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DEVELOPMENT OF CEREAL AGRICULTURE IN PREHISTORIC MAINLAND SOUTHEAST ASIA

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This paper presents archaeobotanical research and analysis from Prehistoric Mainland Southeast Asia in order to understand the development of cereal agriculture in the region. It draws where possible on other disciplines to confirm and strengthen hypotheses. There is enough complementary evidence from archaeobotanical, genetic, morphometric and carbon isotope studies to explore issues on agriculture in Southeast Asia. As a result, we can have a better understanding of the key components that characterise early agricultural development in SEA, particularly the subspecies of rice introduced and cultivation systems practiced. This discussion will be enriched in the future with more studies on plant remains and through a continuation in the discourse between other disciplines and studies from neighbouring regions.

Introduction

Considering the importance in Southeast Asia of cereal agriculture, particularly rice, its history and development remains patchy. Nonetheless, our understanding of cereal agriculture, including rice (*Oryza sativa*) and foxtail millet (*Setaria italica*), has improved in the past two decades. In the 1960s, it was proposed that metallurgy was an independent invention in Southeast Asia (for a review, see Pryce 2009) and it was similarly considered at that time that this region was a centre of rice domestication (Gorman 1977; Sauer 1952; Solheim 1972; cf. Chang 1968, 1970; Chang and Bunting 1976). Today, these views are discredited. We now know that neither rice nor foxtail millet were domesticated in Southeast Asia. These cereals were introduced into Southeast Asia during the Prehistoric Period from China, just like metallurgy.

This paper brings together the sources of evidence for the development and spread of cereal agriculture in prehistoric Southeast Asia. The main line of evidence comes from archaeobotanical research. Other disciplines can be used to endorse and confirm hypotheses arrived at through the analysis of plant remains.

The most concrete evidence for the past use or existence of any plant is the actual remains of the plant itself. The collection of such evidence is done through archaeobotanical sampling. Archaeobotanical research in Southeast Asia in the past decade has more than tripled. The primary data has revealed a complex history of the evolution of agriculture in the region. Likewise, major leaps in the field of archaeobotany in China has provided evidence that establish the centres of domestication for *japonica* rice in the Middle and Lower Yangtze, and for foxtail millet in Northern China (Fuller 2011; Fuller *et al.* 2010; Jones and Liu 2009; Song 2011; Yang *et al.* 2012; Zohary *et al.* 2012). Archaeological evidence from material culture (e.g. shared pottery motifs, existence of tillage tools) has also helped to determine spheres of contact (or lack of) as well as provide further evidence for farming and possibly, its intensification.

Other sources of information come from morphometric analyses of modern and archaeological rice that help distinguish between the two subspecies, *indica* and *japonica*. This type of analysis is not a definitive tool to determine the subspecies because there is much variation in the size and shape of rice, especially in modern rice. However, these analyses give a strong indication when performed on a population level using a medium sized sample (n=>20) and not on discrete units, which can be confirmed later with genetics. Morphometric studies are a financially viable alternative to genetic analysis, but genetics provides more robust findings. Archaeogenetics of plant remains has been a useful discipline in other regions of the world. Ancient DNA has provided resolution for some issues (for a review, see Brown *et al.* 2014) but may also be contentious (e.g. Smith *et al.* [2015] paper on early wheat in Britain predating the first archaeological evidence of the cereal by at least 2000 years). Although extraction of ancient DNA has been most successful with desiccated plant remains, the work done on rice by Tanaka and reported in Castillo *et al.* (2015) has demonstrated that aDNA can also be successfully extracted and amplified from prehistoric charred plant remains.

This article is divided into sections providing a synopsis of the adoption of cereal agriculture in mainland Southeast Asia in the prehistoric period. Figure 1 is a map showing the sites mentioned in the article. This is expanded to a discussion of the possible dispersal routes for the diffusion of rice and foxtail millet to mainland Southeast Asia from China. I limit my discussions to the South China - Southeast Asian zones of interaction. A review of the origins of foxtail millet and rice in China is outside the scope of this paper but there are several studies that present hypotheses for the diffusion of these cereals within China and their arrival into the southern Chinese provinces (Fuller *et al.* 2010; Fuller 2011; Guedes 2011; Jin *et al.* 2014). As will be discussed in this paper, whilst rice in Southeast Asia originated from China, how it came to be cultivated in Southeast Asia is not entirely clear. The section in this paper 'The cereal evidence in Mainland Southeast Asia' reports on the body of evidence used in discussions of cereal agriculture in Mainland SEA. The largest dataset comes from the plant remains recovered through archaeological efforts. The data reported here is not exhaustive and instead provides information from key sites that have helped define our understanding of early cereal agriculture in the region. Genetic and morphometric studies have also been important sources of information to distinguish the subspecies of rice, and therefore determine whether it was Chinese or Indian in origin. The results are discussed within the context of cereal evidence in Mainland SEA. Farming systems and changes in agricultural practices over time are then discussed. The weed flora associated with cereals are used to define systems of land use and cultivation practices in prehistory, specifically whether dryland or wetland. The examination of weed flora in the archaeobotanical assemblage has been applied mainly in Europe and the Near East (Boogard *et al.* 1999; Colledge 1994; Colledge *et al.* 2005; Jones 1981, 2002; Jones *et al.* 2010). This methodology has also been successfully used in Southeast Asian sites (Castillo 2013; Higham *et al.* 2014; Kealhofer and Piperno 1994; Weber *et al.* 2010) and is discussed below. The last section examines other sources of evidence that show changes in farming systems, specifically in the Mun River Valley.

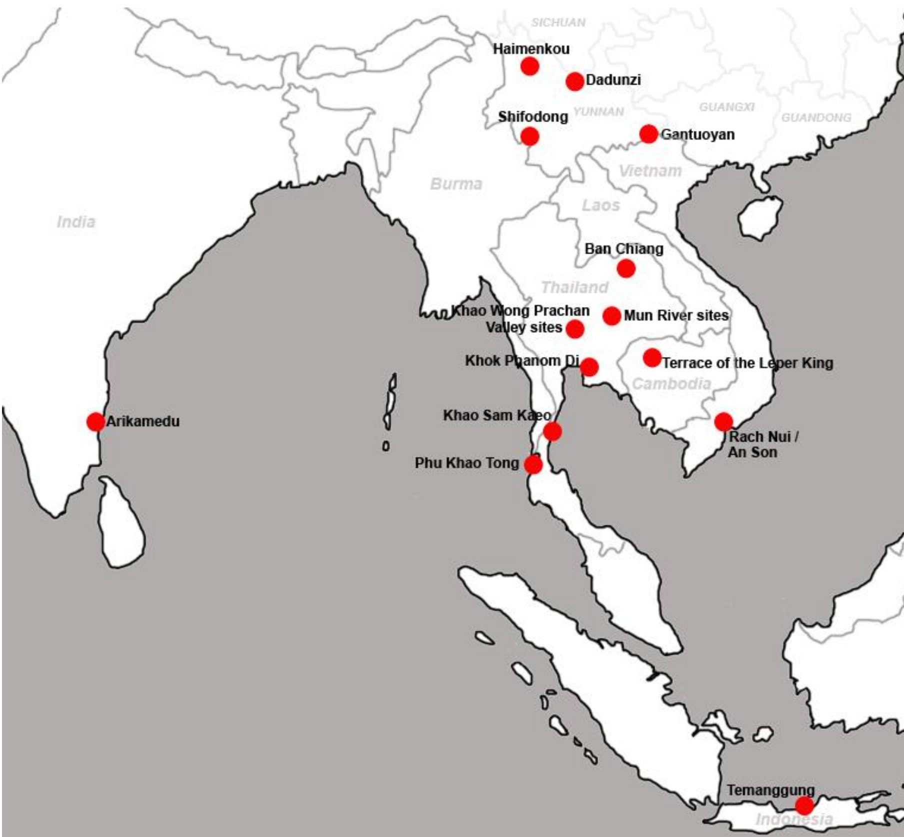

Figure 1: Map showing sites from India, Southeast Asia and China mentioned in the article.

I will draw information from a site in Island Southeast Asia (Temanggung in Indonesia) and from a historic site (Terrace of the Leper King, Cambodia) to elucidate a point. Reviews on cereal cultivation in prehistoric SEA are limited to rice and foxtail millet. This is not to say there were no other cereals cultivated in SEA in prehistoric times, but we lack the evidence. Discussions are more limited for foxtail millet than for rice, because there is more extensive research and so evidence of rice in SEA. One could even comment that there was an obsession with rice and thus, other plant remains were largely overlooked. Another possible explanation is a preservation bias in favour of rice but this will not be explored in this article (see Castillo 2011; 2013).

The adoption of cereal cultivation

Today, the most important cereal in Southeast Asia is rice (*Oryza sativa*) which is consumed as a staple by more than 2.4 billion people in Asia (www.fao.org/wairdocs/tac/x5801e/x5801e08.htm). Rice is the best studied plant remain in Southeast Asian prehistory and although there is a preservation bias in its favour, which makes rice more visible in the archaeological record, rice was probably the main cereal consumed and cultivated in many parts of prehistoric SEA (Castillo 2011; 2013). Foxtail millet (*Setaria italica*) is the other cereal found in the Southeast Asian early prehistoric period. It is widely cultivated in SEA today though almost all production is by small-scale farmers for fodder, household consumption and local trade (Burkill 1935; Léder 2004).

Recent archaeogenetic and morphometric analyses carried out on rice remains from four prehistoric sites in Thailand confirm that rice in Prehistoric Southeast Asia was *Oryza sativa* spp *japonica*, the Chinese domesticate and not the Indian domesticate *O. sativa* spp *indica* (Castillo *et al.* in 2015). So it is concluded that the origin of both rice and foxtail millet in prehistoric Southeast Asia is China, the Lower and Middle Yangtze valley and North China respectively. How these cereals came from China to mainland SEA is still poorly understood, mainly because of a lack of archaeobotanical research in the north of mainland Southeast Asia and in the southern Chinese provinces which form the frontier zone between north and central China and mainland SEA (i.e. Yunnan, Guangxi, and Guangdong).

Dispersal routes

From China to Southeast Asia

In some Southeast Asian sites, the arrival and adoption of rice and foxtail millet could have happened simultaneously. This is the case in some sites in China such as Gantuoyan located in the border of Vietnam and Guangxi, southern China and dating to *ca.* 4000-3000 BP (Lu 2009) as well as several sites in Yunnan dating *ca.* 4000-3100 BP (Jin *et al.* 2014). However, current archaeological evidence in

SEA generally shows a separate uptake of each of these two cereals during the early prehistoric period. Regional variation in the adoption of cereal cultivation in SEA has previously been noted (King *et al.* 2014; White 2011) with less than a handful of sites containing foxtail millet. As mentioned earlier, this variation could also be attributed to a bias in the archaeological record in favour of rice and against millet.

Several dispersal routes are plausible depending on the geographical area in question. As discussed below, it is proposed here that foxtail millet was introduced into Thailand prior to rice. So far, the evidence in SEA points to the crop package of rice and millets breaking apart before arrival into Thailand. In Central Thailand, millets were adopted first in the Khao Wong Prachan Valley, whilst rice was adopted first elsewhere, as in Khok Phanom Di. Perhaps millets and later rice arrived in Central Thailand via Yunnan (Higham 2005; Higham *et al*. 2011). Future excavations in north Laos and eastern Burma may confirm this hypothesis by providing evidence for a millet route via Yunnan and also possibly the presence there of a rice and millet package before it breaks up. Evidence is still needed, including material culture, to support a millet dispersal route via Yunnan. This hypothesis for dispersal may be questionable because the archaeological record provides only limited links in material culture between Yunnan and Southeast Asia in the Neolithic, despite various archaeologists' efforts to find contact between the two regions (Higham and Thosarat 1998; Higham *et al.* 2011; Rispoli 2007).

In Sichuan province, southwestern China and north of Yunnan province, there is evidence for broomcorn and foxtail millet cultivation dating to *ca.* 4000-2500 BC and combined rice and millet farming *ca.* 2700 BC (Guedes 2011). New research shows that foxtail millet and rice were present together in several sites in Yunnan; at Dadunzi *ca.* 4000 BP, Haimenkou *ca.* 3700 BP and the more southerly site Shifodong *ca.* 3100 BP (Jin *et al.* 2014). The dispersal route therefore shows millet together with rice agriculture moving from the north to the southwest of Yunnan and hypothetically into SEA, possibly via Burma or Laos, before it divides into separate cereal dispersal routes. However, the date for millet and rice cultivation at Shifodong, the most southerly site in Yunnan, is *ca.* 3100 BP, much later than the first evidence for foxtail millet in Thailand (2470-2200 cal. BC, Non Pa Wai) suggesting early millet cultivating sites in Yunnan are still to be unearthed. Furthermore, the west of Yunnan bordering Burma is characterized by mountainous terrain which would have made movements of people and cereals difficult. This points to an alternative route discussed below.

On the other hand, the first arrival of rice at a later period in Thailand could have been via any of the southern Chinese provinces; Yunnan, Guangdong and Guangxi routes. Rice was present in Yunnan as early as *ca.* 2500- 2000 BC (Guedes 2011). Alternatively, a combined rice-millet package may have been introduced into Vietnam through Guangxi during the Neolithic. Guangxi has been described as a 'spread zone' to Southeast Asia during the Neolithic with evidence of comparable decorative motifs in pottery (Rispoli 2007). And as mentioned earlier, the site of Gantuoyan in Guangxi has evidence of both rice and millet (Lu 2009).

The cereal evidence in Mainland Southeast Asia

Archaeobotany

Published research on agriculture in Prehistoric SEA in the 20th century revolved around rice (Thompson 1996; White 1995). Until recently, given the lack of archaeobotanical sampling in SEA, with a few notable exceptions (Oliveira 2008; Paz 2001; Thompson 1996; Weber *et al.* 2010), inferences were based on the presence of associated artefacts such as tillage tools and either rice impressions or rice-tempered pottery (Yen 1982; Vanna 2001, 2002; Vincent 2002, 2003; Nguyen 1998; see also Castillo and Fuller 2010 Table 1:1). Vincent (2002, 2003) provides a summary of rice-tempered pottery in Thailand, Vanna (2001, 2002) for Cambodia, and Watabe *et al.* (1974) for Burma. Now, with the development of archaeobotany as a discipline in SEA, studies from several mainland Southeast Asian sites provide evidence of domesticated rice from 2000 BC to the 12th c AD. Rice spikelet base rachilla scars were examined to distinguish between domesticated and wild rice, following the Thompson (1996) and Fuller *et al*. (2009) methodologies. There are more than twenty sites with evidence of domesticated rice across Mainland SEA compared to only a handful reporting foxtail millet.

The limited evidence of foxtail millet in Mainland SEA may be attributed to sampling problems, taphonomic issues or of course, the absence of the crop on-site. The earliest evidence for foxtail millet in SEA is from Non Pa Wai in the Khao Wong Prachan Valley located in Central Thailand. One foxtail millet seed was radiocarbon dated and yielded an AMS date of 2470-2200 cal. BC (Weber *et al.* 2010). Foxtail millet was grown more than a millennium prior to the adoption of rice in the Khao Wong Prachan Valley. Rice replaced foxtail millet as the staple but millet continued to be cultivated and persists to the present-day (*idem*). The two other sites with evidence of foxtail millet are Khao Sam Kaeo located in the Thai-Malay Peninsula and the southern Vietnamese site, Rach Nui. At Khao Sam Kaeo and Rach Nui, rice and foxtail millet were both part of the diet. The route of cereal dispersal to Khao Sam Kaeo was probably a north-south trajectory from central Thailand. Given that both cereals were already present in Central Thailand (i.e. Khao Wong Prachan Valley sites: Non Pa Wai, Nil Kham Haeng and Non Mak La) in the first millennium BC (Weber *et al.* 2010), it is plausible they would have reached the Thai-Malay Peninsula by the middle of the first millennium BC or earlier. On the other hand, Rach Nui shows a different scenario altogether. It is a Neolithic site dating to the 2nd millennium BC (3550-3400 to 3380-3840 BP) with a vegeculture-coastal foraging subsistence strategy and some consumption of foxtail millet and rice (Oxenham *et al.* 2015). There is no evidence of cereal cultivation, which instead points to exchange taking place. However, where these cereals came from and what other products were exchanged remains unresolved. To the southwest of Rach Nui lie Neolithic sites with evidence for rice (eg. An Son) but there is no evidence for millets in any of these sites. Sorting and identification of macroremains from several sites in Southern Vietnam is under way at UCL, Institute of Archaeology by the author and may still reveal the presence of millet.

Genetic and morphometric studies

There are two centres of early rice domestication and two genetically distinct subspecies, *Oryza sativa* spp *japonica* from China and *O. sativa* spp *indica* from India. A morphometric analysis was conducted on rice grains from seven sites in SEA, including one from Insular SEA (Temanggung). Morphometric analysis conducted on prehistoric rice grains has proven to be a useful guide in distinguishing rice as either *japonica*-type or *indica*-type (Castillo 2011, 2013; Castillo *et al.* 2015; Fuller *et al.* 2007; Oka 1988). Whilst the shape of a grain may look like either *japonica* (short and plump) or *indica* (long and thin), it does not confirm it to be of that subspecies. Figure 2 shows the results of the morphometric study where a L/W ratio of <2 is considered *japonica* and >2.2 as *indica*. L/W ratios between 2.01-2.2 correspond to an intermediate range where both *japonica* and *indica* rice grain L/W ratios overlap. These L/W ratios have been determined through measurements of a large dataset of genetically fingerprinted modern rices [*japonica, indica, rufipogon, nivara*] (Castillo *et al.* 2015; Harvey 2006; Fuller *et al.* 2007). The sites dating from the Bronze Age to the Late Iron Age (Ban Non Wat [BNW], Khao Sam Kaeo [KSK], Noen U-Loke [NUL], Non Ban Jak [NBJ] and Phu Khao Thong [PKT]) all show predominantly *japonica*-type rice.

Furthermore, ancient DNA (aDNA) was extracted and analysed from rice grains belonging to the same contexts from four of these sites. The archaeological rice analysed for aDNA came from Northeast Thailand (Ban Non Wat and Noen U-Loke) and the Thai-Malay Peninsula (Khao Sam Kaeo and Phu Khao Thong) with dates ranging from the Bronze to Iron Ages (Table 1). The results of the aDNA and the morphometric analyses are comparable and concurrent. The aDNA from rice from these four sites confirmed the rice was *japonica.*

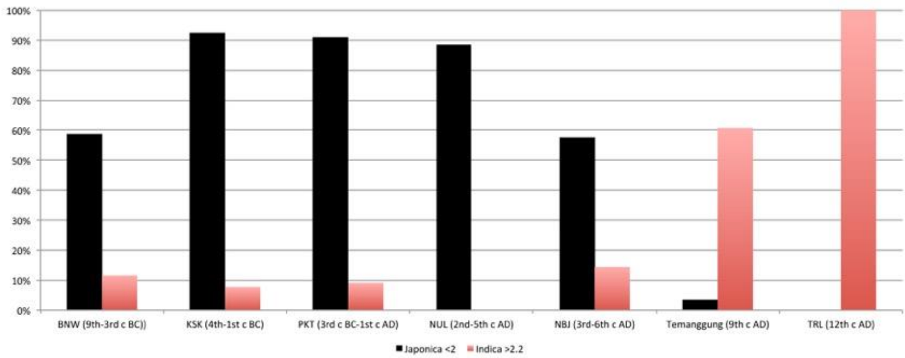

Figure 2: Morphometric results from seven sites in Southeast Asia dating from the Early Bronze to Historic Periods. Date ranges are provided together with the respective site codes. BNW: Ban Non Wat; KSK: Khao Sam Kaeo; PKT: Phu Khao Thong; NUL: Noen U-Loke; NBJ: Non Ban Jak; Temanggung; TRL: Terrace of the Leper King. (Data: Castillo 2013, unpublished; Castillo *et al*. 2015)

Table 1: AMS dates of rice grains.

Sample	Laboratory Reference No.	Radiocarbon Age BP	Calibrated Age (2σ)	δ13C (‰)	Period
Noen U-Loke 105	Wk-562	1650±70	237-562 AD	-	Iron Age
Noen U-Loke 105	Beta 376490	1690±30	255-295 AD and 320-415 AD	-25.2	Iron Age
Phu Khao Thong S7 US5	Beta 376491	1950±30	20-10 BC; 0-90 AD; 100-125 AD	-25.5	Metal Age
Khao Sam Kaeo TP57 US16	Beta 378858	1980±30	45 BC-75 AD	-28.8	Metal Age
Ban Non Wat K500 4:2 GEN Δ	BA121030	2290±45	441-203 BC	-29.66796	Iron Age 1*
Ban Non Wat K500 4:5 GEN Δ	BA121028	2510±40	795-421 BC	-18.68128	Bronze Age 4 - Iron Age 1*
Ban Non Wat V200 7:∑3 Δ2	BA121029	2330±35	515-235 BC	-28.64504	Bronze Age 5 - Iron Age 1*
Ban Non Wat V200 7:∑4 Δ27	BA121031	2375±30	705-389 BC	-24.75305	Bronze Age 5 - Iron Age 1*

* after Higham & Higham 2009 chronology for Ban Non Wat

Successful extraction of aDNA from charred remains included both chloroplast and nuclear genetic sequences, although the recovery of nuclear sequences was poor compared to the chloroplast DNA (cpDNA). Nuclear markers could have confirmed the presence of post-domestication traits, normally attributed to cultural preferences (Fuller and Castillo 2016) such as sticky rice (*Waxy*), white pericarp (*Rc*) or fragrant varieties of rice (BADH2). On the other hand, the high success rates of cpDNA confirmed the subspecies.

The entrepôts Khao Sam Kaeo and Phu Khao Thong in the Thai-Malay

Peninsula are some of the earliest sites to provide evidence of contact with India (Bellina *et al.* 2014). The material culture in these two sites is comprised of seals with brahmi script, hard stone and glass beads made with Indian technology, auspicious Indian symbols made from hard stones, and the largest corpus of rouletted ware found in SEA with parallels in Arikamedu, South India (*idem*; Bouvet 2011). It has now been established that Indian populations, specifically craftsmen, settled in these entrepôts. Therefore, it would have been possible for these Indian populations to introduce *indica* rice to SEA since a South Asian package made up of the pulses mungbean (*Vigna radiata*) and horsegram (*Macrotyloma uniflorum*) was introduced into Southeast Asia via the Thai-Malay Peninsula at the onset of contacts with South Asia [Castillo 2013; Castillo and Fuller 2010]. However, the genetic study by Castillo *et al.* (2015) does not confirm this, instead suggesting *indica* rice was not adopted in SEA during the initial contact with India *ca.* 400 BC to 100 AD and so it must have arrived during the Historic period (Castillo 2013). Again, evidence for the arrival of *indica* rice in SEA is lacking due to a dearth of archaeobotanical studies, especially from the first millennium AD. However, the morphometric studies dating to the Historic Period suggest *indica* rice was present by at least the 12th c AD in Cambodia at the Terrace of the Leper King (Figure 2). The samples were desiccated and found in a foundation deposit together with two other plant remains, mungbean and sesame (*Sesamum indicum*). Although the morphometric analysis identifies the rice as *indica*, aDNA studies will be conducted to verify these results.

As mentioned earlier, morphometric studies act as a guide but need to be considered with the other available sources of information. For example, the morphometric analysis of the rice from Temanggung located in Java, Indonesia and dating to *ca.* 9th c AD would at first sight identify the rice in this site as *indica*-type (Castillo 2014). However, Figure 2 does not include grains with L/W ratios that fall within the <2 and >2.2 range (the *japonica*-*indica* overlapping range) and in the case of Temanggung, there is a large proportion (34%) of rice which falls in this intermediate range. These results taken with other lines of evidence, such as the verified domestication status of the rice and the presence of awns, suggest that the rice in Temanggung belongs to the tropical *japonica* race [also *javanica* or 'bulu']. Tropical *japonicas* are generally long, broad and thick and are often awned, whereas *indica* rices are long, thin, relatively flat and awnless. The morphology of the rice from Temanggung fits the description of tropical *japonica* rices. Incidentally, the rice found in the Thai-Malay Peninsula from KSK and PKT are awned and were probably tropical *japonicas* although the aDNA study did not confirm this.

The conclusions from the latest evidence based on morphometric and genetic analyses as discussed above is that in the Prehistoric period before Indian contact, rice was *japonica*. Furthermore, following Indian presence, the cultivated rice does not change to the Indian subspecies. In fact, in the Thai-Malay Peninsula until the first centuries AD and in the northeast of Thailand until the 6th c. AD, *japonica* rice continues to be cultivated as the principal staple. *Indica* rice may well have been introduced in the first millennium AD. At the height of the Angkorian period *ca.* 12th c AD, *indica* rice seems to be cultivated in Cambodia as is evidenced in the Terrace of the Leper King. On the other hand, *japonica* rice specifically tropical *japonica*, was probably cultivated in Java during the 9th c. AD, a variety of rice that was also probably cultivated in the Thai-Malay Peninsula at KSK and PKT, a millennium prior to Temanggung. Contact and interaction within Southeast Asia is known from as early as the later millennium BC and intensified during the period of initial contact with India (Calo *et al.* 2015). Therefore, it is likely that tropical *japonica* would have been introduced into Island Southeast Asia from the Thai-Malay Peninsula early on. Indian contact did not necessarily substitute the rice subspecies in Java, even though Indianization in the area was pronounced, especially in the first millennium AD. At present, *javanica* rices are found mostly in Indonesia and in the upland areas of Taiwan and in the Cordillera mountains, Philippines (Barker *et al.* 1985), whereas *indica* rices are cultivated in most of the lowlands in Southeast Asia.

Farming systems

The archaeobotanical study conducted by Weber in the Khao Wong Prachan Valley illuminates our understanding of agriculture and subsistence in the region. Weber *et al*. (2010) found that millets were the staple diet before rice in Neolithic and Bronze Age central Thailand and show that multiple phases in Southeast Asian agriculture existed. In a region where archaeologists have concentrated on rice, the study by Weber has been pivotal in pursuing other lines of inquiry regarding the agricultural regime present in Prehistoric Thailand. Furthermore, the weed assemblage in the Khao Wong Prachan Valley indicates a dryland mode of cultivation before the adoption of rice and an undefined farming system when rice agriculture takes place. When rice became the dominant cereal cultivated in the Khao Wong Prachan Valley in the first millennium BC, the weed flora is ambiguous, containing both dryland and wetland species, such as chenopods and sedges respectively. It is possible that when rice cultivation started in the Khao Wong Prachan Valley, an area previously farmed for foxtail millet, the cultivation practice initially used for millets was adopted for rice. This would signify a continuum in cultivation practices or 'opportunistic farming.'

Archaeobotanical studies looking at associated weeds of cultivation in Mainland SEA indicate mostly dryland rainfed farming systems operated until the Iron Age (Castillo 2011). During the Iron Age depending on the site and their date, farming systems were either dryland or wetland. On the other hand, the earliest evidence for domesticated rice in mainland Southeast Asia is from the coastal site Khok Phanom Di *ca.* 2000-1500 BC (Thompson 1996). Extensive archaeobotanical research was conducted in this site and no foxtail millet was found. Rice here was most probably cultivated in nearby swamps under a décrue cultivation system dependent on natural flooding episodes. The millet evidence from the Khao Wong Prachan Valley predates even the earliest domesticated rice from Khok Phanom Di. The Khao Wong Prachan Valley sites and Khok Phanom Di are situated in Central Thailand, some distance from the boundary with China and studies to understand the route for the arrival of both cereals, as well as their associated farming systems, is still needed.

Further south in the Thai-Malay Peninsula, the two entrepôt sites, Khao Sam Kaeo and Phu Khao Thong dating to the Metal Age, indicate a subsistence regime that was rice-centric. Other crops consumed or cultivated include foxtail millet (only in Khao Sam Kaeo) and Indian pulses such as the mungbean and horsegram (in both KSK and PKT). If foxtail millet was cultivated, it would have been, as it is today, small-scale production. In the Thai-Malay Peninsula in the beginning of the twentieth century, foxtail millet was cultivated during periods of rice scarcity showing its secondary importance to rice (Burkill 1935). This could also have been the case in the Late Prehistoric period. The question therefore, is whether millets were cultivated in the Thai-Malay Peninsula prior to rice as is the case in the Khao Wong Prachan Valley. If so, rice cultivation in KSK, like at the Khao Wong Prachan Valley, could have resulted from a switch from one cereal to another, but maintaining the same farming technique. The weed taxa associated with rice at KSK and PKT are from dryland systems (Castillo 2013) and similarly, other crops cultivated in these two sites, such as the pulses, are grown under dryland agricultural regimes.

Further developments in agriculture

Recent carbon isotope studies on teeth and molars from Mun River valley and Sakon Nakhon basin sites in Thailand indicate a shift towards lower $\delta^{13}C$ values beginning in the early Bronze Age (King *et al.* 2013; 2014). This is interpreted as a heavier reliance on C3 plants such as rice during a period of pronounced social stratification and the emergence of an elite class (King *et al.* 2014; Higham and Higham 2009). The archaeobotanical analysis of some of the sites from the Mun River valley, such as Ban Non Wat, conforms with the King *et al.* (2014) view since the dominant cereal in the Bronze Age is rice and it continues to dominate the assemblages until the Iron Age (Castillo 2011; 2013). However, whilst there is rice in abundant quantities in the Bronze Age samples, at the moment it is not possible to confirm a 'heavier reliance' on rice compared to other periods as suggested by King *et al.* (2014).

Whereas rice agriculture in the Bronze and early Iron Ages in Ban Non Wat is dryland, as demonstrated by the weed assemblage, another archaeobotanical study conducted by Miller (2014) shows that during the Iron Age, there is a shift towards wetland rice agriculture. The isotope analysis shows a further increase in the consumption of C3 plants during the Iron Age, particularly in Noen U-Loke located in the Mun River valley interpreted as a further reliance on rice coinciding with a period of agricultural intensification (King *et al.* 2014). A trend that does not appear to take place further north in the Sakon Nakhon Basin (eg. Ban Chiang). Again, the archaeobotanical studies from the Mun River valley (eg. Iron Age site of Non Ban Jak) continue to show a dominance of rice and more importantly wetland rice agriculture as demonstrated by the preponderance of hydrophyllic weeds associated with rice (Higham *et al.* 2014).

At Non Ban Jak, like at Noen U-Loke, innovations take place. These include rice burials, and the presence of agricultural tools such as iron hoes and sickles. Some agricultural tools, such as socketed axes which could have been used for clearing forests or creating rice fields, granite hoes and shell knives have been reported prior to the Iron Age (Higham and Thosarat 2012; Higham 2014). However, in the Iron Age, a wide range of agricultural tools is found across Thailand and not just in the Mun River valley. These tools include iron billhooks, spades, sickles, harvesting knives and hoes (Higham and Thosarat 2012). There are also pronounced changes in the landscape during the Iron Age such as the proliferation of moated mound sites across the Mun River Valley. These sites date from ca. 500 BC to 500 AD although many have evidence of earlier occupation with some dating to the Neolithic (O'Reilly 2014). The moats from these sites have been studied and reported by numerous scholars and were formerly believed to function for defense (Higham and Kijngam 1982; O'Reilly 2000). More recently, a geoarchaeological and paleoenvironmental study has proposed that the moats formed part of a water management system that coincided with a regional trend towards aridity in the Iron Age (Boyd 2008). Boyd and Chang (2010) also believe rice cultivation would have been more difficult during the Iron Age prompting the local populations to control and harness water resources. Presently, the archaeobotany with respect to rice cultivation in the Mun River valley does not provide evidence for these difficult times. Interestingly, the rice cultivated in the Mun River valley during both the Bronze and Iron Ages is *japonica* identified using ancient DNA and morphometric analysis discussed above. There is no change in the variety of rice but there is a transition from a dryland to wetland cultivation technique. The question now is from where did a wetland system of cultivation emerge. Did climate and an ensuing environmental decline propel the inhabitants of the Mun River valley to change technology as proposed by several scholars (Boyd 2008; Boyd and Chang 2010; King *et al.* 2014)? Or was it a transferred technology possibly originating from Southern China?

Conclusion

The entry of rice from China into Mainland SEA is still not fully understood and similarly, neither is the transition in SEA from *japonica* to *indica* rice and from dryland to wetland rice agriculture. There is a dearth of archaeobotanical studies in SEA and southern China but also from sites dating to the late Iron Age and Early Historic periods in SEA. However, the few data available suggest that like the introduction of rice and millet in the region which was at times adopted together but most often separately, the type of rice and farming system adopted in SEA differed in timing and scope. Thus, this resulted in different trajectories for cereal adoption which provides a patchy scenario. However, other disciplines have been integrated in the discussions of cereal cultivation which provide some resolution. The emerging picture in SEA is that there probably was not an overall sweep of cereal diffusion. Similarly, the beginnings of Indian contact did not cause a radical shift to Indian culture, foodstuffs and religion. Through archaeology, we encounter the finite result but we must search for the process behind these results.

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References

Barker, R., Herdt, R. W., & B. Rose 1985. *The rice economy of Asia* (Vol. 2). International Rice Research Institute.

Bellina, B., Silapanth, P., Chaisuwan, B., Allen, J., Bernard, V., Borell, B., Bouvet, P., Castillo, C., Dussubieux, L., Malakie, J., Perronnet, S. and T.O. Pryce, 2014. The development of coastal polities in the Upper Thai-Malay Peninsula of the late first millennium BCE and the inception of the long lasting economic and cultural exchange between the East of the Indian Ocean and the South China Sea, in: Revire, N., Murphy, S.A. (Eds.), *Before Siam: Essays in Art and Archaeology*, River Books, Bangkok.

Bogaard, A., Palmera, C., Jones, G., Charles M. and J.G. Hodgson 1999. A FIBS approach to the use of weed ecology for the archaeobotanical recognition of crop rotation regimes. *Journal of Archaeological Science* 26: 1211-24.

Bouvet, P. 2011. Preliminary study of Indian and Indian style wares from Khao Sam Kaeo (Chumphon, Peninsular Thailand), fourth-second centuries BCE, in *Early interactions between South and Southeast Asia: reflections on cross-cultural exchange*, Manguin, P.-Y., Mani, A. and Wade, G. (eds). Institute of Southeast Asian Studies Publishing, Pasir Panjang, Singapore, 47-82.

Boyd, W.E. 2008. Social change in late Holocene mainland SE Asia: A response to gradual climate change or a critical climatic event?, *Quaternary International* 184(1): 11-23.

Boyd, W.E. and N. Chang 2010. Integrating social and environmental change in prehistory: a discussion of the role of landscape as a heuristic in defining prehistoric possibilities in NE Thailand, in S Haberle, J Stevenson & M Prebble (eds), Terra Australis: 21: *Altered ecologies - fire, climate and human influence on terrestrial landscapes*, ANU E Press, Canberra, ACT, pp. 273-297.

Brown T.A., Cappellini E., Kistler L., Lister D.L., Oliveira H.R., Wales N. and A. Schlumbaum 2015. Recent advances in ancient DNA research and their implications for archaeobotany. *Vegetation History and Archaeobotany* 24:207–14.

Burkill, I.H. 1935. *A dictionary of the economic products of the Malay Peninsula*, Kuala Lumpur: Published on behalf of the Governments of Malaysia and Singapore by the Ministry of Agriculture and Co-operatives.

Calo, A., Prasetyo, B., Bellwood, P., Lankton, J.W., Gratuze, B. Pryce, T.O., Reinecke, A., Leusch, V., Schenk, H., Wood, R., Bawono, R.A., Gede, I.D.K., Yuliati, Ni L.K.C., Castillo, C., Carter, A., Reepmeyer, C. and J. Fenner, J. 2015. Sembiran and Pacung on the northern coast of Bali: a strategic crossroads for early trans-Asiatic exchange. *Antiquity* 89(344): 378-96.

Castillo, C. 2011. Rice in Thailand: the archaeobotanical contribution. *Rice* 4(3-4): 114-20.

Castillo, C. 2013. *The archaeobotany of Khao Sam Kaeo and Phu Khao Thong: The agriculture of late prehistoric Southern Thailand.* Unpublished PhD thesis, Institute of Archaeology, University College London.

Castillo, C.C. (2014). The rice remains from Temanggung: First evidence of tropical *japonica* in Indonesia. *Liangan: Mozaik Peradaban Mataram Kuno di Lereng Sindoro.* Abbas, N. (ed.), Kepel Press, Yogyakarta, 267-78.

Castillo, C. and D.Q. Fuller 2010. Still too fragmentary and dependent upon chance? Advances in the study of early Southeast Asian archaeobotany, in *50 years of archaeology in Southeast Asia: Essays in honour of Ian Glover*, Bellina-Pryce, B., Pryce, T.O., Bacus, E. and Wisseman-Christie, J. (eds.). River Books, Bangkok, 90-111.

Castillo, C.C., Tanaka, K., Sato, Y.-I., Ishikawa, R., Bellina, B., Higham, C., Chang, N., Mohanty, R., Kajale, M., and D.Q. Fuller 2015. Archaeogenetic study of prehistoric rice remains from Thailand and India: Evidence of early *japonica* in South and Southeast Asia. *Archaeological and Anthropological Sciences.*

Chang, K I968. *The archaeology of ancient China*. Haven and London: Yale University Press.

Chang, K I970. The beginnings of agriculture in the Far East. *Antiquity* 44:175-185.

Chang,T.-T. and A.H. Bunting 1976. The Rice Cultures [and Discussion]. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 275(936): 143-157.

Colledge, S. 1994. *Plant Exploitation on Epipalaeolithic and Early Neolithic Sites in the Levant.* PhD dissertation, University of Sheffield.

Colledge, S., Conolly, J. and S. Shennan 2005. The evolution of neolithic farming from SW Asian origins to NW European limits. *European Journal of Archaeology* 8(2): 137-56.

Fuller, D.Q. 2011. Pathways to asian civilizations: Tracing the origins and spread of rice and rice cultures. *Rice* 4: 78-92.

Fuller, D.Q. and C. Castillo (2016). Diversification and cultural construction of a crop: the case of glutinous rice and waxy cereals in the food cultures of eastern Asia. *The Oxford Handbook of the Archaeology of Food and Diet.* Lee-Thorp, J. (ed.), OUP.

Fuller, D.Q., Harvey, E. and L. Qin 2007. Presumed domestication? Evidence for wild rice cultivation and domestication in the fifth millennium BC of the Lower Yangtze region. *Antiquity* 81: 316-31.

Fuller, D.Q., Qin, L. and E.L. Harvey 2009. An evolutionary model for Chinese rice domestication: reassessing the data of the Lower Yangtze region, in *New Approaches to Prehistoric Agriculture,* Ahn, S-M. and Lee, J.-J. (eds.). Sahoi Pyoungnon, Seoul, 312-45.

Fuller, D.Q., Sato, Y.-I., Castillo, C., Qin, L., Weisskopf, A.R., Kingwell-Banham, E.J., Song, J., Ahn, S.-M. and J. Van Etten 2010. Consilience of genetics and archaeobotany in the entangled history of rice. *Archaeological and Anthropological Sciences* 2(2): 115-31.

Gorman, C. 1977. *A priori models and Thai prehistory: a reconsideration of the beginnings of agriculture in Southeastern Asia*. Vol. 321. Mouton Publishers, The Hague, 1977.

Guedes, J.d'A. 2011. Millets, rice, social complexity, and the spread of agriculture to the Chengdu Plain and southwest China. *Rice* 4: 104-13.

Harvey, E.L. 2006. *Early agricultural communities in northern and eastern India: an archaeobotanical investigation.* Unpublished PhD dissertation, Institute of Archaeology, UCL.

Jin, H. Xu, L., Rui, M. Xiaorui, L. and W. Xiaohong 2014. Early Subsistence Practices at Preistoric Dadunzi in Yuanmou, Yunnan: New Evidence for the Origins of Early Agriculture in Southwest China, in *The 'Crescent-Shaped Cultural Communication Belt': Tong Enzheng's Model in Retrospect,* Hein, A. (ed). BAR International Series, Archaeopress, Oxford, pp. 133-40.

Higham, C.F.W. 2005. East Asian agriculture and its impact, in *The human past: world prehistory and the development of human societies,* Scarre, C. (ed.). Thames and Hudson, London, 234-63.

Higham, C., and A. Kijngam 1982. Irregular earthworks in NE Thailand: new insight.

Antiquity 56(217):102-110.

Higham, C.F.W. and R. Thosarat 1998. *Prehistoric Thailand: From early settlement to Sukhothai*. Thames and Hudson, London.

Higham, C.F.W. and R. Thosarat 2012. *Early Thailand: from prehistory to Sukhothai.* River Books, Bangkok.

Higham, C.F.W. and T. Higham 2009. A new chronological framework for prehistoric Southeast Asia, based on a bayesian model from Ban Non Wat, *Antiquity* 83: 125-44.

Higham, C.F.W., Higham, T., Ciarla, R., Douka, K., Kijngam, A. and F. Rispoli 2011. The origins of the Bronze Age of Southeast Asia. *Journal of World Prehistory* 24: 227-74.

Higham, C., Cameron, J., Chang, N., Castillo, C., O'Reilly, D. and F. Petchey 2014. The excavation of Non Ban Jak, Northeast Thailand - A report on the first three seasons. *Journal of Indo-Pacific Archaeology* 34:1-41.

Jones, G. 2002. Weed ecology as a method for the archaeobotanical recognition of crop husbandry practices. *Acta Palaeobotanica* 42: 185-93.

Jones, G., Charles, M., Bogaard, A. and J. Hodgson 2010. Crops and weeds: The role of weed functional ecology in the identification of crop husbandry methods. *Journal of Archaeological Science*: 37(1): 70-7.

Jones, M.K. 1981. The development of crop husbrandry, *in The Environment of Man: the Iron Age to the Anglo-Saxon Period*, Jones, M.K. and Dimbleby, G.W. (eds). British Archaeological Reports, Oxford, 87: 95-128.

Jones, M., and X. Liu 2009. Origins of Agriculture in East Asia. *Science* 324:730-731.

Kealhofer, L. and D.R. Piperno 1994. Early agriculture in Southeast Asia: Phytolith evidence from the Bang Pakong Valley, Thailand. *Antiquity* 68(260): 564-72.

King, C.L., Bentley, R.A., Tayles, N., Viðarsdóttir, U.S., Nowell, G. and C.G. Macpherson 2013. Moving peoples, changing diets: isotopic differences highlight migration and subsistence changes in the Upper Mun River Valley, Thailand. *Journal of Archaeological Science* 40:1681-8.

King, C.L., Bentley, R.A., Higham, C., Tayles, N., Viðarsdóttir, U.S., Layton, R., Macpherson, C.G. and G. Nowell 2014. Economic change after the agricultural revolution in Southeast Asia?. *Antiquity 88*(339), 112-125.

Léder, I. 2004. Sorghum and millets, in *Encyclopedia of life support systems (EOLSS)*, Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford.

Lu, T.L.D. 2009. Prehistoric coexistence: the expansion of farming society from the Yangzi River to Western South China, in *Interactions between hunter–gatherers and farmers: from prehistory to present*, Ikeya, K., Ogawa, H. and Mitchell, P. (eds). National Museum of Ethnology, Osaka, 47-52.

Miller, K. 2014. *Archaeobotanical Remains from Ban Non Wat: Rice Agriculture in Prehistoric Thailand*. Unpublished MSc thesis, Institute of Archaeology, University College London.

Nguyen, X.H., 1998. Rice remains from various archaeological sites in north and south

Vietnam, in Southeast Asian Archaeology 1996. *Proceedings of the 6th International Conference of the European Association of Southeast Asian Archaeologists, Leiden, 2-6 September 1996*, Klokke, M.J. and Bruijn, T.d. (eds). Centre for South-East Asian Studies, University of Hull, Hull, 27-46.

Oka, H. 1988. *Origins of cultivated rice*. Elsevier, Amsterdam.

Oliveira, N.V. 2008. *Subsistence archaeobotany: Food production and the agricultural transition in East Timor.* PhD dissertation, Australian National University, Canberra.

O'Reilly, D.J.W. 2000. From the Bronze Age to the Iron Age in Thailand: Applying the heterarchical approach. *Asian Perspectives* 39(1):1-19.

O'Reilly, D.J.W. 2014. Increasing complexity and the political economy model; a consideration of Iron Age moated sites in Thailand. *Journal of Anthropological Archaeology* 35 (2014): 297-309.

Oxenham, M.F., Piper, P. Bellwood, P., Bui, C.H., Nguyen, K.T.K, Nguyen, Q.M., Campos, F., Castillo, C., Wood, R., Sarjeant, C., Amano, N., Willis, A. and J. Ceron 2015. Emergence and Diversification of the Neolithic in Southern Vietnam: Insights from Coastal Rach Nui. *Journal of Island & Coastal Archaeology.*

Paz, V. 2001. Archaeobotany and cultural transformation: Patterns of early plant utilisation in northern Wallacea. PhD dissertation, University of Cambridge.

Pryce, T.O. 2008. *Prehistoric Copper Production and Technological Reproduction in the Khao Wong Prachan Valley of central Thailand.* Unpublished PhD thesis, Institute of Archaeology, University College London.

Rispoli, F., 2007. The incised and impressed pottery style of mainland Southeast Asia: following the paths of Neolithization. East and West 57: 235-304.

Sauer, C.O. 1952. *Agricultural origins and dispersals*. NewYork: American Geographical Society.

Smith, O., Momber, G., Bates, R., Garwood, P., Fitch, S., Pallen, M., Gaffney, V. and R.G. Allaby 2015. Sedimentary DNA from a submerged site reveals wheat in the British Isles 8000 years ago. *Science* 347(6225): 998-1001.

Solheim, W.G., II. I972. An earlier agriculturarl evolution. *Scientific America* 226 (4): 34-41.

Song, J., 2011. *The agricultural economy during the Longshan period: an archaeobotanical perspective from Shandong and Shanxi*. Unpublished PhD dissertation, Institute of Archaeology, University of London.

Thompson, G.B. 1996. *The excavation of Khok Phanom Di, a prehistoric site in central Thailand. Vol. IV: subsistence and environment: the botanical evidence (the biological remains, part II).* The Society of Antiquaries of London, London.

Vanna, L. 2001. Early rice cultivation in the central floodplain of Cambodia – Evidence from rice remains in prehistoric pottery, in *Setsutaro Kobayashi Memorial Fund Research Paper*. Japan: Graduate Division of Foreign Studies, Sophia University, pp. 1-62.

Vanna, L. 2002. Rice remains in the prehistoric pottery tempers of the shell midden site of Samrong Sen: implications for early rice cultivation in central Cambodia. *Aséanie* 9: 13-

34.

Vincent, B. 2002. Ceramic technologies in Bronze Age Thailand. *Indo-Pacific Prehistory Association Bulletin* 22: 73-82.

Vincent, B. 2003. Rice in pottery: new evidence for early rice cultivation in Thailand. *Indo-Pacific Prehistory Association Bulletin* 23: 51-8.

Yen, D.E. 1982. Ban Chiang pottery and rice. *Expedition* 24(1):51-64.

Watabe, T., Tanaka, K. and Nyunt, K. 1974. Ancient rice grains recovered from ruins in Burma - A study on the alteration of cultivated rice. *Preliminary Report of the Kyoto University Scientific Survey to Burma* pp. 1-18.

Weber, S., Lehman, H., Barela, T., Hawks, S. and Harriman, D. 2010. Rice or millets: early farming strategies in prehistoric central Thailand. *Archaeological and Anthropological Sciences* 2(2): 79-88.

White, J.C. 1995. Modelling the development of early rice agriculture: Ethnoecological perspectives from northeast Thailand. *Asian Perspectives* 34(1): 37-68.

White, J.C. 2011. Emergence of cultural diversity in mainland Southeast Asia: a view from prehistory, in *Dynamics of human diversity,* N. Enfield (ed.). Canberra: Pacific Linguistics, pp. 9–46.

Yang, X., Wan, Z., Perry, L., Lu, H., Wang, Q., Zhao, C., Li, J., Xie, F., Yu, J., Cui, T., Wang, T., Li, M. and Q. Ge 2012. Early millet use in northern China, *PNAS* 109, 3726-30.

Zohary, D., Hopf, M. and E. Weiss 2012. *Domestication of plants in the Old World: The origin and spread of domesticated plants in south-west Asia, Europe, and the Mediterranean Basin,* 4th ed. Oxford University Press, Oxford.

Electronic sources

www.fao.org - Food and Agriculture Organization of the United Nations: www.fao.org/wairdocs/tac/x5801e/x5801e08.htm accessed on 1/04/2015