Site of Baodun yields earliest evidence for the spread of rice and foxtail millet agriculture to south-west China

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The Chengdu plain of south-west China lies outside the main centres of early domestication in the Huanghe and Yangzi valleys, but its importance in Chinese prehistory is demonstrated by the spectacular Sanxingdui bronzes of the second millennium BC and by the number of walled enclosures of the third millennium BC associated with the Baodun culture. The latter illustrate the development of social complexity. Paradoxically, however, these are not the outcome of a long settled agricultural history but appear to be associated with the movement of the first farming communities into this region. Recent excavations at the Baodun type site have recovered plant remains indicating not only the importance of rice cultivation, but also the role played by millet in the economy of these and other sites in south-west China. Rice cultivation in paddy fields was supplemented by millet cultivation in neighboring uplands. Together they illustrate how farmers moving into this area from the Middle Yangzi adjusted their cultivation practices to adapt to their newly colonised territories.

Keywords: China, Sichuan, Baodun, third millennium BC, rice, foxtail millet, spread of agriculture

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Text S1: radiocarbon dates

AMS dates were obtained for rice grains and, in one instance, wood charcoal from the three Baodun phases and from the Han phase of Baodun (Table S1). These dates clearly situate Baodun period activity at the site between 2700–2000 BC. Examination of the dates makes it immediately apparent that the three phases represented by pottery chronology are not reflected in the distribution of archaeobotanical material across the site and that substantial mixing of deposits has occurred (Figure 2 in main paper). It is possible that burrowing rodents and insects could have moved later archaeobotanical material downwards. In addition, extraction of clay or earth to build houses or to dig trenches or pits may have moved earlier material to the (then) surface. It is clear from these dates, however, that rice was continuously present throughout the occupation of the site. Dates were calibrated using Oxcal v.4.1.7 (Reimer *et al*. 2009).

Table S1. Uncalibrated radiocarbon dates and laboratory numbers for the site of Baodun. Dates are listed in stratigraphic order within each phase, with the archaeologically oldest context at the top of the list.

Lab no.	Stratigraphic information	Phase	Date	Plant part
BA110047	T 1830 (5)	Baodun Phase 1	3890±35	Rice
BA110048	T 2426 (5)	Baodun Phase 1	3830±30	Rice
BA110049	T 2426 (5) H6	Baodun Phase 1	4010±50	Rice
BA110050	T 2431 (5)	Baodun Phase 1	3730±30	Rice
BA110058	T 2431 (4) H1	Baodun Phase 1	4060±30	Rice
BA110059	T 2431 (4) H1	Baodun Phase 1	4000±30	Rice
BA110051	T 1830 (4) H3	Baodun Phase 1	3705±30	Rice
BA110061	T 2431 (4) H11	Baodun Phase 1	4005±30	Rice
BA110062	T 2431 (4) H8	Baodun Phase 1	4015±35	Rice
BA110060	T 2431 (4) H2	Baodun Phase 1	3885±30	Rice
BA110052	T 2341 (4) H9	Baodun Phase 1	3830±30	Rice
BA111218	T 3312 (7)	Baodun Phase 1	3995±20	Wood
BA111219	T 3411 (7) H18	Baodun Phase 1	3735±20	Rice
BA111215	T 3411 (7) H17	Baodun Phase 1	3840±25	Rice

Table S1. Continued.

Lab no.	Stratigraphic information	Phase	Date	Plant part
BA110055	T 2426 (4)	Baodun Phase 2	3990±30	Rice
BA110057	T 2431 (3) G1	Baodun Phase 2	4000±30	Rice
BA111220	T 3211 (6) H10	Baodun Phase 2	3795±25	Rice
BA111216	T 3209 (5c) H8	Baodun Phase 3	3795±25	Rice
BA111217	T 3211 (6)	Baodun Phase 3	3885±25	Rice
BA110056	T 2431 (3)	Han	2150±25	Rice
BA110053	T 2426 (3)	Han	2015±30	Rice
BA110054	T 2426 (3)	Han	3565±25	Rice

Reference

REIMER, P.J., M.G.L BAILLIE, E. BARD, A. BAYLISS, J.W. BECK, P.G BLACKWELL, C. BRONK RAMSEY, C.E. BUCK, G.S. BURR, R.L. EDWARDS, M. FRIEDRICH, P.M. GROOTES, T.P. GUILDERSON, I. HAJDAS, T.J. HEATON, A.G. HOGG, K.A. HUGHEN, K.F. KAISER, B. KROMER, F.G. MCCORMAC, S.W. MANNING, R.W. REIMER, D.A. RICHARDS, J.R. SOUTHON, S. TALAMO, C.S.M, TURNEY, J. VAN DER PLICHT & C.E. WEYHENMEYER. 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50 000 years cal BP. *Radiocarbon* 51: 1111–50.

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Text S2: sorting and identification

To ensure efficiency and maximum data collection, different methods were applied to the sorting of fractions. A 2mm fraction was sorted in its entirety. Bone and shell were removed from all fractions. Seeds and plant parts were then identified; wood charcoal was reserved for subsequent analysis. The 1mm and 0.5mm fractions were sorted in their entirety for both carbonised and modern seeds; however, wood charcoal and other fragmentary plant parts were not pulled from these fractions. Owing to the large amount of inorganic residue such as sand in the 0.25mm fraction, an average of one quarter of this fraction was sorted. Identifiable plant parts such as rice spikelet bases were pulled from all fractions.

Most seeds could be identified to genus, with some identified to species (e.g. *Setaria italica*). In many cases the morphologies of archaeobotanical specimens fail to match those of modern fresh and charred specimens precisely; such uncertain identifications are marked with a ‘cf.’ before the genus or species, depending on the level of certainty.

Identification of taxa from Baodun was carried out on the basis of morphology and by reference to two different sources:

1) A personal reference collection was created by collecting plants in the field supplemented by samples from the USDA and Harvard University Herbarium. Specimens that could not be removed from the Harvard University Herbarium were consulted and documented in the collections, often forming the object of a loan in order to photograph them. Collections at University College London were also accessed on two separate occasions to check identifications with the help of Professor Dorian Fuller. On one occasion, reference material of Professor Zhao Zhijun at the Chinese Academy of Social Sciences was consulted.

2) Illustrated archaeobotanical and modern seed identification guides (Musil 1963; Soerjani *et al*. 1987; Moody 1989; Nakayama *et al*. 1996; Li 1998; Raju 1999; Cappers *et al*. 2006, 2010; Fuller 2006; Jacomet 2006; Nesbitt 2006; Liu *et al*. 2008). The *Flora of China* was frequently used to determine the list of species present in the Chengdu plain and to narrow down identifications (Wu & Raven 2006).

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Text S3: Job's tears

Job's tears (*Coix* sp.) were recovered in the form of fragmentary utricles as well as charred caryopsis (Figure S1). Job's tears have a rich history of exploitation, and starchy varieties are used as food crops, for medicinal purposes and as beads throughout East and Southeast Asia (van den Bergh & Iamsupasit 1996; Arora 1977; Roder 2006). Job's tears may have been domesticated somewhere in eastern Asia or on the Indian subcontinent (Jain & Banerjee 1974; Simoons 1991). Watt (1908) has proposed that populations moving across the Himalayas may have played an important role in the distribution of this crop. Only a handful of archaeological finds have been reported. In China, aside from a single early identification at the site of Hemudu (*c*. 5000–4500 BC) (Zhejiang Sheng Wenwu Kaogu Yanjisuo 2003), finds of Job's tears all post-date the Han dynasty. The early date of the Job's tears at Baodun (*c*. 2700–2000 BC) thus makes them important for understanding when the exploitation of this crop began.

Identification was made on the basis of comparison to modern reference material collected by the authors. We identified Job's tears in the samples on the basis of the following criteria. On both carbonised and uncarbonised specimens the outer surface of the utricle was translucent, lustrous and showed a characteristic cleaving pattern. This surface has minute cell structuring. The interior surface shows clear fibrous bundles that correspond closely to the specimens described by Jiang *et al*. (2008)[1]. Only two species of *Coix* are naturally distributed in China: the annual cultivated *Coix lacryma-jobi* and the wild perennial *Coix aquatica* (Chen & Phillips 2006). Because of the very fragmentary nature of our specimens, we were not able to distinguish between the two. Although only one caryopsis was recovered from Baodun, the large number and high ubiquity of utricle fragments present makes it possible that these *Coix* sp. may have been

[1] In addition to Job's tears, we also unearthed a large number of *Hackelochloa* sp. utricles. Initially, these appeared very similar to the specimens of *Coix*. Finds of several intact specimens of *Hackelochloa* allowed us to separate them on the basis of the following characteristics: the surface of the utricle of *Hackelochloa* is either smooth or has a reticulated, wrinkled surface pattern. More complete specimens have a hard triangular apex, which is another important distinctive characteristic (Figure S2c). In addition, the interior surface of *Hackelochloa* utricles show distinctive rows of ladder-like patterns, while those of *Coix* are generally thicker and have clear fibrous bundles (Figure S1). *Hackelochloa* has been reported as a weed of dry land cultivation (Soerjani *et al*. 1987). We found that both of these utricles were preserved in a silicified state when charred.

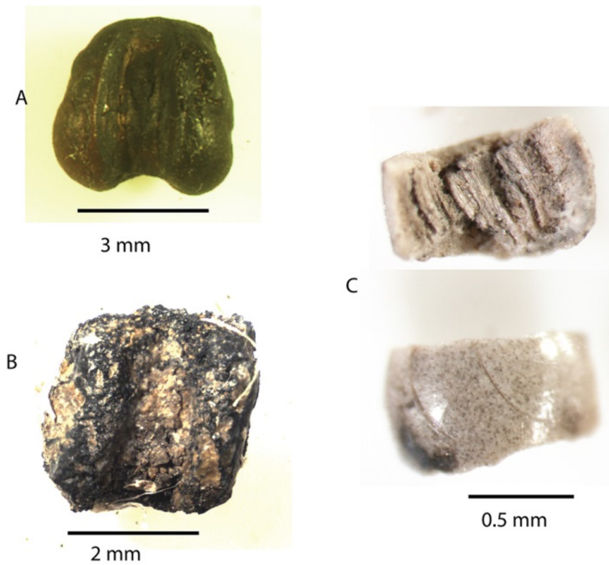

*Figure S1. Job's tears (*Coix *sp.): a) charred modern caryopsis; b) archaeological caryopsis from Baodun; c) utricle fragments from T3213 H7 (Phase 3).*

gathered or cultivated as a food source at the site. However, the perennial *Coix aquatica* has been observed as a weed of aquatic environments, and we cannot eliminate the possibility that these were in fact weeds of rice paddy agriculture (Soerjani *et al*. 1987). The fact that the utricles of all specimens uncovered at Baodun were recovered in a highly fragmentary form suggests they may have been exploited as a food source rather than as jewellery. In contrast, a number of intact utricles from the weed *Hackelochloa* sp. were identified in the assemblage. This suggests that should *Coix* have entered the assemblage as a weed, one would expect to find at least a few intact specimens.

The single Job's tears caryopsis unearthed from Baodun is small (3mm in diameter). Domesticated Job's tears (var. *ma-yuen*) marketed for food in China today measure on average 1–2mm larger than the example unearthed from Baodun. In addition, Job's tears quickly undergo massive increases in size due to charring (Figure S3). It is likely, therefore, that the example unearthed was a wild variety such as *Coix lacryma-jobi* var. *puellarum*, although it is also possible that it is immature. Our charring experiments further indicate that Job's tears caryopses quickly become unrecognisable when exposed to heat (Figure S3). This could explain the large number of utricles but very small numbers of caryopses present in the Baodun assemblage.

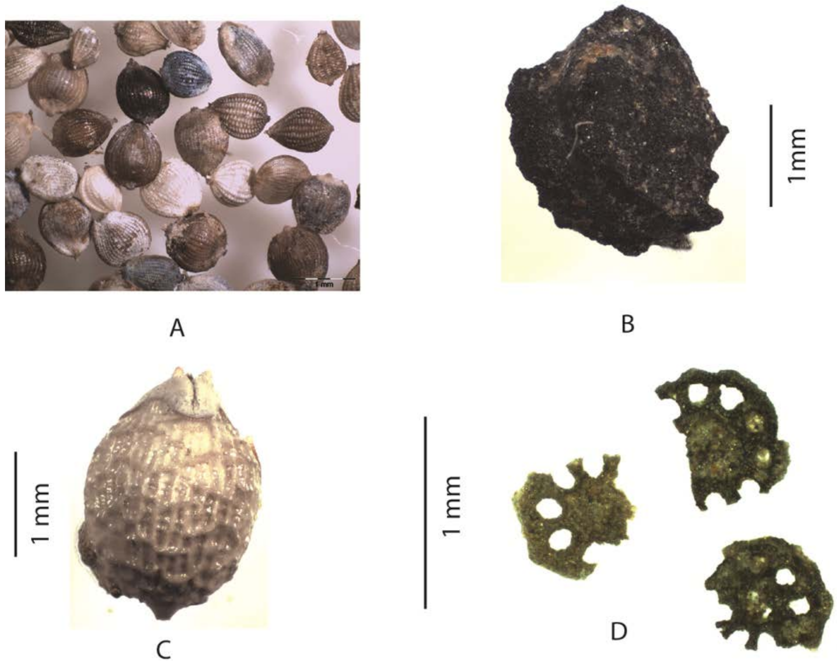

Figure S2. Weedy taxa represented at Baodun: a) Fimbristylis *sp. from T1586 H2 (Phase 2); b)* Potamogeton *sp. from T3628 H23 (Phase 2); c)* Hackelochloa *sp. from T1586 H2 (Phase 2); d)* Equisetum *sp. from T2426 H6 (Phase 1).*

In addition to the Job's tears found at the site of Hemudu, there are other archaeological finds reported, including, for example, starch grains from the Xishan site (*c*. 1046–256 BC) (Ge *et al*. 2010). Aside from these earlier finds, solid evidence for Job's tears exploitation appears in the record several millennia later. Finds have been unearthed at the Sampula cemetery in Xinjiang (0 AD) (Jiang *et al.* 2008). A number of seeds were also reported from a set of Eastern Han (AD 25–220) dynasty tombs in Xi'an (Zhao 2010) as well as in Luoyang (Yu 1977). Historical mentions of Job's tears date to the Han dynasty, when it is reported to have been brought to northern China from the kingdom of Nanyue in southern China by the general Ma Yuan (Smith 1969; Simoons 1991). The Indian subcontinent has a better record of early exploitation. Large quantities of *Coix* were unearthed at the Harappan site of Kuntasi (*c*. 2200–1700 BC), where they were presumably made into beads (Kajale 1996). Closer to China, Job's tears have also been found in layers of the site of Mebrak in Nepal dating to *c*. 400–100 BC. In Southeast

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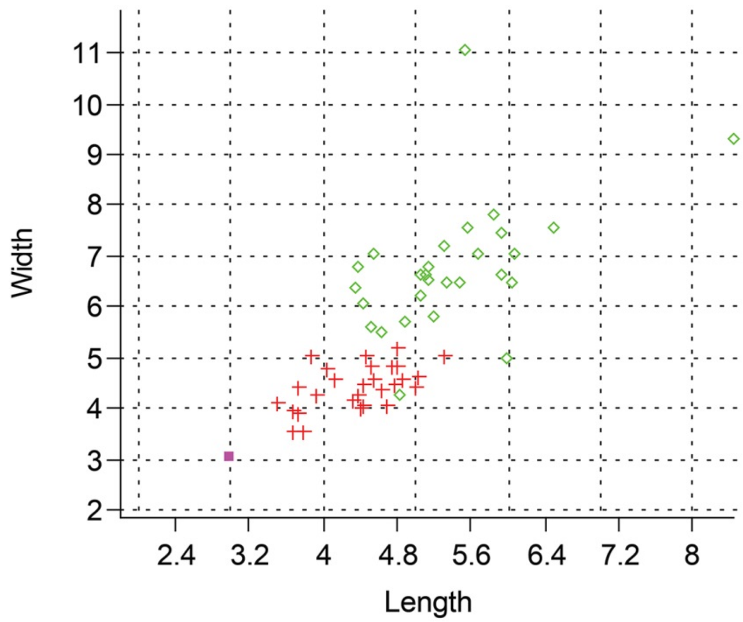

Figure S3. Job's tears carbonisation experiment. After being carbonised at 300° Fahrenheit for 30 minutes in a muffle furnace, a collection of 75 Job's tears was distorted beyond recognition and impossible to measure. Charring in a muffle furnace at the same temperature for 15 minutes yielded only 20 per cent fully carbonised caryopses, although these had become extremely puffed and experienced a huge increase in size. Job's tears may thus be biased against preservation by carbonisation. Archaeological specimen from Baodun (Phase 3, T 3212 H7) = pink square; uncarbonised domesticated Job's tears = red cross; carbonised domesticated Job's tears (these are the same caryopses as those measured in red) = green circles.

Asia, Job's tears have been uncovered from sites in the Khao Wong Prachan valley in Central Thailand (of unknown date) (Weber *et al*. 2010).

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Text S4: pulses

Large numbers of a small round vetch (*Vicia* sp.) were identified in the assemblage (Figure S4c). The *Vicia* sp. present in our sample was small seeded and spherical. Thirteen species of *Vicia* are endemic to China (Bao & Turland 2010), with overlapping morphological characteristics making them difficult to identify to species. The specimens unearthed at Baodun are characterised by an average diameter of 1.5mm but with a large range in sizes, pointing either to the existence of several different species or of different stages of maturity. *Vicia* had a ubiquity of 42 per cent, which is the same as for foxtail millet, and may have been either gathered or cultivated. *Vicia* is a common ground cover in dryland fields, and it grows extensively in disturbed areas around sites (Wang 1990). It is possible that its introduction into the site may have been as a dryland weed. The use of different species of *Vicia* as a food staple in other areas of the world is well documented both archaeologically and historically. Bitter vetch (*Vicia ervilia*) has been identified from archaeological sites as early as the seventh–sixth millennia BC in Turkey (Zohary & Hopf 2000). There are also reports of it occurring in archaeological sites in the Uttar Pradesh region of northern India (Pokharia 2008), and it was well known as a fallback food in Europe in historical times (Zohary & Hopf 2000). Today in Sichuan Province, the leaves of Chinese species of vetch are commonly used in both soups and stir-fry. The seeds of *V. sativa* are reported as being collected in times of famine (Hu 2005).

Species of *Vigna* can be identified on the basis of overall shape, hilum and plumule position (Crawford & Lee 2003; Fuller & Harvey 2006). Two poorly preserved cotyledons of *Vigna* sp. were found in the Baodun layers of the site (Figure S4a). Fourteen species of *Vigna* are native to China. Although one of these was too fragmentary to attempt an identification, for the other cotyledon dating to the earliest layers of the site only adzuki bean (*V. angularis*) corresponded to this specimen in terms of overall shape. The small size of these cotyledons fits into the size range for wild *V. angularis*. Its poor state of preservation, however makes this difficult to confirm. There is strong evidence to indicate that *V. angularis* was domesticated in Japan (Crawford 1992), however some genetic studies suggest a possible centre of diversity in Nepal, Bhutan and

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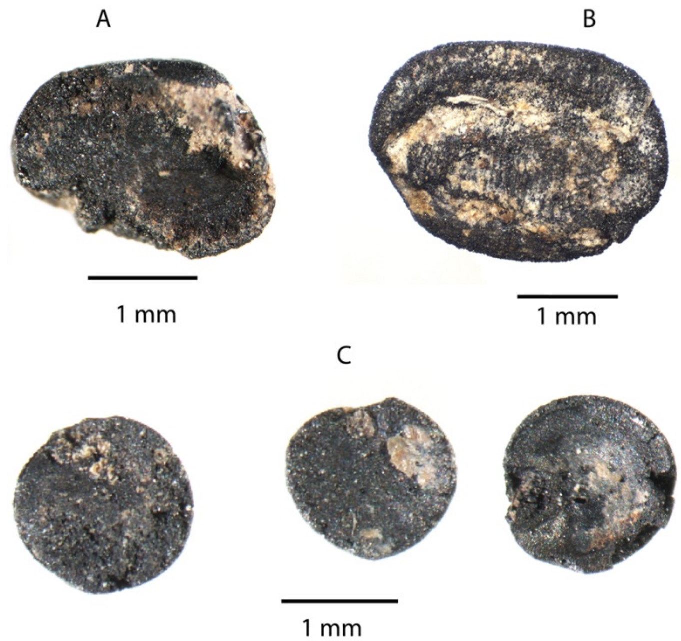

Figure S4. Pulses recovered from Baodun: ***a)*** Vigna *sp. (cf.* angularis*). This specimen was found in layers associated with the Baodun period, from T2431 H11 (Phase 1). This specimen shows a short plumule which is characteristic of the adzuki bean;* ***b)*** Vigna *sp. (cf.* radiata*). This specimen shows a long plumule characteristic of mung bean and belongs to the Han dynasty component of the site (from T 3411 layer 4);* ***c)*** *three different specimens of* Vicia *sp. from T 2426 (5) (Phase 1).*

the general Himalayan region (Han *et al*. 2005; Xu *et al*. 2008). The lack of archaeobotanical work in this region makes it difficult to establish if this area could have been a second centre of domestication. As such, the find of possible *V. angularis* makes it a tantalising piece in the puzzle of this species' use. In addition to the *Vigna* found in the Baodun layers, one specimen of a small mung bean (*V. radiata*) was found in layers of the site associated with the Han dynasty (206 BC–AD 220). The small size of this specimen makes it possible that it was wild or immature (Figure S4b). Wild *V. radiata* are found throughout the eastern Ghats of the Indian subcontinent and western Himalayan foothills (Fuller & Harvey 2006). It is unclear whether or not Sichuan fits into this wild range, although given its proximity to this region that is likely.

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Text S5: condiments and fruits

Remains of a number of other economically important species were unearthed from Baodun including some from the beefsteak plant (*Perilla* sp.), which is also grown in an upland environment. The beefsteak plant is used widely in Japan and Korea and to a limited extent in China for its aromatic leaves, oil and seeds. Archaeologically it is well represented throughout Japan and China (Crawford 1992; Zhao & Xu 2004; Zhao & Fang 2007; Zhao 2010).

Fruits are an important component of any diet; in many instances, however, these are under-represented in archaeological sites. A single seed of wild hawthorn (*Cratageus* sp.) was recovered from ash pit 5 (Figure S5). *Cratageus* has a long history of consumption in China, although to date it has only been described at sites from northern China (Fuller & Zhang 2007).

*Figure S5. A hawthorn (*Cratageus *sp.) endocarp viewed from two different angles from T2121 H5 (Phase 2).*

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