

## Is there a centre of early agriculture and plant domestication in southern China?

Tim Denham\*, Yekun Zhang and Aleese Barron

School of Archaeology and Anthropology, AD Hope Building, Australian National University, Canberra ACT 2601, Australia

\*corresponding author

*The archaeobotanical evidence for a putative third centre of early agriculture and plant domestication in southern, subtropical China is reviewed. The available data are consistent with the exploitation of vegetatively reproducing plants, including plant management and resource intensification. Currently, there is nothing in the published archaeobotanical records that is diagnostic of early cultivation or plant domestication based on vegetative propagation in southern China. Vegetative propagation is associated with traditional cultivation in wet, tropical and subtropical environments of Africa, the Americas, Southeast Asia (mainland and island), New Guinea and the Pacific, although it occurs to some degree in many agricultural systems. The uncertainties raised by this review are not unique to southern China, they plague the identification of early cultivation based on the vegetative propagation of plants in other regions of the world.*

Early agriculture and plant domestication is well-attested for different cereals in two regions of China: foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) along the Yellow River from at least 8000 cal BP (Zhao 2004; Bettinger et al. 2010); and, of rice (*Oryza sativa*) along the middle and lower reaches of the Yangtze River sometime between c. 8000-6000 cal BP (Fuller et al. 2009; Fuller 2011; Deng et al. 2015). The dates of early agriculture based on cereal cultivation vary depending in part upon the lines of evidence relied upon (e.g., compare Fuller et al. 2007 and Liu et al. 2007). A third region of early agriculture has been proposed along the Pearl River in southern China, primarily comprising the present-day provinces of Guangdong and Guangxi (Zhao 2006, 2011). In contrast to the other two regions, the southern centre is reportedly based on the vegetative propagation and cultivation of sub/tropical plants – including underground stem/rhizome (e.g., lotus root, *Nelumbo nucifera*), corms (e.g., taro, *Colocasia esculenta*), tubers (e.g., yams, *Dioscorea* spp.), bananas (*Musa* spp.) and palms (e.g., fishtail palm, *Caryota* sp.). These vegetational practices are considered to predate the southward expansion of rice cultivation to the region around c. 5500-5000 cal BP (Guedes et al. 2013; Yang et al. 2016).

The archaeobotanical evidence for the putative third centre of early agriculture in southern China is assessed against a range of human-plant domesticatory relationships. The assessment of the southern Chinese evidence sheds light on broader problems with the investigation of early plant exploitation, cultivation and domestication in the wet tropics and subtropics.

These reflections identify the need to reinvigorate the study of archaeological parenchyma, in concert with starch and phytolith analyses, within tropical archaeobotany.

### **Human-plant domesticatory relationships**

The character of human-plant domesticatory relationships can be exemplified against a range of plant exploitation practices including gathering, management, resource intensification and cultivation (Harris 1990, 2007). Early scenarios can be envisaged in which people exploit plants through the gathering of bark, buds, fruits, leaves, nuts, roots, sago, seeds and tubers, among many other plant parts. Here there is limited directed selection occurring, except through the potential reduction in populations of exploited species resulting from the preferential gathering of selected species and phenotypes.

An increased intensity of human management, namely through levels of intervention in promoting the conditions for growth of plants, occurs as a result of tending and weeding, periodic pruning and burning to encourage new growth, as well as clearing of vegetation around stands of favoured plants. Here, the level of human intervention in plant lifecycles increases, with attendant human-directed selection of favoured phenotypic traits among managed plants. The basis of phenotypic selection can be characterised in various ways - for example cultural, ecological, or energetic. In general terms, specific species or specific phenotypes of a species may be selected based on: ease of growth, hardiness and resistance to stress (whether disease, pest or environmentally-induced); productivity (including yield volume, synchronicity of yield, and inter-annual reliability of production); ease of processing (such as hard seed coat or nut casing, extraction of edible portion, spininess, toxicity, acidity); ease of cooking (pounding, soaking, heating, roasting, etc.); yield in terms of calories, protein, oil and nutrients; as well as, colour, taste and palatability, texture and so on.

These types of human-plant relationship occur in a broad range of lifeways, from 'hunting-gathering' to 'farming'; they all exert varying degrees of selective pressure on exploited plants. The degrees to which these phenotypic preferences become more frequent within a population, as well as the degrees to which genetic markers of preferential selection become fixed, reflect numerous factors including persistence of human practices (namely, continuity in directed selection) and degree of inter-breeding with populations not subject to the same degree of selective pressure (namely, extent of genetic isolation) (Larson et al. 2014).

Often, there is a lack of research on food plants that may have been managed in this way. An interesting example concerns *murnong* or yam daisy (*Microseris scapigera*; Gott 1983) that was intensively utilised for its underground storage organ by Aborigines in Southeast Australia. There is clear evidence that Aboriginal land management practices increased the density of *murnong* across the landscape (namely, resource intensification) and potentially led to the creation of ecotypes due to the expansion of plants into new landscapes within the human niche. The creation of new phenotypes and genotypes as a result of extensive, resource intensification practices is probably common in the past, and yet the character of

these domesticatory relationships is often excluded from orthodox discussions of ‘domestication’ because they are a result of practices by people often referred to as ‘hunter-gatherers’.

A stepped change in human directed selection occurs with planting, including transplanting. Plants as a group, as well as many species, exhibit two modes of reproduction – sexual and asexual. People have exploited and domesticated plants using both forms of biological reproduction, which have plausibly affected the ways in which plants exhibit domestication traits (Ladizinsky 1998).

Sexual reproduction in plants has been exploited by people through the harvesting, storage and planting of seed from favoured species and phenotypes. Domestication based on sexual reproduction is commonly associated with annuals, especially cereal and legume cultivation, but also extends to a whole range of plant groups, from herbaceous plants to trees. Early cultivation leading to domestication based on sexual reproduction has been claimed for cereals and legumes in Southwest Asia, including barley (*Hordeum vulgare*) and wheat (*Triticum* spp.), peas (*Pisum sativum*) and lentil (*Lens culinaris*); millets and rice in China; sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum glaucum*) in Africa; maize (*Zea mays*) and squash (*Cucurbita* spp.) in the Americas; among others (Fuller et al. 2014).

Early forms of agriculture and domestication have also been based on the asexual reproduction of plants. Globally significant crop plants that are cultivated and have been domesticated under vegetative propagation include: bananas (*Musa* spp.), sago (*Metroxylon sagu*), sugarcane (*Saccharum officinarum*), taro (*Colocasia esculenta*) and yams (*Dioscorea* spp.) from the Indo-Pacific region; as well as, manioc (*Manihot esculenta*), potato (*Solanum tuberosum*) and sweet potato (*Ipomoea batatas*) from South America. There are also numerous regionally important plants – such as Enset (*Ensete ventricosum*) and yam (*Dioscorea cayenensis*) in Ethiopia (Hildebrand 2007). People may vegetatively propagate plants even though they know that they reproduce from seed. In other cases, prolonged clonal reproduction may have led to the loss of sexual reproductive capacity, i.e., marita pandanus (*Pandanus conoideus*) in New Guinea. Vegetative propagation tends to predominate in cultivation practices within the wet tropics and subtropics (see Denham et al. 2007).

Early forms of cultivation, like current agricultural practices, vary in their reliance upon sexual and asexual reproduction. Early cultivation in northern and central China focussed on millets (foxtail and broomcorn) and rice, respectively; while the putative southern Chinese domestication centre focussed on a range of herbs, palms and root crops. Although sexual and asexual modes of cultivation and domestication are usually discussed separately, they likely co-occurred in most regions in the past.

## **The archaeobotanical evidence**

Three sites provide archaeobotanical evidence most relevant to early vegetative-based plant exploitation in southern China: Zengpiyan, Niulandong and Xincun (Figures 1 and 2). Each site has yielded archaeobotanical remains of vegetatively propagated plants that predate c. 4500 cal BP: macroremains, phytoliths and starch at Zengpiyan (Institute of Archaeology 2003); starch at Niulandong (Wan 2012); and, phytoliths and starch at Xincun (Yang et al. 2013).

Zengpiyan is a cave in northern Guangxi Province that was excavated in the 1970s and in 2001. The later excavations were designed for systematic archaeobotanical recovery from the cave deposits that were left intact during the previous excavations (Zhao 2011). The chronology of occupation extends from c. 12,000 cal BP to c. 7000 cal BP (Institute of Archaeology 2003:433-445; Zhao 2011). No archaeobotanical materials were recovered during the original excavations, whereas re-excavation yielded a variety of charred plant remains including “wood, seeds, nuts, roots, and tubers” (Table 1; Institute of Archaeology 2003:286-293; Zhao 2011:S303). The charred tuber or root remains from Zengpiyan were not identified to species or genus level.

Starch residue analysis was conducted on 25 artefacts. Starch from a subterranean storage organ – such as root, tuber or corm - was found on the used edges of five artefacts, representing each phase of occupation (Lu 2003:646-651). Based on a published image, the starch granules broadly conform to *Colocasia* in terms of size (1-8  $\mu\text{m}$ ), shape (spherical) and clustering of grains into sheets (Fullagar et al. 2006). Caution is needed: the identification of taro from starch granules is problematic because it can be confused with metabolic starch or other species (Crowther 2005).

Taken together, the macrobotanical and starch granule evidence from Zengpiyan is consistent with the exploitation of rhizomes, tubers and corms during the early Holocene. However, the remains are not abundant, rather they are sparse. Similar archaeobotanical evidence has been forthcoming from Pleistocene and early Holocene hunter-gatherer sites across the tropics of Southeast Asia (Barton & Paz 2007), Island Melanesia (Barton & White 1993; Loy et al. 1992) and New Guinea (Summerhayes et al. 2010). There is nothing in the evidence to suggest cultivation of these plants.

Niulandong cave is located in Guangdong Province. The site was occupied around 12,000 cal BP to 8000 cal BP. Macrobotanical material was not recovered during excavation and starch residue analysis was undertaken on the used edges and unused parts of eight stone artefacts likely employed for plant processing (Jin et al. 1998; Liu 2003; Wan 2012). In total, 109 starch granules were extracted and identified: 21 cycads (Cycadaceae), 9 unidentified rhizomes, 3 Zingiberaceae, 34 panicoid grasses (Panicoideae) and 42 unidentified (Wan 2012). Although starch granule analysis for eight artefacts at Niulandong indicates the exploitation of rhizomes together with other types of plant during the early Holocene, such activities are consistent with broad spectrum exploitation of wild plants.

Xincun is an open site along the coast of Guangdong Province. The site was occupied from approximately c. 5500 cal BP to c. 4400 cal BP (Yang et al. 2013). Residues were extracted

from eight artefacts for starch analysis and four artefacts for phytolith analysis. Numerous economically useful plants were identified among the 454 starch granules, including 78 from fishtail palm, 17 from banana and 48 from several freshwater roots and tubers. The last group of plants comprised: 29 water chestnut (cf. *Eleocharis dulcis*), 17 chinese arrowhead (*Sagittaria* sp.) and 2 lotus root (cf. *Nelumbo nucifera*). Of 1950 identified phytoliths, 56% derived from palms (Aracaceae).

The archaeobotanical residues from twelve artefacts at Xincun indicated exploitation of palms, bananas and various roots and tubers. Although many of these plants are still eaten in southern China today - such as bananas, palms for sago, as well as roots, tubers and rhizomes – and are usually propagated vegetatively there, these findings solely indicate that people were targeting certain kinds of starch-rich plant (Yang et al. 2013). These types of record, indicating the exploitation of vegetatively propagated plants prior to the advent of millet and rice cultivation, are now emerging with the application of more comprehensive archaeobotanical sampling strategies at archaeological sites across Southeast Asia (e.g., Oliveira 2012; Castillo et al. 2017).

Palaeopathology and material culture have also been used to infer early agriculture in this region, but these lines of evidence are highly inferential and are not necessarily linked to vegetatively reproducing plants. For instance, the incidence of dental caries in early Holocene burials at Zengpiyan (Institute of Archaeology 2003:420-421) and Liyudun (Chen & Li 2013) has been considered to reflect agricultural populations subsisting on tuber and root crops. Such inferences are problematic in the absence of abundant archaeobotanical evidence and especially since stable isotope analysis at Liyudun suggests a maritime diet. Similarly, there has been a tendency to assume some form of cultivation existed in this region prior to the advent of domesticated rice from c. 5500-5000 cal BP (Zhao 2011). This inference has persisted despite the lack of relevant archaeobotanical evidence from Dingsishan (Chen 2011; Zhao et al. 2005), Guye (unpublished) and Xiaojin (Chen 2011; Archaeological Team of Guangxi Province 2004).

### **Exploitation of vegetatively reproducing plants**

Numerous authors have suggested that early modern humans had a predisposition to the exploitation of vegetatively reproducing plants (from Sauer 1952). Such an orientation to these particular plant resources appears to be more marked in the wet tropics and subtropics than elsewhere (Harris 1972; Yen 1990; Piperno & Pearsall 1998; Denham et al. 2003; Clement et al. 2010; Barton & Denham 2011; Denham 2013). This reflects, in part, the prevalence of vegetatively reproducing plants in less seasonal climates and, in part, the greater caloric yield from sago palms, roots, tubers and rhizomes in comparison to grass seeds within wet tropical rainforests (e.g., Denham & Barton 2006). However, the clonal exploitation of plants is likely to be part of most plant exploitation and cultivation strategies.

An early predisposition to the exploitation of roots and tubers is evident across the wet tropics of Island Southeast Asia (e.g., Niah Cave on Borneo; Barton & Paz 2007), Island Melanesia (e.g., Kilu Cave in the Solomon Islands; Loy et al. 1992) and New Guinea (e.g., Ivane Valley; Summerhayes et al. 2010) (see reviews in Barton & Denham 2011 and Blench 2013). The archaeobotanical records from the early Holocene at Zengpiyan and Niulandong conform to this pattern of broad spectrum plant exploitation, including subterranean storage organs. A key aspect of these exploitation strategies likely included the active management and intensification of plant resources in the landscape, potentially aided by replanting and translocation (Barton & Denham 2011, 2017) – as also witnessed in the tropical rainforests of northern Australia (Hynes & Chase 1982; Denham 2008). Through time, people increasingly locked on to specific oil-, protein- and starch-rich plants and became more reliant on them for their diet, while simultaneously increasing the density of favoured species in the landscape (Denham & Barton 2006; Denham et al. 2009a). These types of practice conform to the archaeobotanical record from Xincun, where favoured species were targeted from at least 5500-4400 cal BP, with several food plants still being important in the region today.

Based on current evidence, the archaeobotanical record from southern China is not suggestive of nascent cultivation or domestication prior to the adoption of rice from c. 5500-5000 cal BP. The evidence conforms well to similar records of plant exploitation from wet tropical and subtropical environments across Southeast Asia and Melanesia. Cultivation of vegetatively-propagated crops could have occurred in southern China before the adoption of rice; as yet there is no evidence to substantiate such a claim.

### **Taking a broader view**

Forms of plant exploitation, cultivation and domestication based on sexual and asexual reproductive capacity of plants, respectively, require different archaeobotanical methods for their investigation. Macrobotanical remains of fruit stones, nutshells and seeds often preserve well in charred form at archaeological sites. Changes in shattering versus non-shattering percentages and grain size for seeds can be recorded as indicators of domestication status (Fuller et al. 2014), as well as of the dependence of people on cultivated plants (Smith 2001; Harris 2007).

By contrast, several key staples under cultivation in the wet tropics and subtropics do not yield hardier archaeobotanical remains that readily preserve in archaeological contexts. Many vegetatively-propagated root crops – such as manioc, sweet potato, taro and yams, as well as other crops such as sugarcane - are usually harvested prior to seed-set. The exploitation, cultivation and domestication of these crops in the wet tropics and subtropics has a lower archaeobotanical visibility and requires a different methodological suite, such as that employed for the New Guinea highlands (Denham et al. 2003, 2009b). A mixed-method suite for the investigation of tropical plant exploitation comprises macrobotany (Pearsall 2000), archaeological parenchyma (Hather 2000), phytolith analysis (Piperno 2006) and starch granule analysis (Torrence & Barton 2006) (see Hather 1994). Of these, the archaeobotanical

analysis of parenchymatous tissues is the least widely adopted, yet may have the greatest potential.

Archaeological parenchyma usually preserves at archaeological sites in charred or desiccated form (e.g., Ugent et al. 1981; Hather and Kirch 1991). For the wet tropics, the analysis of archaeological parenchyma was conceived as a major breakthrough in the investigation of cultivation and domestication of vegetatively propagated crops (Hather 1992, 1994). Even allowing for the phenotypic plasticity of many plant parts, especially underground storage organs, the analysis of archaeological parenchyma enables the taxonomic identification of plants under cultivation and a gauge of domestication status (Figures 3-4). Currently, the technique is underutilised, with a lack of expertise and accessible collections. Despite these limitations the analysis of archaeological parenchyma, in conjunction with starch and phytolith analyses, has the potential to address a range of questions concerning plant exploitation across a vast region from southern China to northern Australia:

- Did people engage in the cultivation and domestication of vegetatively propagated crops in southern China prior to the advent of cereal cultivation c. 5500-5000 cal BP?
- Did people engage in vegetative forms of agriculture in parts of Island Southeast Asia prior to the dispersal of rice and other cultural traits from the Asian mainland from c. 4000 cal BP? Previous studies of plant use in the region, including of archaeological parenchyma (Paz 2001; Barton and Paz 2007; Oliveira 2012), suggest continuity rather than discontinuity in plant exploitation practices (Denham 2013).
- Although the wetland archaeological evidence for cultivation practices is well-attested for multiple sites in the highlands of Papua New Guinea (Golson et al. 2017), to what extent were people dependent upon cultivated foods for their subsistence?
- Did people in northern Australia engage in nascent forms of cultivation during the Holocene (Jones and Meehan 1989; Denham et al. 2009c)?

The archaeobotanical records from southern China should not be looked at in isolation, rather they need to be considered in broader regional and global contexts. Currently, the evidence for early agriculture based on vegetative propagation in southern China is consistent with records of hunter-gatherer exploitation across Southeast Asia, Melanesia and northern Australia. For southern China, there is a disproportionate reliance on small samples of artefact residues from three sites. The continued investigation of plant exploitation and any early cultivation based on vegetatively propagated plants in the region requires the systematic application of a suite of archaeobotanical techniques that has been successfully applied to the investigation of early cultivation and plant domestication in other subtropical and tropical regions. Hopefully, this discursive piece is a spur to the publication of more definitive archaeobotanical findings from this intriguing region, if they exist, as well as to future research.

## Figure Captions

**Figure 1.** Map of sites discussed in southern China: 1 - Xiaojin; 2 - Zengpiyan; 3- Dingsishan; 4 - Niulandong; 5 - Guye; 6 - Xincun; 7 – Liyudun

**Figure 2.** Timeline depicting key sites with archaeobotanical evidence of vegetatively propagated plants. The grey zone represents the approximate date for the introduction of rice cultivation to southern China.

**Figure 3.** Visualisation of taro (*Colocasia esculenta*) parenchyma reference sample (Hather Ref. \*\*\*\*) using microCT (Varslot et al. 2011; Limaye 2012). Left-hand image depicts a 2D virtual cross-section through a whole corm, with \*\*\* in red, \*\*\* in blue and \*\*\* in yellow. Right-hand image depicts a rendered 3D visualisation of an interior surface \*\*\*\*?.

**Figure 4.** Visualisation of greater yam (*Dioscorea alata*) parenchyma reference sample (Hather Ref. \*\*\*\*) using microCT (Varslot et al. 2011; Limaye 2012): right-hand image is a 3D visualisation of the \*\*\* of the tuber; upper-left is a close-up of \*\*\* showing \*\*\*\* (blue) and \*\*\* (yellow); and, lower-left depicts a high resolution close-up of \*\*\*\*.

**Table 1.** Summary of archaeobotanical findings from re-excavation of Zengpiyan in 2001 (Institute of Archaeology 2003:287)

Time	Tuberous remains (grams)	Charred plant remains (grams)	Number of seeds	Volume of soil (litres)
Period 1 12,000-11,000 cal BP	0.43	2.45	5	1382
Period 2 11,000-10,000 cal BP	0.17	2	4	1006
Period 3 10,000-9000 cal BP	1.76	15.72	51	4150
Period 4 9000-8000 cal BP	0.49	7.24	7	1053
Period 5 8000-7000 cal BP	3.21	8.59	15	1151
<b>Total</b>	6.06	36	82	8742

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