu museum and other sites under research by the provincial institute. This occurred while he was on an AHRB Research Leave grant. We have also benefited from discussions with Zhao Zhijun. Our current archaeobotanical collaboration at Tianluoshan has been made possible by Sun, Zheng, Zhao and the provincial director, Cao Jin Yan. The authors' involvement in this project is supported by grants from the Sino-British Trust of the British Academy and China National Education Ministry Project Grant for the Center for the Study of Chinese Archaeology at Peking University. Research on the morphometrics of modern rice species was conducted by E. Harvey as a research student supported by an Art and Humanities Research Board studentship. We thank two anonymous peer-reviewers for their suggestions.

References

- BELLWOOD, P. 1997. *Prehistory of the Indo-Malaysian archipelago*, second edition. Honolulu: University of Hawaii Press.
- CHANG, K.-C. 1986. *The Archaeology of Ancient China*. New Haven: Yale University Press.
- CHANG, T.T. 1989. Domestication and the spread of cultivated rices, in D.R. Harris & G.C. Hillman (ed.) *Foraging and Farming. The Evolution of Plant Exploitation*: 408-17. London: Unwin Hyman.
- CHEN, W.-B., I. NAKAMURA, Y.-I. SATO & H. NAKAI. 1993. Indica and Japonica differentiation in Chinese landraces. *Euphytica* 74: 195-201.

- CHENG, C., R. MOTOHASHI, S. TCHUCHIMOTO, Y. FUKUTA, H. OHTSUBO & E. OHTSUBO. 2003. Polyphyletic Origin of Cultivated Rice: Based on the Interspersion Patterns of SINEs. *Molecular Biology and Evolution* 20: 67-75.
- COHEN, D.J. 1998. The Origins of Domesticated Cereals and the Pleistocene-Holocene Transition in East Asia. *The Review of Archaeology* 19: 22-9.
- COLLEDGE, S. 1998. Identifying pre-domestication cultivation using multivariate analysis, in A.B. Damania, J. Valkoun, G. Willcox & C.O. Qualset (ed.) *The origins of agriculture and crop domestication*: 121-31. Aleppo, Syria: ICARDA.
- CRAWFORD, G. 2006. East Asian Plant Domestication, in M.T. Stark (ed.) *Archaeology of Asia*: 77-95. Oxford: Blackwell.
- CRAWFORD, G. & C. SHEN. 1998. The origins of rice agriculture: recent progress in East Asia. *Antiquity* 72: 858-66.
- CRAWFORD, G., A. UNDERHILL, Z. ZHAO, G. LEE, G. FEINMAN, L. NICHOLAS, F. LUAN, H. YU, H. FANG & F. CAI. 2005. Late Neolithic Plant Remains from Northern China: Preliminary Results from Liangchengzhen, Shandong. *Current Anthropology* 46(2): 309-17.
- FULLER, D.Q. 2002. Fifty Years of Archaeobotanical Studies in India: Laying a Solid Foundation, in S. Settar & R. Korisettar (ed.) *Indian Archaeology in Retrospect, Volume III. Archaeology and Interactive Disciplines*: 247-363. New Delhi: Manohar.
- FULLER, D.Q., L. QIN & E.L. HARVEY. In press. Evidence for a late onset of agriculture in the Lower Yangtze region and challenges for an archaeobotany of rice, in A. Sanchez-Mazas, R. Blench, M. Ross, M. Lin & I. Pejros (ed.) *Human migrations in continental East Asia and Taiwan: genetic, linguistic and archaeological evidence*. London: Taylor & Francis.
- GEPTS, P. 2004. Crop Domestication as a long-term selection experiment. *Plant Breeding Reviews* 24: 1-44.
- GU, J. 2003. The Rice Paddy Land from Chuodun Site of Majiabang Period, in *Chuodun Shan Site: collected papers, Dongnan Wenhua [southeast Culture] 2003* (special issue 1): 42-5 [in Chinese].
- HARLAN, J.R., J.M.J. DE WET & E.G. PRICE. 1973. Comparative evolution of cereals. *Evolution* 27: 311-25.
- HARRIS, D.R. 1984. Ethnohistorical evidence for the exploitation of wild grasses and forbs: its scope and archaeological implications, in W.A. van Zeist & W.C. Casparie (ed.) *Plants and Ancient Man: Studies in Palaeoethnobotany*: 63-9. Rotterdam: A.A. Balkema.
- 1990. *Settling Down and Breaking Ground: Rethinking the Neolithic Revolution* (Twelfth Kroon-Voordact Lecture). Amsterdam: Netherlands Museum of Anthropology and Prehistory.
- 1996. Introduction: themes and concepts in the study of early agriculture, in D.R. Harris (ed.) *The Origins and Spread of Agriculture and Pastoralism in Eurasia*: 1-9. London: UCL Press.
- HARVEY, E.L. 2006. Early agricultural communities in Northern and Eastern India: an archaeobotanical investigation. Unpublished PhD thesis, University College London.
- HELBAEK, H. 1960. The palaeoethnobotany of the Near East and Europe, in R.J. Braidwood & B. Howe (ed.) *Prehistoric Investigations in Iraqi Kurdistan*: 99-108. Chicago: University of Chicago Press.
- HENAN PROVINCIAL INSTITUTE OF ARCHAEOLOGY. 1999. *Wuyang jiahu (Jiahu Site in Wuyang)*. Beijing: Science Press [in Chinese].
- HIGHAM, C. 2005. East Asian Agriculture and its Impact, in C. Scarre (ed.) *The Human Past. World Prehistory and the Development of Human Societies*: 234-63. London: Thames & Hudson.
- HILLMAN, G. & M.S. DAVIES. 1990. Measured Domestication Rates in Wild Wheats and Barley Under Primitive Cultivation and their Archaeological Implications. *Journal of World Prehistory* 4: 157-222.
- HOSHIKAWA, K. 1993. Anthesis, Fertilization and Development of Caryopsis, in T. Matsuo & K. Hoshikawa (ed.) *Science of the Rice Plant, Volume One. Morphology*: 339-76. Tokyo: Food and Agriculture Policy Research Center.
- HUANG, F. & M. ZHANG. 2000. Pollen and phytolith evidence for rice cultivation during the Neolithic at Longquizhuang, eastern Jainghuai, China. *Vegetation History and Archaeobotany* 9: 161-8.
- JIANG, L. & L. LIU. 2006. New evidence for the origins of sedentism and rice domestication in the Lower Yangzi River, China. *Antiquity* 80: 355-61.
- JONES, M.K. & T. BROWN. 2001. Agricultural origins: the evidence from modern and ancient DNA. *The Holocene* 10: 769-76.
- KEELEY, L.H. 1995. Protoagricultural practices among Hunter-Gatherers: a cross-cultural survey, in T.D. Price & A.B. Gebauer (ed.) *Last Hunters, First Farmers. New Perspectives on the Prehistoric Transition to Agriculture*: 243-72. Santa Fe: School of American Research Press.
- KUZMIN, Y.V. 2006. Chronology of the earliest pottery in East Asia: progress and pitfalls. *Antiquity* 80: 362-71.
- LI, C., Y. ZHANG, K. YING, X. LIANG & B. HAN. 2004. Sequence variation of simple sequence repeats on chromosome-4 in two subspecies of Asian cultivated rice. *Theoretical and Applied Genetics* 108: 392-400.

Evidence for wild rice cultivation and domestication

- LIU, J. 1985. Some observations on the archaeological site of Hemudu, Zhejiang Province, China. *Bulletin of the Indo-Pacific Prehistory Association* 6: 40-5.
- LONDO, J.P., Y.-C. CHIANG, K.-H. HUNG, T.-Y. CHIANG & B.A. SCHAAL. 2006. Phylogeography of Asian wild rice, *Oryza rufipogon*, reveals multiple independent domestications of cultivated rice, *Oryza sativa*. *Proceedings of the National Academy of Sciences (USA)* 103: 9578-83.
- LU, T.L.D. 1999. *The Transition from Foraging to Farming and the Origin of Agriculture in China* (British Archaeological Reports International Series 774). Oxford: John & Erica Hedges.
- MENNINGER, E.A. 1977. *Edible nuts of the world*. Stuart (FL): Horticultural Books.
- OKA, H.I. 1988. *Origin of Cultivated Rice*. Tokyo: Japanese Scientific Societies Press.
- PEARSALL, D.M., D.R. PIPERNO, E.H. DINAN, M. UMLAUF, Z. ZHAO & R.A. BENFER JR. 1995. Distinguishing rice (*Oryza sativa* Poaceae) from wild *Oryza* species through phytolith analysis: results of preliminary research. *Economic Botany* 49(2): 183-96.
- PEI, A. 1998. Notes on new advancements and revelations in the agricultural archaeology of early rice domestication in the Dongting Lake region. *Antiquity* 72: 878-85.
- PIPERNO, D.R. & D.M. PEARSALL. 1998. *The Origins of Agriculture in the Lowland Neotropics*. New York: Academic Press.
- QIN, L. 2000. Review of the history and issues in the study of Liangzhu culture, *Kaoguxue yanjiu* [Archaeological Studies] 2000(4): 77-100 [in Chinese].
- 2003. A Study of Prehistoric Social Structure in Taihu Area. Unpublished PhD thesis, Peking University [in Chinese].
- RICE, P. 1999. On the origins of pottery. *Journal of Archaeological Method and Theory* 6: 1-54.
- SANO, R. & H. MORISHIMA. 1992. Indica-Japonica differentiation of rice cultivars viewed from variations in key characters of isozyme, with special reference to Himalayan hilly areas. *Theoretical and Applied Genetics*, 84: 266-74.
- SATO, Y.-I. 2002. Origin of Rice Cultivation in the Yangtze River Basin, in Y. Yasuda (ed.) *The Origins of Pottery and Agriculture*: 143-50. New Delhi: Lustre Press/Roli Books.
- SATO, Y.-I., R. ISHIKAWA & H. MORISHIMA. 1990. Nonrandom association of genes and characters found in indica x japonica hybrids of rice. *Heredity* 65: 75-9.
- TANG, L. 2003. The Primitive Rice Remains from Chuodun Site, in *Chuodun Shan Site: collected papers, Dongnan Wenhua* [southeast Culture], 2003 (special issue 1): 46-9 [in Chinese].
- TANNO, K.-I. & G. WILLCOX. 2006. How Fast was Wild Wheat Domesticated? *Science* 311: 1886.
- TAO, J., M.-T. CHEN & S. XU. 2006. A Holocene environmental record from the southern Yangtze River delta, eastern China. *Palaeogeography, Palaeoclimatology, Palaeoecology* 230: 204-29.
- THOMPSON, G.B. 1996. *The Excavations of Khok Phanom Di, a prehistoric site in Central Thailand. Volume IV. Subsistence and environment: the botanical evidence. The Biological Remains Part III*. London: The Society of Antiquaries of London.
- 1997. Archaeobotanical indicators of rice domestication – a critical evaluation of diagnostic criteria, in R. Ciarla & F. Rispoli (ed.) *South-East Asian Archaeology 1992*: 159-74. Rome: Istituto Italiano per l’Africa e l’Oriente.
- TSANG, C.-H. 2005. Recent discoveries at the Tapenkeng culture sites in Taiwan: implications for the problem of Austronesian origins, in L. Sagart, R. Blench & A. Sanchez-Mazas (ed.) *The Peopling of East Asia. Putting together archaeology, linguistics and genetics*: 63-74. London: Routledge-Curzon.
- USHER, G. 1974. *Dictionary of plants used by man*. New York: Hafner.
- VAUGHAN, D.A. 1994. *The wild relatives of rice: a genetic resources handbook*. Los Banos, Philippines: International Rice Research Institute.
- VAUGHAN, D.A., H. MORISHIMA & K. KADOWAKI. 2003. Diversity in the *Oryza* genus. *Current Opinion in Plant Biology* 6: 139-46.
- WAN, J. & H. IKEHASHI. 1997. Identification of two types of differentiation in cultivated rice (*Oryza sativa* L.) detected by polymorphism of isozymes and hybrid sterility. *Euphytica* 94: 151-61.
- WANG, C. & J. DING. 2000. The Plant Opal Analysis of Shaoqingshan Site, Kunshan City, Jiangsu Province, *Kaogu* (Archaeology) 2000(4): 87-93 [in Chinese].
- WEISS, E., M.E. KISLEV & A. HARTMANN. 2006. Autonomous cultivation before domestication. *Science* 312: 1608-10.
- WILKE, P.J., R. BETTINGER, T.F. KING & J.F. O’CONNELL. 1972. Harvest selection and domestication in seed plants. *Antiquity* 46: 203-9.
- WILLCOX, G. 2004. Measuring grain size and identifying Near Eastern cereal domestication: evidence from the Euphrates valley. *Journal of Archaeological Science* 31: 145-50.
- WINTERHALDER, B. & C. GOLAND. 1993. On population, foraging efficiency and plant domestication. *Current Anthropology* 34: 710-15.
- YASUDA, Y. 2002. Origins of pottery and agriculture in East Asia, in Y. Yasuda (ed.) *The Origins of Pottery and Agriculture*: 119-42. New Delhi: Lustre Press/Roli Books.

- YOU, X. 1976. Some Issues on Rice Grains and Bone-Spade *Si* Unearthed from Layer 4 of Hemudu Site. *Wenwu (Cultural Relics)* 8: 20-23 [in Chinese].
- ZHANG, J. & X. WANG. 1998. Notes on the recent discovery of ancient cultivated rice at Jiahu, Henan Province: a new theory concerning the origin of *Oryza japonica* in China. *Antiquity* 72: 897-901.
- ZHANG, W. 2002. The bi-peak tubercle of rice, the character of ancient rice and the origin of cultivated rice, in Y. Yasuda (ed.) *The Origins of Pottery and Agriculture*: 205-16. New Delhi: Lustre Press/Roli Books.
- ZHAO, S. & W.-T. WU. 1987. Early Neolithic Hemudu Culture along the Hangzhou estuary and the Origin of Domestic Paddy Rice in China. *Asian Perspectives* 27: 29-34.
- ZHAO, Z. 1998. The Middle Yangtze region in China is one place where rice was domesticated: phytolith evidence from the Diaotonghuan Cave, Northern Jaingxi. *Antiquity* 72: 885-97.
- 2005. Palaeoethnobotany and its new achievements in China. *Kaogu (Archaeology)* 2005(7): 42-9 [in Chinese].
- Zhejiang Provincial Institute of Cultural Relics and Archaeology. 2003. *Hemudu: xinshiqi shidai yizhi kaogu fajue baogao (Hemudu: an Excavation Report of the Neolithic Site)*. Beijing: Cultural Relics Publishing House [in Chinese].
- 2004. *Kuahuqiao*. Beijing: Cultural Relics Publishing House [in Chinese].
- ZHENG, Y., X. YOU, J. XU, Q. BIAN & W. YU. 1994. Rice Phytolith Analysis of Hemudu Site. *Journal of Zhejiang Agriculture University* 1994(1): 81-5 [in Chinese].
- ZHENG, Y., Y. DONG, A. MATSUI, T. UDATSU & H. FUJIWARA. 2003. Molecular genetic basis of determining subspecies of ancient rice using shape of phytoliths, *Journal of Archaeological Science* 30: 1215-21.
- ZHENG, Y., L.-P. JIANG & J.-M. ZHENG. 2004a. Study on the Remains of Ancient Rice from Kuahuqiao Site in Zhejiang Province. *Chinese Journal of Rice Science* 18:119-24 [in Chinese].
- ZHENG, Y., A. MATSUI & H. FUJIWARA. 2004b. Phytoliths of rice detected in the Neolithic sites in the Valley of the Taihu Lake in China. *Environmental Archaeology* 8: 177-83.
- ZHOU, J. 1981. Investigation of Ancient Rice from Mid and Lower Yangtze River. *Yunnan nongye keji (Yunnan Agriculture Science and Technique)* 6: 1-6 [in Chinese].
- 2003. The Morphological Investigation and Identification of Rice Grain from Hemudu Site, in Zhejiang Provincial Institute of Cultural Relics and Archaeology *Hemudu: xinshiqi shidai yizhi kaogu fajue baogao (Hemudu: an Excavation Report of the Neolithic Site)*: 429-30. Beijing: Cultural Relics Publishing House [in Chinese].
- ZOHARY, D. & M. HOPF. 2000. *Domestication of Plants in the Old World*, third edition. Oxford: Oxford University Press.
- ZOU, H., J. GU, M. LI, L. TANG, J. DING & Q. YAO. 2000. Findings of paddies of Majiabang Culture at Caoxieshan, Jiangsu Province, in W. Yan & Y. Yasuda (ed.) *The Origins of Rice Agriculture, Pottery and Cities*: 97-114. Beijing: Cultural Relics Publishing House [in Chinese].