The Archaeobotany of Khao Sam Kaeo and Phu Khao Thong: The Agriculture of Late Prehistoric Southern Thailand
(Volume 1)

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Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy of University College London

2013

Declaration

I hereby declare that this dissertation consists of original work undertaken by the undersigned. Where other sources of information have been used, they have been acknowledged.

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Abstract

The Thai-Malay Peninsula lies at the heart of Southeast Asia. Geographically, the narrowest point is forty kilometres and forms a barrier against straightforward navigation from the Indian Ocean to the South China Sea and vice versa. This would have either led vessels to cabotage the southernmost part of the peninsula or portage across the peninsula to avoid circumnavigating. The peninsula made easy crossing points strategic locations commercially and politically.

Early movements of people along exchange routes would have required areas for rest, ports, repair of boats and replenishment of goods. These feeder stations may have grown to become entrepôts and urban centres. This study investigates the archaeobotany of two sites in the Thai-Malay Peninsula, Khao Sam Kaeo and Phu Khao Thong. Khao Sam Kaeo is located on the east whereas Phu Khao Thong lies on the west of the peninsula and both date to the Late Prehistoric period (*ca.* 400-100 BC). Khao Sam Kaeo has been identified as the earliest urban site from the Late Prehistoric period in Southeast Asia engaged in trans-Asiatic exchange networks. There is evidence of craft specialisation and material culture that links the site to India, China and the rest of Southeast Asia. Phu Khao Thong has similar material culture as Khao Sam Kaeo.

The purpose of examining the archaeobotanical results from Khao Sam Kaeo is to add to the understanding of how an early urban site with an active exchange network and specialised craft production would have supported itself. The results provide insights into exchanged foodstuffs and the agricultural base that sustained the different communities at Khao Sam Kaeo: the local population, temporary settlers and transient voyagers. The archaeobotany of Khao Sam Kaeo is compared to the contemporaneous site Phu Khao Thong. Phu Khao Thong lies closer to the Indian Ocean and has more Indian domesticates in the assemblage.

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ACKNOWLEDGEMENTS

This dissertation, in fact my whole life as a PhD student, would have never transpired if it had not been for a core group of people. If it had not been for the support, encouragement and interest these individuals exhibited, I would have never become an archaeologist, let alone complete this dissertation.

I have profoundly enjoyed writing and working on this dissertation and it has been largely due to my three supervisors, Prof. Dorian Fuller, Prof. Vincent Pigott and Dr. Bérénice Bellina. They made me work hard on my PhD but they likewise, provided me with their time and expertise. I know I am one of the privileged few to have benefitted from three archaeologists with distinct points of view and different specialisations. I also consider myself lucky to have known them as friends. There have been many occasions during the PhD that their friendship was more important than intellectual pursuit. Bérénice has had the triple role of supervisor, project boss and great friend. She welcomed me to her site and her home. Vince was the first person to mention archaeobotany to me as a specialisation and pushed me to Dorian's room where I was greeted by an audible 'hrummph.' Vince has been opening doors for me ever since. Dorian has now stopped 'hrummphing' at me and instead drowns me with work. But this work is opportunity.

Prof. Ian Glover pushed me to pursue archaeology and opened his personal library to me. He has likewise been a great friend. Discussions with Ian and Bérénice over some beers or bottles of wine, sometimes undrinkable, in different Southeast Asian countries have become part of what I look forward to in my travels. Dr. Roger Blench has also been generous with his ideas, time and books. It is always a pleasure to meet up with Roger and have a proper argument about rice, tubers, Austronesians or just about anything.

Dr. Alison Weisskopf has taught me most of what I know about phytoliths. She dedicated her personal time to teach me phytolith extraction while she was finishing her PhD and for this, I thank her. Even if I did not include the phytolith results in the dissertation, it is an avenue open to me. Alison has also been a confidant and fellow traveller and I look forward to more future travels.

I also thank Dr. Katsunori Tanaka for his archaeogenetics work using my samples from Thailand. I hope to continue working with him after my PhD. His work will now be the foundation for many aDNA studies from Southeast Asia as he is one of the first academics to work on ancient plant material from this region.

The help of Dr. Mark Nesbitt and Dr. Chalermpol Suwanphakdee is extremely appreciated in my quest for the long pepper identifications. Mark unlocked the great vaults of the Economic Botany Collection at Kew Gardens. Without his help, I would have never been able to properly identify long pepper. Pol was in the process of writing-up his PhD dissertation, specialising in the Family Piperaceae, when he kindly looked at my Piperaceae specimens. Dr. Wolfgang Stuppy, the seed morphologist from the Royal Botanic Gardens Millennium Seed Bank at Kew dedicated one day to look at some difficult samples. In Thailand, I visited Dr. Siriporn Zungsontiporn and Panarat Charoenchai from the Weed Science Group in the Department of Agriculture who provided me with fresh samples of *Spilanthes paniculata* and *Spilanthes acmella.*

Vincent Bernard together with Bérénice taught me how to excavate, draw sections and generally, have a great time doing fieldwork. He is one of my incentives to do fieldwork in Thailand. I would have struggled even more than I already did with Thai language if it had not been for several invaluable bilingual, often multilingual colleagues. Thippawan Wongadsapaiboon also known as 'Tip' took a month from her schedule to help with my research in the Northeast of Thailand in February 2010. Jean-Pierre Gaston was also an immense help during two seasons at Khao Sam Kaeo where he helped me interview rice farmers and also did some ethnographic work himself. Chaowana Khaikaew (also known as Kop) likewise conducted interviews in my behalf in the surrounding areas of Khao Sam Kaeo. The co-director of the Thai-Franco Mission at Khao Sam Kaeo was Praon Silapanth, who helped me with the organisation of things archaeobotanical. Pattayaraj Thamwongsa (Gem) spotted the Noen U-Loke rice grains in the Phimai Rice Institute and helped me with translations which resulted in the aDNA and morphometric studies found in this dissertation.

There have been conference or fieldwork trips that could only have happened with the help of fellow archaeologists such as Dr. Qin Ling, Prof. Peter Bellwood, Dr. Nigel Chang, Prof. Charles Higham, Dr. Ratchanie Thosarat, Dr. Magnus Fiskesjo and Kien Nguyen. I would also like to thank Dr. Rasmi Shoocongdej, Prof. Mark Thomas, Dr. Andrew Bevan, Dr. Victor Paz, Dr. Carol Lentfer, Sandra Bond, Dr. Jixiang Song, Mervyn Jupe, Kevin Reeves, Dr. Michele Wollstonecroft and Nattha Chuenttawana for their help in some aspect of this PhD; whether it was plant identification, help with accessing local information, the use of UCL facilities, discussions about my work, fieldwork assistance or help with the charring experiments.

The three upgrade examiners, Dr. Sue Colledge, Dr. Michelle Wollstonecroft and Prof. Cyprian Broodbank were also very helpful in guiding me halfway to the end. I also thank Prof. Cyprian Broodbank for believing in my work and supporting me in my quest for scholarships and funding as Graduate Tutor. Likewise, Prof. Stephen Shennan and Thomas Rynsaard have been instrumental in scholarships and funding. Prof. Shennan helped me secure the Royal Thai Embassy research grant and Thomas helped administer it.

Prof. Ken Thomas and Prof. Gillian Thompson deserve special mention as my examiners during the VIVA. I thank them for their comments and suggestions. These have been taken into account in this final version of the dissertation and I thank them for having read all 598 pages with a critical eye.

Funding came from several sources including the Arts and Humanities Research Council (AHRC) funded my PhD, UCL Graduate School funded trips and courses, the French Ministry of Foreign Affairs funded most of the field expenses at Khao Sam Kaeo, and the Royal Thai Embassy in London funded a two and a half month stay in Thailand.

Friends and family made sure I kept my sense of humour and humanity. The list is long but I am especially grateful to my parents, Maty and Frankie, and tita Lines. Katarina, Tess, Ngaia and Nickie for looking after me. Support sometimes required that I was left alone to work and this was just as important as having them around when I needed them. The last few months were spent hidden away at home and the only excursions were to my local Caffé Nero where the baristas kept me pumped up with caffeine and the only social conversation. Although I am not religious, the loveliest comment came from my mother-in-law who was confounded by the long hours I spent upstairs writing and thought it was probably best to 'just submit it and pray.'

Of course, as everyone that knows me is aware, this PhD is also a product of the incredible support my husband John Watson has given me. During the entire time we started to date culminating in our marriage, John has had to deal with my erratic student/archaeologist lifestyle. Although our engagement took almost as long as the PhD, John has been my companion and support system but also, my editor. John accompanied me to at least one excavation and learned the technique of bucket flotation; he has also acted as a conference spouse in many occasions; and during the last few months of writing did the important job of cooking. I dedicate this dissertation to him.

CHAPTER 1
Introduction

1.1 INTRODUCTION

Exchange routes and coastal sites that form part of a trade network have been the subject of much academic scholarship (Sedov 1996), especially that pertaining to the Indo-Roman trade (Cappers 2006; MacDowall 1996; Miller 1969; Tomber 2008; van der Veen 2011). Movements of people along early exchange routes required areas for rest, nourishment, safe harbour during storms, boat repairs, and stocking-up for onward journeys. These regional entrepôts were central to the consolidation and redistribution of goods (Miller 1969; Tomber 2008). Entrepôts were important in the prehistoric world, not only for trade but also for cultural exchange. This study investigates the archaeobotany of two such sites in the Thai-Malay Peninsula, at the urban centre and entrepôt Khao Sam Kaeo and the entrepôt Phu Khao Thong, during the period from the fourth to the first century BC, a period of intensified foreign contact, in order to understand: the mode of subsistence in early urban sites, the types of crops available (whether crops were native or introduced, adopted or dropped), the system of cultivation practiced, and the histories of certain crops in Southeast Asia, particularly rice and the pulses.

In the Thai-Malay Peninsula, entrepôts were established along the coasts to cater to the needs of merchants and were supplied with local products by interior settlements (Jacq-Hergoualch 1997). These interior settlements were located in ecozones where sought-after products for trade were sourced, such as forest products and precious metals (gold and tin). Moreover, the interior settlements participated in the trade networks by providing inland transportation and support (porters, wagons, pack animals, boats and rafts) when trans-peninsular crossings were undertaken (Bellina et al. in preparation). Although Khao Sam Kaeo and Phu Khao Thong are currently 5 km and 2.8 km from the sea respectively, they would have been situated closer to the coastline 2500 years ago when the sea level was *ca.* 2.5 m higher than the current level. The Tha Tapao River connects Khao Sam Kaeo to the South China Sea and also to the interior of the Peninsula. Phu Khao Thong, on the other hand, is *ca.* 20 km from the mouth of the Kraburi River, where one can start the journey across the Isthmus of Kra (Bellina et al. in preparation). Furthermore, Khao Sam Kaeo was not only an entrepôt, but also an urban settlement with several communities of people engaged in the manufacture of finished goods. On the other hand, Phu Khao Thong was not an urban settlement and it is hypothesised that most of the habitation was at the nearby site Ban Kluai Nok approximately 1.1 km away.

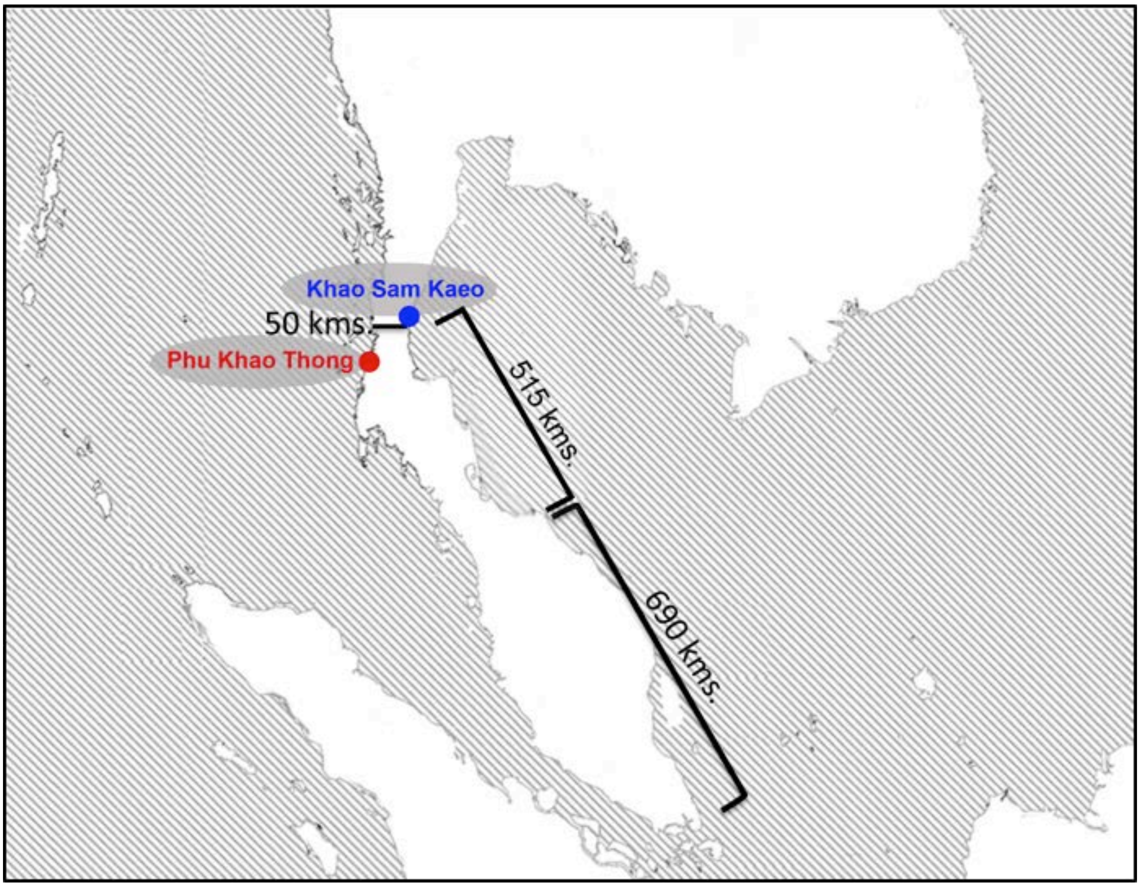


Figure 1.1: Map of the Thai-Malay Peninsula showing the location of the two areas of study, Khao Sam Kaeo and Phu Khao Thong and the approximate distance of the Kra Isthmus, and the length of the Peninsula (Base map: www.d-maps.com).

The Bay of Bengal lies to the west of the Thai-Malay Peninsula and to the east, the South China Sea. The Thai-Malay Peninsula has been described as a 'stepping stone' (Wheatley 1961) and as a 'crossroads of the maritime silk road' (Jacq-Hergoualc'h 2002). Geographically, the narrowest point, the Isthmus of Kra, is fifty kilometres and the Peninsula forms a barrier against straightforward navigation from the Indian Ocean to the South China Sea and vice versa (Jacq-Hergoualc'h 2002). The length of the Southern Peninsula that starts at the Isthmus of Kra is approximately 1,205 km or 690 km from the lower end of the Peninsula (Figure 1.1). During the Prehistoric Period, because of the obstacle of the Thai-Malay Peninsula, vessels would have either cabotaged the southernmost part of the peninsula or portaged across the Peninsula to avoid circumnavigation. However, since there is no evidence of material culture demonstrating foreign contact (e.g. South Asian rouletted and knobbed ware, early stone and glass beads) in the southernmost part of the peninsula it appears that cabotage during the last few centuries BC did not occur. The earliest evidence of foreign contact in the Malay coast dates to the first century BC at the earliest, in the form of northern Vietnamese Dongson bronze drums (Jacq-Hergoualc'h 2002). This signifies that overland routes were most commonly used over cabotage at this early period making crossing points of the Peninsula important commercial and economic locations. The Chinese annals *Ch'ien Han Shu* (also *Qian Hanshu*) refers to the Thai-Malay Peninsula as a place of trade for luxury goods and a barrier to cross in order to reach India (Wheatley 1961). The *Ch'ien Han Shu* also contains the first record of a trans-peninsular crossing dated to the reign of Emperor Wudi (140-87 BC) during the Western Han period. It relates a mission from China to Huangzhi, which is a place interpreted by modern scholars somewhere in India (Jacq-Hergoualc'h 2002). Another Chinese annal, the *Liang-shu,* mentions the importance of the Peninsula, particularly the Kra Isthmus, in the control of trade which motivated the Kingdom of Funan, in the third century AD to consolidate its power in the Peninsula by incorporating a dozen polities into its kingdom (Wheatley 1961). An entry from the *Liang-shu* shows the vibrant character of *Tun-sun* (also *Tien-sun* and *Dun Sun*), one of the polities subsumed by Funan which is located in the Peninsula and thought to be in the Kra Isthmus:

> More than 3,000 *li* from the southern frontier of *Fu-nan* is the kingdom of *Tun-sun,* which is situated on an ocean stepping-stone. The land is 1,000 *li* in extent; the city is 10 *li* from the sea. There are five kings who all acknowledge themselves vassals of *Fu-nan*. The eastern frontier of *Tun-sun* is in communication with *Chiao-chou* (Tong-king), the western with *T'ien-chu* (India) and *An-hsi* (Parthia). All the countries beyond the frontier come and go in pursuit of trade, because *Tun-sun* curves round and projects into the sea for more than 1,000 *li*. The *Chang-hai* (Gulf of Siam) is of great extent and ocean-going junks have not yet crossed it direct. At this mart East and West meet together so that daily there are innumerable people there. Precious goods and rare merchandise-there is nothing which is not there (*Liang-shu, chapter 54, folio 7*) (Wheatley 1961:16).

Khao Sam Kaeo is located in the Isthmus of Kra, and lies at one end of a possible trans-peninsular crossing route, in fact the shortest one known. Although there is reservation by some scholars about how often and accessible these inland routes were (Jacq-Hergoualc'h 1997, 2002), the *Ch'ien Han Shu* attests to the use of trans-peninsular crossings during the Late Prehistoric Period which is the period that concerns this study.

Sea routes circumnavigating the Peninsula may have been used in the Late Prehistoric Period but it was not until the first century BC onwards that they were preferred over trans-peninsular overland routes (Wheatley 1961). This may have contributed to the decline of Khao Sam Kaeo during the Historic Period. The main settlement period at Khao Sam Kaeo is the fourth to the first century BC based on conventional and AMS radiocarbon dating and relative dating of material artefacts (Chapter 7). There is evidence at the site of a settled community, craft specialisation and material culture that links Khao Sam Kaeo to India, China and the rest of Southeast Asia. Khao Sam Kaeo has been identified as the earliest urban site from the Late Prehistoric Period in Southeast Asia engaged in trans-Asiatic exchange networks (Bellina 2002; Bellina and Silapanth 2006; Bellina-Pryce and Silapanth 2008; Bellina et al. in preparation). Therefore, Khao Sam Kaeo was not only an entrepôt, but it was an urban site.

Khao Sam Kaeo is on the east coast of the Thai-Malay Peninsula facing the Gulf of Siam and Phu Khao Thong, is in the west coast facing the Bay of Bengal and the first point of entry for ships from South Asia. Phu Khao Thong, like Khao Sam Kaeo, was an entrepôt, albeit smaller. However, unlike Khao Sam Kaeo, it was not an urban settlement, but several contemporaneous archaeological sites near Phu Khao Thong have been identified and are believed to form part of a trading complex and one of them, Ban Kluai Nok, possibly a settlement (Bellina et al. in preparation). Phu Khao Thong's chronology overlaps with that of Khao Sam Kaeo, but it remained an active centre until the first centuries AD. The chronology at Phu Khao Thong is established based on three AMS dates provided by the present study and the relative dating of survey material (Chapter 8). Excavations were conducted at Khao Sam Kaeo from 2005 to 2009, but there has not been an in depth archaeological investigation at Phu Khao Thong. Therefore, Khao Sam Kaeo is the main area of study in this dissertation and the study of Phu Khao Thong is as a comparison.

The archaeobotanical studies of Khao Sam Kaeo and Phu Khao Thong form part of the Franco-Thai project designed to address the main issue of trans-Asiatic exchanges and its effects on the political, economic and social landscape of Peninsular Thailand during the Late Prehistoric Period. The main purpose of the archaeobotanical study at Khao Sam Kaeo is to add to the understanding of how an early urban site with an active exchange network and specialised craft production would have supported itself. The results also provide insights into exchanged foodstuffs and information on the agricultural base that sustained the different communities at Khao Sam Kaeo: the local population, temporary settlers and transient voyagers (Bellina and Bernard in preparation). The archaeobotanical study at Phu Khao Thong provides comparative evidence of the similarity in subsistence regimes in these two contemporaneous sites in Metal Age Peninsular Thailand. Phu Khao Thong demonstrates stronger Indian links than Khao Sam Kaeo in the form of introduced crops, and material culture evidence, particularly the pottery and stone industry (Bellina et al. in preparation; Bouvet 2012). This is not surprising given its location.

The research undertaken here is an important body of work given the paucity of archaeobotanical studies in Mainland Southeast Asia. In addition to questions of exchange, it is the author's view that hard evidence (i.e. archaeobotany) is essential in discussions of origins of agriculture and movements of crops (especially rice), two topics widely discussed amongst Southeast Asian scholars (e.g. Bellwood 2007; Higham 1995, 2013). With the exception of a few sites, notably Non Pa Wai, Nil Kham Haeng and Non Mak La in the Khao Wong Prachan Valley, central Thailand, Ban Non Wat and Non Ban Jak in northeastern Thailand and Khok Phanom Di in southeastern Thailand, most excavations so far have not included the systematic collection of soil samples for macroremains analysis as part of their methodology to study past agricultural regimes. This is because the majority of projects have focused on excavating burials rather than settlements. Most conclusions about agriculture at these sites have been inferred from the presence of organic impressions or rice temper in pottery. Likewise, phytolith studies have only been conducted in a few sites in Thailand. Theories and hypotheses relating to early agriculture should provide the evidence to substantiate them. Formerly, it was believed that tropical climates deterred the application of archaeobotanical methodologies in areas such as Southeast Asia and tropical America. However, several studies, particularly those in Southeast Asia have demonstrated that although preservation of plant remains is lower than in arid regions, the correct methodology yields ample results (Castillo and Fuller 2010; Castillo 2011; Thompson 1996; Weber 2010). Furthermore, this study is not dedicated solely to the study of rice. The analysis of other crops, such as the pulses, shows associated cultural and social dimensions. Pulses introduced from South Asia were linked to the different social groups that were settled or traveling to the entrepôts studied. Introduced crops were sometimes incorporated in local diets whereas others were not, which may indicate a role for cultural preferences. Other non-rice crops are the cash crops that strengthen the role of the two sites as places of commerce, where different populations interacted. Finally, the weed flora is incorporated in discussions of agriculture to show that cultivation systems in the Late Prehistoric Period were different from the wetland rice systems found in China.

In addition to addressing the research questions, this study gives background, presenting a review of the geography of the area of study (Chapter 2) and the state of archaeobotany in Southeast Asia (Chapter 3). The methodology (Chapter 4) and an overview of preservation bias (Chapter 5) are presented, followed by two chapters on the results and interpretations of the archaeobotanical remains from Khao Sam Kaeo (Chapter 6) and Phu Khao Thong (Chapter 7). Specific results from charring experiments and their interpretation are then discussed (Chapter 8) and since rice was the most important economic crop in both sites studied, a chapter dedicated to rice is included (Chapter 9). Finally, further discussions and the conclusion provide a synthesis of these interpretations (Chapter 10).

1.2 RESEARCH QUESTIONS

The study addresses the following research questions:

- *What was the subsistence strategy of the inhabitants in Late Prehistoric Peninsular Thailand and how did they make use of their habitats in their subsistence strategy?*

  The late prehistoric urban site of Khao Sam Kaeo was occupied for at least 400 years. The archaeobotanical study conducted at this site examines how a settled community of approximately 34 hectares subsisted. The settlement was made up of a local population and also temporary settlers and transient voyagers (Bellina-Pryce 2008). To maintain and support its population, it was considered that some form of farming such as cereal, legume cultivation or arboriculture took place in the surrounding habitats. Likewise, the smaller site Phu Khao Thong acted as an entrepôt and had an agricultural base that fed both a local population and travellers.

- *What were the types of agricultural systems during the Late Prehistory in Peninsular Thailand?*
  This archaeobotanical study also addresses issues of cultivation practices. Although it has been demonstrated in one other study dating to the Historical Period in the Thai-Malay Peninsula that communities were dependent on dryland cereal cultivation and not on irrigated rice agriculture (Allen in preparation, 1991), to give a regional understanding of what agricultural systems were used, other sites in the Thai-Malay Peninsula are examined. Khao Sam Kaeo and Phu Khao Thong present such an opportunity. In this study, the archaeobotanical assemblage, specifically the weed flora, is used to define the systems of land use, such as wetland or dryland cultivation.

- *As evidenced by the existence of material culture of South Asian origin, the Late Prehistoric Period in mainland Southeast Asia is traditionally regarded as pre-Indianisation. More recently, technologies, movements of specialists and early symbolic (religious) representations found in Peninsular Thailand have been linked to external influences* (Bellina-Pryce 2008; Bellina and Silapanth 2006). *What evidence does the archaeobotany provide of links with other cultural groups?*
  Certain species of plants are not native to the area of study and the existence of these in the archaeobotanical assemblage signifies exchange through links with other culture groups. Furthermore, South Asian crops and material culture have been found elsewhere in Mainland Southeast Asia (e.g. Ban Don Ta Phet: Glover 1990; Glover and Bellina 2011) during the same period of study demonstrating early connections with India.

- *What crops and plants were consumed and used during Late Prehistory in Peninsular Thailand? Which crops and plants were of indigenous origins and which were brought in and why?*
  Through archaeobotany the agricultural produce is determined to be indigenous or introduced by routes such as exchange networks or accompanying immigration. The study also determines whether the plants eaten were domesticated or wild. Archaeobotany helps demonstrate that trans-Asiatic exchanges occurred not only in craft technologies and final products, but also in

the introduction of crops and possibly farming techniques. Furthermore, some crops are of Southeast Asian, possibly Thai, origin and their presence in Peninsular Thailand provides the earliest dates showing local consumption and maybe even domestication.

- *How do the archaeobotanical results from the sites Khao Sam Kaeo and Phu Khao Thong contribute to the overall understanding of agricultural evolution in Mainland Southeast Asia so far presented in the literature?*

  Hypotheses about the origins and the movement of rice from its native China to the rest of Southeast Asia have been central themes in Southeast Asian archaeology. Systems of cultivation and the development of early rice cultivation in the region have also been discussed by other authors (Thompson 1997; White 1995). This study presents new evidence from Khao Sam Kaeo and Phu Khao Thong in relation to existing discussions and data.

1.3 A NOTE ON 'INDIANISATION'

The terms 'Indianisation' and 'pre-Indianisation' are used in this study and represent traditional scholarship where new phases linked to Indian contact in Southeast Asian prehistory were recognised. However, the term 'Indianisation' is outdated. The term arose from the belief that before Indian contact, Southeast Asia was in either the Hoabinhian or Neolithic levels of technology and life-style (Coedes 1968; cf. Christie 1995). Supposedly, state formation in Southeast Asia only emulated the Indian tradition. This approach is now widely discredited. The term 'Indianisation' has also been used to describe the process where elements of Indian culture were transferred across the Bay of Bengal (Glover 1996). This presupposes a one-sided transfer. Instead, as is considered in this thesis the Late Prehistoric Period in Southeast Asia, particularly in Peninsular Thailand, was a period of more direct and sustained contact between regional and foreign groups of people. As a result, such contacts allowed for a flow of technologies, information and products as evidenced in Khao Sam Kaeo and Phu Khao Thong by the excavated cultural material and in accordance with this study, the plant remains. Dissemination of technologies, information and products, including plant products, was not a one-sided process. Furthermore, such disseminations did not just come from South Asia. It is true that the South Asian influence or contact is more easily detected but this is partly due to an improved understanding of which artefacts originated in India and which crops are native to South Asia. In the case of rice, we have a general idea that it originated from China, but its trajectory into Peninsular Thailand remains obscure. In addition there is some limited evidence for the introduction of plants from Southeast Asia into southern India by this period or even centuries earlier from archaeobotany and historical linguistics relating to Indonesian sandal wood, coconuts, Areca nut, mango and Citrus fruits (Fuller 2007; Fuller et al. 2011). In other words there is evidence for multiple directions of crop transfers, with beginnings in a pre-urban, and pre-Indianisation period. Although this study mainly provides evidence for introductions into Peninsular Thailand, especially from South Asia, it also identifies possible outward dispersals of indigenous plants. So the terms 'pre-Indianisation' and 'Indianisation' are used in this study to indicate the presence of Indian cultural aspects.

1.4 THEORETICAL FRAMEWORK

The theoretical framework used in this study draws from 'world-systems.' 'World-systems' is a favoured model used to define large-scale, long-distance contact (Bevan 2007). 'World-systems' is defined by Stein (1999) as a model that *'emphasizes the role of long-distance trade dominated by the core area as the main factor explaining both the political economy of the periphery and its trajectory of developmental change*.' World-systems theory was formulated in the 1970s by Immanuel Wallerstein to explain the emergence of European capitalism through interregional trade (1974). The model considers a macro-scale system where polities interact mainly through trade although as a consequence of differences in labour, technologies and resources, hegemony is created in one polity and reliance in the other. The social, political and economic changes for the polities involved in the world-system are caused by their interactions or relationships. Wallerstein's original theoretical model involved the division of regions into cores, semi-peripheries and peripheries (Stein 1999). The cores maintain political centralisation and economic power over peripheries and semi-peripheries, it controls the exchange system and terms of trade, and maintains a population of skilled labour to produce luxury items. Peripheries supply raw materials and are dependent on the core for luxuries and finished products. The semi-periphery lies between the core and periphery and acts as an intermediary between the two (*ibid.*). The original world-systems model by Wallerstein changed after critics pointed out that whilst the model was formulated to explain modern capitalist systems, it was overly economistic and did not take into account agency, particularly from the point of view of peripheries (Blanton and Feinman 1984; Hall and Chase-Dunn 1993; Hall et al. 2011; Kardulias and Hall 2008; Stein 1999). The major criticism was that the peripheries were passive entities that accepted whatever the core dictated. Stein (1999) also points out that it is not always the case that a core is dominant and a periphery weak. These revisions produced 'world-systems analysis' which adopts the generalisations found in world-systems theory whilst retaining an understanding of agency, specifically those in the peripheries (Hall et al. 2011; Kardulias and Hall 2008). In effect, world-systems analysis is considered a paradigm and many different world-systems exist, not just one (Hall et al. 2011). The basic premise is that no past culture existed in isolation and it was the interactions between cores and peripheries that shaped social and political spheres.

For 'world-systems' to retain its explanatory power, at least for this study, the underlying structure of Wallerstein's 'world-systems' needs to remain; that is, the existence of division of labour, political hegemony, technological gaps and bulk commodity transfers between cores and peripheries (Bevan 2007). It is an effective model to explain directional and asymmetric exchanges in trade such as in Bronze Age eastern Mediterranean (Bevan 2007; Sherrat and Sherrat 1993). 'World-systems' has also been used to define the Indian Ocean as a unified space where trade resulted in an exchange of goods, knowledge, beliefs and values whilst retaining the power base at a core (Beaujard 2005). According to Beaujard (2005), there were three main areas operating in the Indian Ocean: the China Sea, the eastern Indian Ocean and the western Indian Ocean; and the cores which held the power in each of these main areas were China, India and western Asia / Egypt (also Chase-Dunn and Hall 1997). Furthermore, the two main 'world-systems' applicable to the Indian Ocean were the Eurasian and African 'world-systems' which only came into full effect in the first century AD. Under this precept, it is this world system that resulted in the 'Indianisation' of Southeast Asia (Beaujard 2005) and if China and India were cores in a world-system, then Southeast Asia was a periphery. This asymmetric relationship between the Indian core and Southeast Asian periphery permitted the transmission of ideological, political and religious elements from India to Southeast Asia, impacting Southeast Asian historical development. However, in the period that led to this 'Indianisation,' known as 'pre-Indianisation,' there was no 'world-systems' applicable to this region, but there were regional and local cores and peripheries at play, one of which in the Late Prehistoric

Period was in the Thai-Malay Peninsula. These cores and peripheries in the Thai-Malay Peninsula would eventually form part of the world-system, with India acting as the dominant economic core as it did in the period of 'Indianisation.' The supply of luxury items from India to Southeast Asia started during the period when Khao Sam Kaeo and Phu Khao Thong were operating as entrepôts (fourth to first century BC). This long-distance trade with India created the demand for Indian prestige items and later the adoption of socio-political Indian ideologies ('Indianisation'). In turn, India obtained spices, metals and forest products from Southeast Asia (Jacq-Hergoualc'h 2002; Wheatley 1961).

But it can be posited that the sites Khao Sam Kaeo and Phu Khao Thong situated in the Isthmus of Kra in the Late Prehistoric Period (i.e. fourth century BC to the first centuries AD) acted as cores on a regional scale. In support of this view: as mentioned in the *Ch'ien Han Shu* and the *Liang-shu,* the Isthmus of Kra was where trade of luxury items and control of trade took place, respectively; there are no records of unified political dominance in the Thai-Malay Peninsula in the third century BC as was the case in India under the Mauryas and in China under King Qin Shi Huangdi and later the Han; and from the evidence of the material culture and the archaeobotanical record, there were links and interactions between the commercial centres, the urban settlement Khao Sam Kaeo and the entrepôt Phu Khao Thong. Furthermore, before circumpeninsular navigation became commonplace in the first century BC (Wheatley 1961), the control of trans-peninsular routes would have provided a measure of economic and political dominance in the peninsula which would have allowed for an accumulation of wealth in these sites. So I would argue that Khao Sam Kaeo and Phu Khao Thong acted as cores in relation to trade networks in that supplies were brought in from peripheries (e.g. interior of the Peninsula) and luxury items were manufactured locally. These luxury items, such as the stone and glass beads manufactured in Khao Sam Kaeo, formed part of an extensive Southeast Asian exchange system. The dominance of Khao Sam Kaeo and similar entrepôts and urban centres in the Peninsula over the Southeast Asian market cannot be demonstrated, but its importance was sufficient for the Kingdom of Funan to conquer and subsume the polities in the Isthmus of Kra during the first centuries AD. *'As the commerce of peninsular South-East Asia developed one region stood out as of greater strategic significance in the control of trade than even the Mekong delta, namely the isthmian tract of the Malay Peninsula* (Wheatley 1961).'

CHAPTER 2
Geography: Present and Past

2.1 PHYSICAL GEOGRAPHY

Southeast Asia is an area unified primarily by its climate and to a lesser extent its physiography (Robinson 1966; Bellwood 1992). If one were to adhere strictly to climate as the underlying similarity, the territorial boundaries would be significantly different from what is referred to as Southeast Asia and the apt term 'monsoon Asia' would instead be used. This term would include South Asian and East Asian countries (Robinson 1966). In this research, I refer to Southeast Asia as the geographic zone that lies broadly between China, India and Australia. However, it is significant, in the archaeobotanical sense, that the area of study bears certain similarities with South and East Asian environments including climate. Past human activities have allowed for the transfer of certain crops and agricultural technologies from one region to another. The adoption of either the farming technology or the type of crop relies heavily on the environmental and climatic conditions of the host area. The resemblance in some aspects of the environment to the country of origin greatly increases the chances for adoption whilst the inverse also holds true.

Geographically, Southeast Asia is divided into Mainland and Insular Southeast Asia. These divisions have been used to define the archaeological activity as well as the archaeobotanical areas of study. Though the whole of Southeast Asia is defined by a series of hills, valleys or plains and rivers, the river systems in the mainland are longer, cutting across north – south. The islands have volcanic environments still active in some zones. The general physiography characteristically known as the highlands and lowlands has contributed to the anthropological dichotomy of inland upland peoples versus coastal and riverine settlers (Bellwood 1992; Scott 2009). Terms still used in archaeological and anthropological discussions to date with the dynamics of interaction between them as a central theme in understanding economic and social hierarchies in Southeast Asian Late Prehistory and early historic periods (Bronson 1997; Burling 1965; Manguin 2002; Scott 2009; Trần 2010; Yamagata 2006).

Thailand is situated in Mainland Southeast Asia, extends from 5° 37' to 20° 27' North and 97° 22' to 105° 37' East and covers 513,115 km^2. The larger mass of land lies to the north and forms a series of mountain ranges with corresponding valleys and broad basins as well as long rivers. The southern part of Thailand forms a narrow peninsula flanked by Myanmar and the Andaman Sea to the west and the Gulf of Thailand to the east. Using physiographical factors, Thailand is either divided into five or six regions (Collins et al. 1991; Ogawa et al. 1961; Higham and Thosarat 1998a; Kawaguchi and Kyuma 1969). The natural boundaries made up of mountain ranges and rivers have also acted as cultural barriers (Burling 1965). In this research the six-region system is used following Collins due to the heightened differences in climate, and therefore vegetation, in the Thai-Malay Peninsula which are only accommodated for in the six-region system. The Thai-Malay Peninsula or the Southern Peninsula is where the sites of this study lies. Figure 1.1 shows the map of Thailand divided into six regions.

The **Northern Highlands** borders Myanmar to the west and Laos to the north. The area is mainly made up of mountains and hills with elevations between 1,500 and 2,000 m. These form ridges running north to south and are separated by valleys of 300 to 500 m in altitude. These highlands are the source of many of the main rivers running parallel to the ridges forming alluvial plains where lowland agriculture is practiced and the majority of the population is settled. The highest mountains are also found in this region and the highest peak is the Doi Inthanon at 2,595 m. Various hill tribes are known to presently inhabit the area and engage in upland rice or shifting cultivation. Some of the ethnic minorities living in the highlands are the Hmong, Mein, Lahu, Lisu and Akha. Their main agricultural crops are rice, maize and opium (Ganjanapan 1998; Robinson 1966; Hirsch 1990). Some hill tribes such as the Karen and the Lua migrated from Burma and practice both shifting cultivation and irrigated wetland rice cultivation. Teak is also abundant in this region and is of great commercial importance (Robinson 1966).

The **Northeast**, also known as the Khorat Plateau, is composed of two shallow basins with an average altitude of 130-200 m, the Khorat Basin and the Sakhon Nakhon Basin. Running across the two basins is the Phu Phan Range. To the north and east lies Laos with the Mekong River acting as a boundary; and to the south lies Cambodia separated by the Dangkrek Range (800-1,600 m in altitude). Another well-defined division is found to the west where the Phetchabun Range lies running north to south and separating the Northeast from the Central Plain.

Figure 2.1: Map of Thailand showing the six regions and the sites Khao Sam Kaeo and Phu Khao Thong (Map by author based on Kawaguchi and Kyuma 1969).

The **Central Plain** (also known as the Chao Phraya Plains) is a vast, flat and low-lying area dedicated predominantly to rice cultivation. Originating from the Northern Highlands, flow the Ping and Nan Rivers, which join to become the Chao Phraya. The Chao Phraya River cuts southwards across the whole of the Central Plain's expanse, and flows into the Gulf of Thailand. The capital city of Bangkok is situated in this region.

Directly to the west of the Central Plain is the **Tenasserim Range** with an altitude averaging 1,000 m. However, on the Thai side, the mountains average 600 m. The range forms a natural boundary with Myanmar starting from the Northern Highlands and ending at the Kra Isthmus in the Thai-Malay Peninsula, the Kra Isthmus being the narrowest stretch of the Peninsula. To the east lies the Gulf of Thailand. The **Tenasserim Range** covers the upper Thai Peninsula extending from Petchaburi province to the north and Chumphon and Ranong provinces as the southern limits where the **Southern Peninsula** region starts.

The **South-East Uplands** (also known as the Chanthaburi Region) are found to the east of the Central Plain and south of the Khorat Plateau. This region is made up predominantly of plains and valleys. It shares the extension of the Cardamom Mountains with Cambodia to the east and has the Gulf of Thailand to the south and southwest. The Bang Pakong and the Chanthaburi Rivers drain into the Gulf of Thailand.

The **Southern Peninsula** is the area of this study. The northern boundary is delineated by the provinces of Chumphon and Ranong located at the Kra Isthmus and the rest of the region extending southwards to the Malaysian border. The Kra Isthmus is the narrow stretch of land that connects the Thai-Malay Peninsula to the mainland. To the west lies the Andaman Sea and to the east lies the Gulf of Thailand. The Kra Isthmus is divided by modern boundaries where the west portion belongs to Myanmar and the eastern side to Thailand. The river systems in the **Southern Peninsula** are shorter compared to the rest of the Thai regions and lies in close proximity to the active tectonic areas of Insular Southeast Asia but is itself considered geologically stable (Horton et al. 2005).

The Late Prehistoric site Khao Sam Kaeo is in Chumphon province at the narrowest part of the Peninsula and is five km from the coast. It lies 10°31’-32’ N and 99°11’-12’ E in the village of Sam Kaeo, Na Cha Ang Subdistrict. The site consists of four hills. To the west of the hills flows the Tha Tapao River whereas the eastern side is surrounded by arboricultural land. The site’s boundaries are defined by the excavations so far undertaken and as of 2008, the area extends to approximately 34 hectares (Figure 2.2).

The comparative site Phu Khao Thong is also located in the Kra Isthmus but on the western coast of the Peninsula. It is 2.5 km from the coast with coordinates of 9°22’49" N and 98°25’19" E in Suksamran Subdistrict, Ranong province. It consists of one hill although it was part of a trading complex situated in a bay and protected from the open sea by small islands (Bellina et al. in preparation).

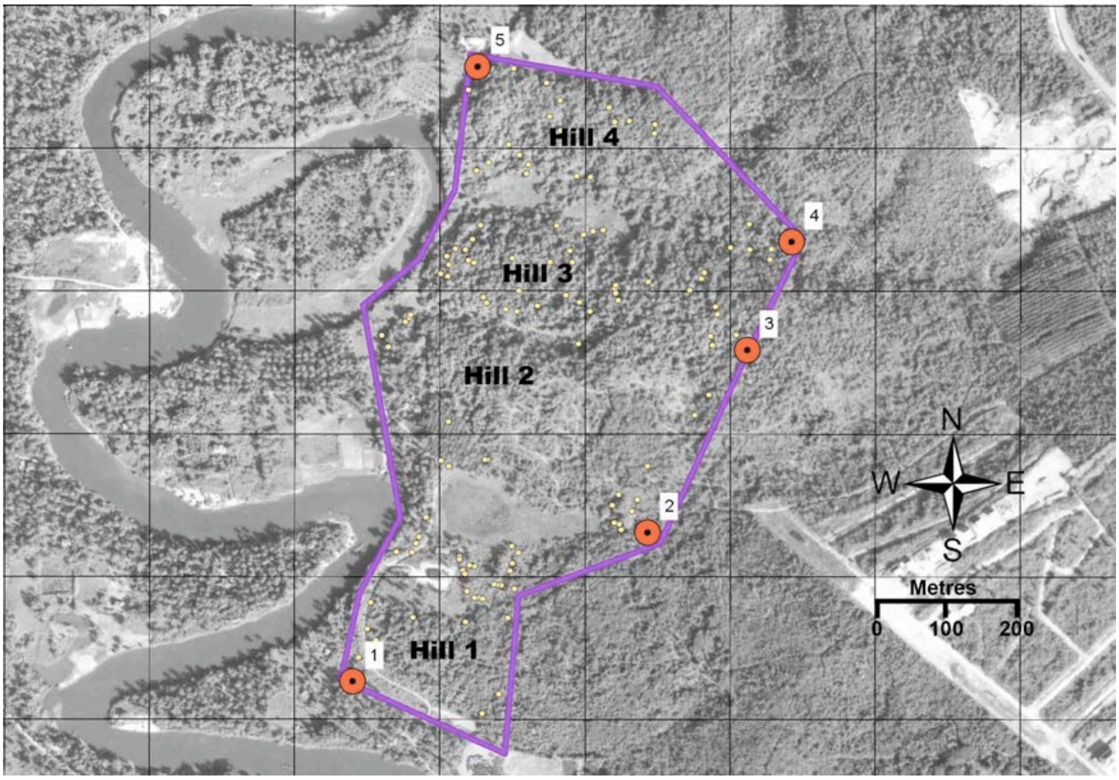


Figure 2.2: Aerial view of Khao Sam Kaeo showing the meandering Tha Tapao River to the west and the site demarcations (Photo courtesy of Bellina and Silapanth).

Figure 2.3 is the elevation map and shows the corresponding regions mentioned above. The ‘highlands’ are commonly seen as above 200 m and correspondingly, the ‘lowlands’ below 200 m (Bellwood 1992). The Northern Highlands and the Tenasserim Range regions generally have altitudes higher than 305 m. The Central Plain, the flattest region where the average altitude is less than 153 m, normally gets inundated during the rainy season, and has extensive rice cultivation (Higham and Thosarat 1998). Spencer (1966) provides a distribution map of present day shifting cultivation, a cultivation technique normally associated with hill peoples (Burling 1965). The dominant users of this practice in Thailand are all found in the hills of the Northern Highlands and the

Tenasserim Range. In contrast, it is absent in the Central Plain (Scott 2009; Spencer 1966).

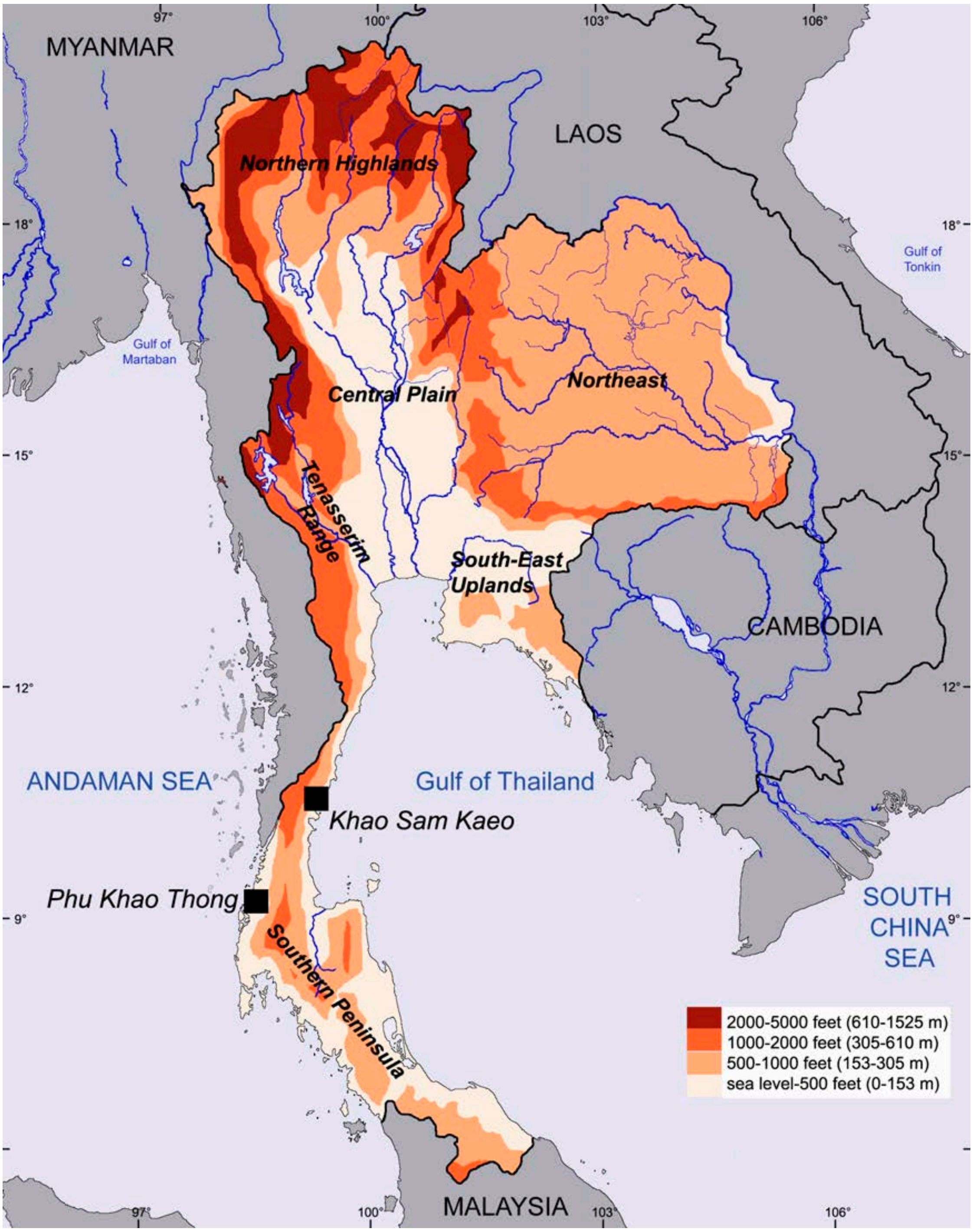


Figure 2.3: Elevation map of Thailand with corresponding regions (Map by author based on Thailand Elevation Digital map from www.maps.com).

Several trans-peninsular routes in the Thai-Malay peninsula have been suggested as possible passages between the east and west coasts (Jacq-Hergoualc'h 2002; Noonsuk 2013; Wheatley 1961). Focusing only on the Kra Isthmus and using spatial analysis, Bevan (2009) proposed two possible routes (Figure 2.4). The two routes take into consideration the rivers which are accessible by canoe, and possible upland zones which would require portaging.

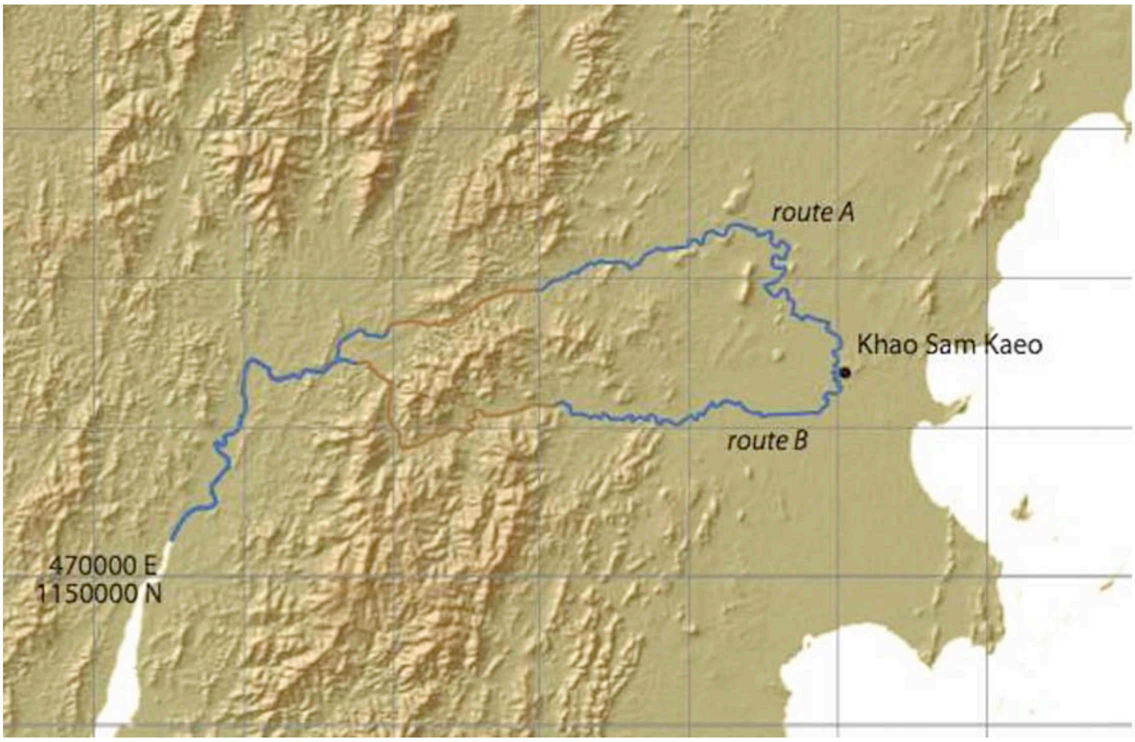


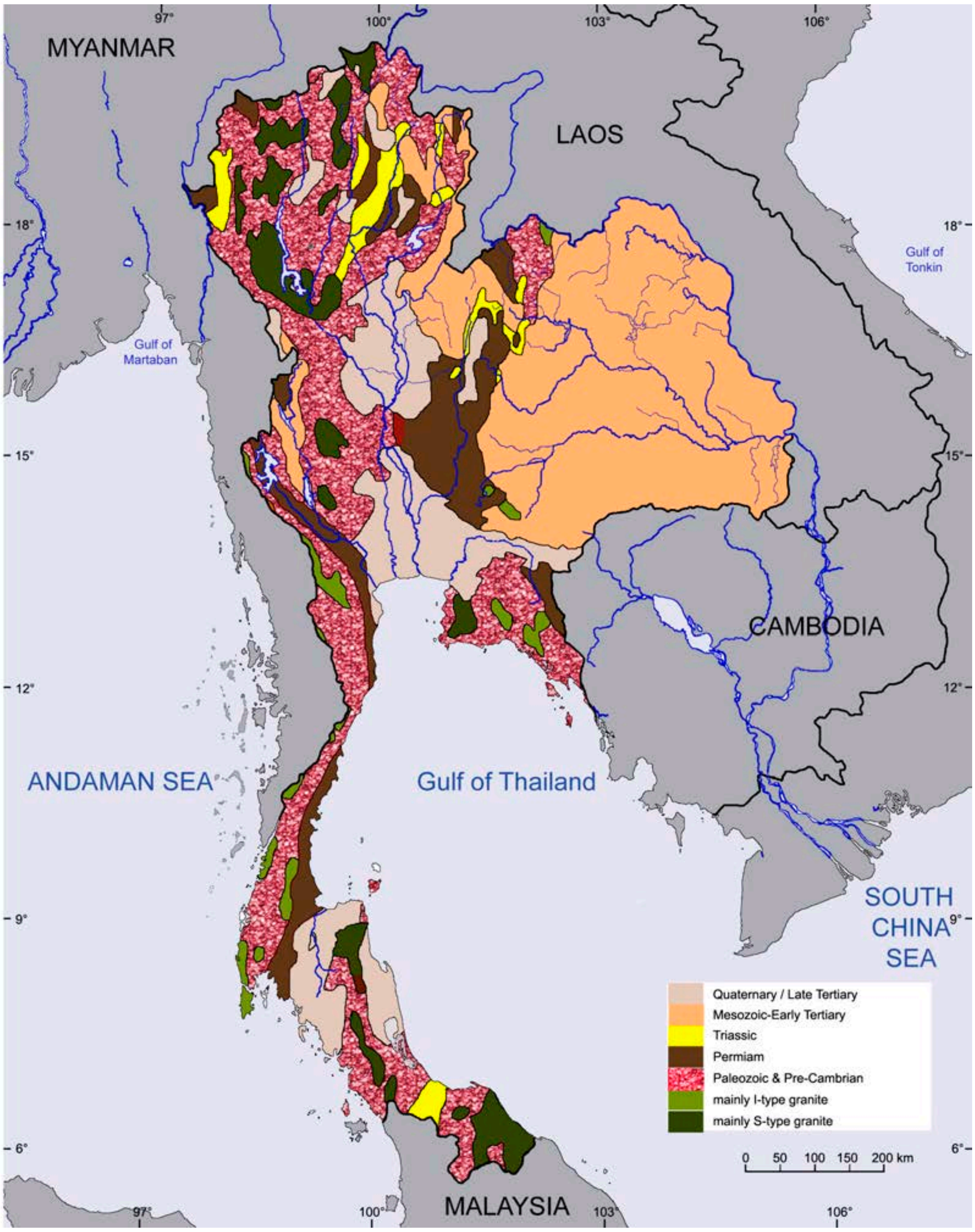
Figure 2.4: Suggested river (blue) and terrestrial routes (brown) across the narrowest part of the Thai-Malay peninsula (the Kra Isthmus) which shows Khao Sam Kaeo (Source: Bevan 2009).

2.2 GEOLOGY

The geologic evolution of Thailand spans a period from Precambrian to Quaternary and displays regional historical variances (Dheeradilok et al. 1992; Wannakomol 2005). A main geological feature is the north-south linear trend in all the regions except in the Khorat Plateau found in the Northeast (Bunopas 1983). Figure 2.5 shows the major geological divisions of Thailand. Precambrian and Palaeozoic formations dominate the western range extending from the Northern Highlands down to the Southern Peninsula. There are Mesozoic outliers situated in the west and north of Thailand, a few small Tertiary basins in the Tenasserim Range and the Southern Peninsula though more are found in the Northern Highlands. The tertiary basins located in the south, which include the Southern Peninsula, the Andaman Sea and the Gulf of Thailand, evolved earlier than those found in the north and Central Plain. Tertiary basins normally have fossil fuel deposits and therefore have commercial value (i.e. coal, petroleum, hydrocarbons)

(Dheeradikol et al. 1992). Finally, Quaternary formations are found in inter-montane basins in the Northern Highlands and in the Southern Peninsula mostly along the west coast (Dheeradikol et al. 1992).

A



B

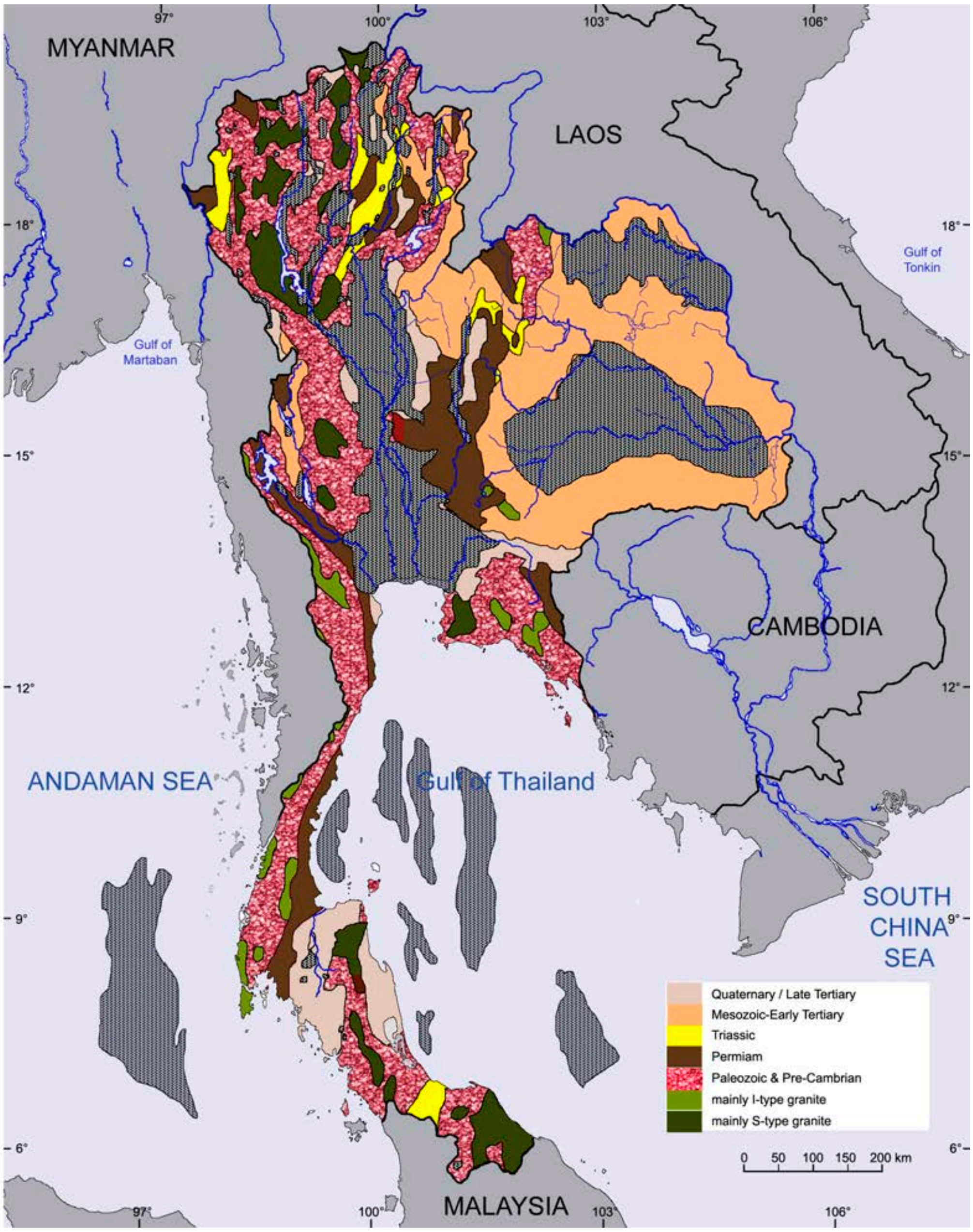


Figure 2.5: Map 'A' shows the geology of Thailand. Map 'B' shows the tertiary basins in dark grey (Maps by author based on Dheeradilok et al. 1992 and Wannakomol 2005).

The Northeast region is generally made up of Quaternary sediments found mainly in the broad alluvial plains of the Khorat Plateau. It also has an extensive Mesozoic outcrop which resulted in the formation of thick layers of rock salt and potash deposits (Dheeradikol et al. 1992). Salt in the Khorat Plateau was an important commodity during the Iron Age and Higham and Thosarat (1998) believe it was one of trade items that made communities in this area wealthy. Like the Northeast, the Central Plain is largely made up of Quaternary formations, these having been deposited over a number of Tertiary basins (Wannakomol 2005). The soils found in the Central Plain are mainly made up of Quaternary alluvial sediments (Kawaguchi and Kyuma 1969).

2.3 CLIMATE and RAINFALL

Under the Köppen-Geiger climate classification, the majority of Southeast Asia belongs to the Tropical (A) climate type (Peel et al. 2007), though northern parts of Vietnam, Laos and Myanmar belong to the Temperate Dry/Hot Summer (Csa) classification. Figure 2.6 shows the climatic classification of Southeast Asia in relation to South and East Asian countries which have more variation in their climates. Thailand is mainly Tropical Savannah (Aw) where the temperature of the coldest month is above 18°C and winters are dry due to the northeast monsoon. The Southern Peninsula region and a small area bordering Cambodia in the South-East Uplands region have a Tropical Monsoon (Am) climate.

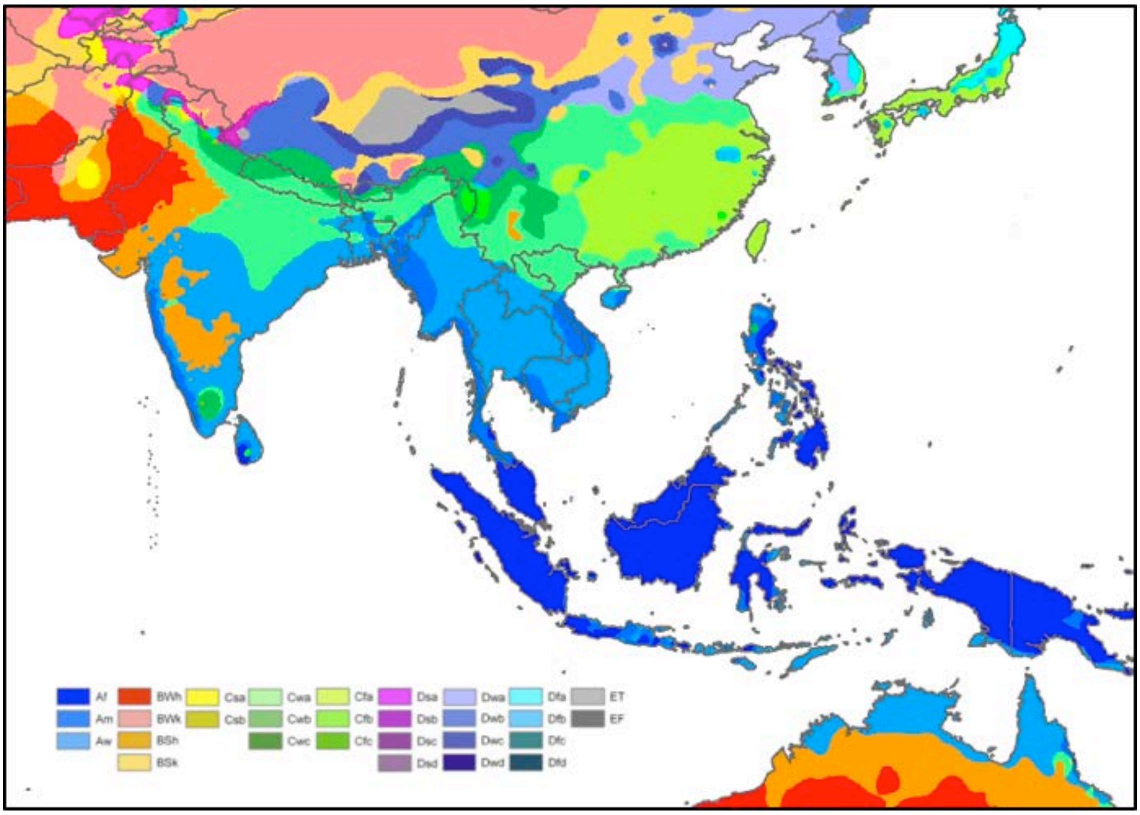


Figure 2.6: Köppen-Geiger climate type map of Southeast Asia (Peel et al. 2007, Figure 5).

The monsoons are the major influence in Thailand's climate. Consequently, Thailand belongs to the tropical monsoon climatic region (Robinson 1966). Robinson (1966) characterises this climatic type as displaying extreme seasonal changes, mean annual temperatures above 21°C, summer season temperature averaging 25-32°C, high variances in temperature range, rainfall in excess of 762 mm and finally, a distinct dry season in winter. Thailand exhibits all of these characteristics but has some regional variations. In particular, the Southern Peninsula contrasts significantly with the rest of Thailand.

There are three seasons in Thailand: rainy (wet/southwest monsoon), winter (dry/northeast monsoon) and summer (hot). The rainy season is from mid-May to mid-October with August to September being the wettest months of the year. The Southern Peninsula has a different rainfall pattern compared to the rest of Thailand with more annual rainy days. The west coast of the Southern Peninsula, where Ranong is located, has on average 176 days of rain per year (see Table 2.1). Furthermore, the rainy season in the east coast of Southern Thailand where Chumphon lies lasts until January and November is the wettest month of the year.

Region	Winter (dry)	Summer (hot)	Rainy (wet)	Annual rainy days
Northern Highlands	105.5	182.5	952.1	123
Northeast	71.9	214.2	1085.8	117
Central Plain	124.4	187.1	903.3	113
South-East Uplands	187.9	250.9	1417.6	131
Southern – East Coast	**759.3**	249.6	707.3	148
Southern – West Coast	445.9	**383.7**	**1895.7**	**176**

Table 2.1: Seasonal rainfall in mm based on the 1971-2000 period. The Thai Meteorological Department is a government body and therefore uses the five region administrative system. The regional divisions vary slightly from the physiographic map where the north of the Tenasserim Range is part of the Central Plain and the south is part of the Southern Peninsula – East Coast. The highest figures are highlighted in red (data from the Thai Meteorological Department; www.tmd.go.th).

The winter season takes place from mid-October to mid-February when temperatures drop and rainfall is at its lowest. But as discussed above this is not the case in the Southern Peninsula. Finally, the summer season is mid-February to mid-May. The summer temperatures in all parts of Thailand average 25-30°C though at times have been known to exceed 40°C. The North, Northeast and the Central regions exhibit the highest temperatures during the summer season as well as the largest variance in temperature range. The hottest month of the year is April. Due to the prolonged rainy season in the east coast of the Southern Peninsula, archaeological excavations are scheduled from mid-February to mid-April and even during this period, thunderstorms occur.

2.4 VEGETATION

The facts above place the Southern Peninsula within the rest of Thailand in terms of physical geography, geology, climate and rainfall. Khao Sam Kaeo, the area of research is located in the east coast of the Southern Peninsula. I will briefly look at vegetation in the whole of Thailand but with a focus on the Southern Peninsula. The vegetation in the Southern Peninsula region also does not resemble the rest of Thailand in this respect due to the longer rainy season. Vegetation is inextricably linked to climate and rainfall and as Maxwell (2004) points out the '*dry + hot season last(s) from 4-6 weeks in the peninsula and 3-4 months in the north and north-east*.' In the same article, Maxwell complains that there is no current vegetation study deemed by him accurate and definitive. In this section, I attempt to collate several studies and have relied primarily on older but well-researched works such as that of Whitmore (1984, 1998) and Collins et al. (1991) to establish the main vegetation groups and their significance to human populations settled in these areas. Humans have always exploited their surroundings, including forests, for products with economic value. These may be important as subsistence items or traded as commodities. Forest products have and continue to shape exchange networks between different human populations. A list of products derived from the main forest groups is found in Appendix 2.1. For a more detailed species list found in each particular forest formation see Appendix 2.2. Figure 2.7 plots the different forest formations found in Thailand and corresponds to the following main groups:

A) **Lowland rain forest** comprises ***tropical lowland evergreen*** and ***semi-evergreen forests***. Whitmore (1984) makes the suggestion that ***tropical lowland evergreen forests*** are more akin to the Malayan-type and ***semi-evergreen forests*** to the Thai-type forests though Chumphon province is represented by both. ***Lowland evergreen forest*** is the most predominant type of forest in tropical Southeast Asia and has the largest number of species found of any of the formations but with no dominant tree species (Whitmore 1984; Whitmore 1998). These forests are found in perhumid areas and occur from sea-level altitudes up to 1,200 m. The first layer (or primary growth) is characterised by a dense evergreen canopy that reach heights of 45 m or more. It is also characterised by trees that tower over the tree canopy known as 'emergents.' The trees found in ***lowland evergreen forests*** of Thailand are predominantly Dipterocarpaceae *(Anisoptera, Balanocarpus, Dipterocarpus, Drybalanops, Hopea, Parashorea, Shorea)* which are important economic goods as timber. The second layer is composed of shade-dwelling trees (Maxwell (2004) refers to them as secondary growth of evergreen scrub). Finally, the ground vegetation (or tertiary growth) is made up of *Iguanura, Pinanga* and to a lesser degree *Areca, Nenga* and *Rhopaloblaste.* ***Semi-evergreen forests*** are characterised by a mix of evergreen and deciduous trees that grow to 30-40 m, have three stories and occasionally have emergents. A large number of species are represented though to a lesser extent than the ***lowland evergreen forests***. Also present are woody climbers, bamboos, ferns and orchids. Bamboos are found mainly in disturbed areas. At present, these are the most widely spread forest formation in Thailand (Collins et al. 1991).

Trees from the Fagaceae family also occur in lowland rain forests, several species indigenous to Thailand from the *Castanopsis, Lithocarpus* and *Quercus* genera have economic uses, particularly *Castanopsis* and *Lithocarpus* which produce edible nuts. A list of Fagaceae species from Thailand with economic uses is found in Appendix 2.3, many of which occur in Peninsular Thailand.

Rain forests yield a variety of products ranging from construction timber and wood used for flooring, furniture and posts to traditional medicine, dye and edible fruits (Appendix 2.1). Open areas in forests and forest margins are rich in fruits, nuts, vegetables like palms, ferns and bamboo shoots and tubers, and many tribes like the Batek, Semang and Senoi gather these forest products. The understorey has many plants with economic uses such as those from the families Zingiberaceae and Dioscoreaceae. Many species from these two families are found in lowland tropical habitats. Plants belonging to the genera *Costus* and *Zingiber* from the Zingiberaceae family normally grow in evergreen forests (Kealhofer and Piperno 1998). Another important forest resource are edible tubers from the genus *Dioscorea* growing in the shaded forest floors and forest margin habitats of tropical lowland evergreen forests (Wilkin and Thapyai 2009). Appendix 2.4 is a list of the forty-two species of *Dioscorea* found in Thailand, including a section on their economic uses. The highest diversity of *Dioscorea,* the genus to which the main edible cultigens belong (*Dioscorea alata* and *D. esculenta*), is found in seasonally wet tropical environments like Thailand. The diversity of *Dioscorea* in Thailand is four times higher than Malaysia, which has an ever-wet climate. Tribes such as the Semang, which reside in the lowlands and forest margins of tropical rain forests in southern Thailand and northern peninsular Malaysia, resist full-time farming and instead opt for gathering wild yams readily available in the forests (Bisht and Bankoti 2004). They also gather other forest products including bamboo shoots, nuts, fruits and honey in exchange for cultivated and manufactured products. Another tribe, the Senoi, reside in transitional rain forest zones such as the foothills (*ibid.*). The subsistence regime of the Senoi is based on cereal cultivation and nowadays they grow rice and maize, recent introductions that replaced Job's tears and foxtail millet. In the past thirty years, these tribes have converted to rubber tree plantations as part of a government scheme to transform them to Malay-style villages (*ibid.*). Another tribe, the Batek, live in the lowland tropical rain forests in Peninsular Malaysia and subsist through foraging although they trade forest products for rice, sugar, flour, tobacco, cloth and metal tools (*ibid.*).

B) **Montane rain forest** is divided into ***tropical lower*** and ***upper montane forests***. ***Tropical lower montane rain forests*** (also known as hill evergreen forest and temperate evergreen forest) form at altitudes of 900-1,500 m (Whitmore 1998:19) though other authors consider the lower limits to be from 800 to 1,200 m (Blasco et al. 1996). The canopy is typically 15 to 33 m high and occasionally has emergent trees above the canopy. The forest has two stories with a predominance of Fagaceae (*Castanopsis, Lithocarpus, Quercus)* and various Lauraceae in the upper story and shows continuity with the subtropical forests of South China. There are thirty-three species of *Castanopsis,* fifty-six of *Lithocarpus,* and twenty-nine species of *Quercus* indigenous to Thailand. Eighteen *Castanopsis* and six *Lithocarpus* and two *Quercus* produce edible nuts (Phengklai 2008). Acorns (*Cyclobalanopsis, Lithocarpus* and *Quercus*) were staple wild foods of the Lower and Middle Yangtze, China during the mid-Holocene until rice cultivation emerged as the staple (Fuller and Qin 2010). Evidence of acorn use in Southeast Asia is found in the Hoabinhian sites Con

Moong cave (*ca.* 12000 BP) and Dong Can cave (*ca.* 11000 BP) in Vietnam during the Terminal Pleistocene (Nguyen 2008). It is therefore expected that if these resources were available in the forests of Thailand in the Late Prehistory, the local populations would have likewise gathered them for food. The lower story has small trees and shrubs such as *Gordonia, Camellia, Pyrenaria, Acer, Carya, Carpinus, Tristania* and *Macaranga* (Smitinand 1989). The conifers *Pinus kesiya* and *Pinus merkusii* are common in the Northern Highlands and the Khorat Plateau and occur in altitudes of 200 to 1,300 m. This forest formation is sometimes called ***coniferous forest*** (Smitinand 1977). Both, *Pinus kesiya* and *Pinus merkusii* are valued for timber and oleoresin. ***Tropical upper montane forests*** form above 1,500 m, trees reach heights of 10-18 m and have a flat canopy outline. Leaves of flowering trees are very small and belong to the microphyll classification (Whitmore1984b).

C) **Monsoon forest** formations are defined by a pronounced dry season, the annual shortages of water caused by the monsoons (Whitmore 1998). Trees are normally smaller than those found in rain forests and are deciduous in nature. Another difference between monsoon and rain forests is the regular occurrence of forest fires and therefore, the presence of fire resistant species such as teak (*Tectona grandis*) (Whitmore 1984). Finally, there are fewer dipterocarps in monsoon forests than in rain forests. Some authors have divided the monsoon forest formation into two main sub-types ***mixed deciduous*** and ***deciduous dipterocarp forests*** (Ogawa et al. 1961; Smitinand 1989) or ***tropical dry deciduous*** and ***tropical moist deciduous*** (Blasco et al. 1996). A ***mixed deciduous forest*** is composed of several deciduous species of trees that shed their leaves seasonally. It may also be the case that one particular species dominates the forest such as teak (*Tectona grandis*) in northern Thailand (Anderson 1993). This type of forest is mostly found in the Northern Highlands and mostly is comprised of *Tectona, Pterocarpus, Xylia, Dalbergia, Acacia, Albizzia* and *Vitex* (Ogawa et al. 1961). Taller trees abound such as *Tectona grandis, Terminalia mucronata, Xylia xylocarpa, Holarrhena pubescens, Engelhardia serrata* and *Vitex peduncularis* (Anderson 1993). The second story is composed of many bamboos and lianas. On the other hand, ***deciduous dipterocarp forests*** are dominated by Dipterocarpaceae. Trees are on average

15-25 m tall. Species found in this type of forest are *Pentacme siamensis, Shorea obtusa, Dipterocarpus tuberculatus, Dipterocarpus obtusifolius* and *Dipterocarpus intricatus*. Other trees present and not from the Dipterocarpaceae family are *Gluta usitata, Quercus aliena, Quercus kerrii* and *Aporusa wallichii*. As of 1991, there were 31,500 km^2 of monsoon forest covering Thailand (Whitmore 1991).

As in the tropical lowland evergreen forests, aroids and yams (such as from the genus *Dioscorea*) are found in forest margins and open spaces of mixed deciduous forests. At least one species, *Dioscorea glabra* is still used as famine food, but edible tubers would have formed part of the hunter-gatherer resource base and/or vegecultural base, potentially making these local groups of people resistant to the adoption of rice when it became available. During ethnoecological fieldwork in the Northeast of Thailand, White (1984) found at least five species of wild yams eaten and sold in markets; therefore hypothesising that like in the present-day, the inhabitants of Ban Chiang during prehistoric times would have exploited these resources.

D) The **wetland rain forests** comprise at least four different sub-groups of which the ***mangrove rain forest*** is the most common in Thailand. Mangrove habitats are situated between land and sea and consequently are specifically adapted to saline and brackish water. They are found along coastlines, river mouths and tidal swamps. These forests provide a wide range of plants and animals of economic importance and displaying unique characteristics. Some of these peculiarities are in the form of pneumatophores, aerial, stilt and buttress roots, thick leathery leaves that store water and viviparous flora (Yamada 1997; Smitinand 1977; Whitmore 1988). It is also a habitat rich in crabs, mudskippers and prawns. These forest formations are characterised by a single layer of trees with heights of 6-24 m with a dominant species community (Yamada 1997; Smitinand 1977). There is approximately 1,600 km^2 of mangrove forest in Thailand (Blasco 1996:627). The main genera are *Avicennia, Rhizophora, Bruguiera, Sonneratia, Kandelia, Ceriops, Lumnitzera, Xylocarpus* and palms (such as *Nypa fruticans*). Many mangrove rain forests have been converted to shrimp farms and fisheries (Whitmore 1984). ***Mangrove rain forests*** yield many products ranging from timber, firewood, charcoal, edible fruits, dyes and traditional medicine (Appendix 2.2), as well as seafood protein sources.

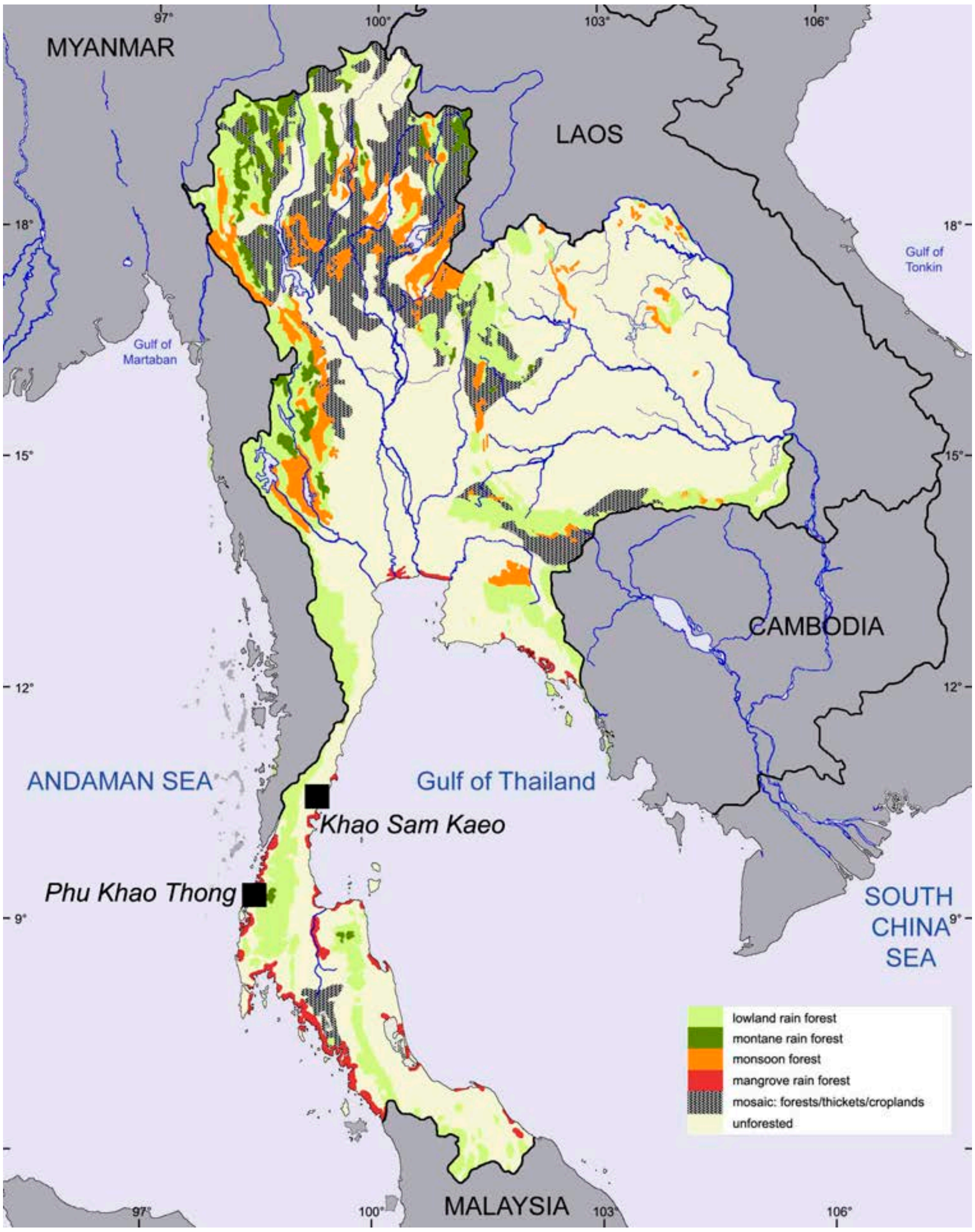


Figure 2.7: Vegetation map of Thailand (Map by author based on data from Collins et al. 1991 and Blasco et al. 1996).

E) There are also many unforested areas in Thailand. This is land under cultivation and urban areas. Included in this group is agricultural land in the form of wetland rice, upland crops and shifting cultivation. Cropland areas have normally been identified in the plains of the major rivers and in Thailand this would correspond to the Chao Phraya (Stibig et al. 2007) situated in the Central Plains, known as the rice bowl of Thailand. The area intensively cultivated for rice in recent and historical times present a challenge in terms of reconstructing pre-agricultural vegetation as there is little which can be regarded as non-anthropogenic in these regions. For example, the landscape in the 1900s changed considerably as a result of government irrigation and flood-control programs, introduction and extensive plantation of rubber and coastal degradation caused by shrimp aquaculture (Robinson 1966; Dierberg and Kiattisimkul 1996). Areas under cultivation may also be in the form of plantations such as the cash-crops rubber, oil palm, coconut palm and coffee. Rubber plantations abound the Southern Peninsula, including Khao Sam Kaeo and its surroundings. In contrast, the Southern Peninsula does not cultivate much rice.

Areas where cultivation systems are in place and disturbed areas are preferred habitats for certain comestibles such as yams (*Dioscorea esculenta*) and wild ricebean (*Vigna umbellata*) (Tomooka et al. 2000, 2002; Wilkin and Thapyai 2009). Habitats where wild *Vigna umbellata* was collected are found in Appendix 2.5, these are mostly from disturbed habitats (Tomooka et al. 2000). This suggests that in Prehistoric times when rice became the staple, cultivation of yams and the gathering of wild ricebean alongside rice cultivation could have been practiced.

forest type	%
tropical lowland evergreen rain forest	1.90
tropical semi-evergreen rain forest	4.30
dry evergreen	21.00
tropical lower montane rain forest	1.90
mangrove rain forest	1.70
mixed deciduous	22.60
bamboo	4.30
coniferous forest	1.30
scrub	0.80

Table 2.2: Proportion of forest types found in Thailand (FAO and UNEP 1981).

Table 2.2 shows the share of each forest type found in Thailand as of 1981. The largest share is taken by lowland rain forests (tropical lowland evergreen rain forest, tropical semi-evergreen rain forest and dry evergreen), followed by monsoon forests (mixed deciduous). The majority of the tropical lowland evergreen rain forests, as well as the mangrove rain forests lie in the Southern Peninsula.

The Southern Peninsula region is perhaps best described as transitional in terms of vegetation. The region is slightly seasonal (not perhumid) except in the southernmost part bordering Malaysia where the climate is more perhumid and this is where the Malay-type or ***lowland evergreen rain forest*** is found (Whitmore 1984; Collins et al. 1991). The area known as the transition zone where ***tropical lowland evergreen rain forest*** changes to ***tropical semi-evergreen rain forest*** lies directly north of the border between Malaysia and Thailand. Beyond this zone as one moves northwards, rainfall decreases and seasonality intensifies. However, the western coast of the Southern Peninsula starting from the Isthmus of Kra southwards is wetter and has an average of 176 days of rain a year. It has been noted that the forest formation in this area is a mosaic of tropical lowland evergreen and semi-evergreen rain forests (Whitmore 1984; Champion and Seth 1968). ***Tropical semi-evergreen rain forests*** are more abundant in Thailand than ***lowland evergreen rain forests*** and therefore, Whitmore calls them Thai-type forests. There are fewer Dipterocarpaceae in the semi-evergreen forests found in the Isthmus of Kra compared to the more southerly evergreen forests. There are 30 species of Dipterocarps in the Isthmus of Kra compared to 156 species found in Peninsular Malaysia (Jacobs 1988). Dipterocarps are particularly important for timber and resin. Resin is used for varnish, boat-caulking and medicinal and preservative uses such as camphor (Corlett and Primack 2005). Another notable delineation in the vegetation found in the Southern Peninsula is that **monsoon forests** are found north of the Kra Isthmus as the dry season becomes more pronounced and do not occur in the Southern Peninsula. Likewise, ***montane rain forests*** are found mainly in the Northern Highlands of Thailand and seldom found in the Southern Peninsula. Finally, the ***mangrove rain forests*** are found mainly along the east and west coasts of the Southern Peninsula and only a few patches along the coastline of the Central Plain and South-East Uplands regions. ***Mangrove forests*** in the Southern Peninsula are similar as those found in Malaysia (Simitinand 1977).

The Southern Peninsula was originally forested but due to economic demand for tree crops such as rubber, many lowlands have been converted to plantations (Collins et al. 1991:222).

2. 5 SOILS

Soil quality is one of the major factors that affect cultivation practices and agroecosystem management (Marten and Vityakon 1986). Likewise, soil is affected by cultivation practices and other factors such as the parent rock material, rainfall, dry season length, topography, drainage and vegetation (Nuttonson 1963; Yoothong et al. 1996).

The soils in most of Thailand are deemed to have very low fertility due to heavy rainfall that causes leaching and ultimately leads to acidic soils. Historically, acid soils have mainly been left uncultivated because of the amount of work required, as well as the need for technological knowhow, to convert them to productive land (von Uexküll and Mutert 1995). But in modern times in the humid tropics, cash crops (e.g. palm oil, tea, coffee, pineapple, rambutan, mangosteen and rubber) and tuber crops (e.g. cassava, yams and sweet potatoes) are grown mainly on acid soils (*ibid.*). Soil erosion is another problem faced by farmers in the undulating hills and mountainous areas of Thailand, where heavy rainfall causes soil erosion in forests cleared for farming (see section 2.6 on flooding). Furthermore, the fertile plains of Thailand are surrounded by sloping lands covered in slow-growing open forest generally made up of a shallow layer of sandy soil and hard lateritic bedrock. Like the acid soils, these sandy and lateritic soils need a large investment to make them arable and therefore are generally left uncultivated. Most of the Northeast region is made up of these sandy and lateritic soils. However, pockets of fertile, alluvial wet and sticky soils are found throughout low-lying areas in Thailand which is where agriculture is concentrated. Soluble plant nutrients are found in the ashes of plants burned during forest clearings, which are washed away or leached during periods of heavy rainfall. These plant nutrients are carried downstream from hilly and mountainous forest clearings to the lowlands, deltas, coastal and freshwater swamps and give rise to pockets of highly fertile soils, mixed with alluvial deposition silt.

The main soils in Thailand are called 'laterite soils.' These are red coloured soils found in the humid tropics characteristically porous, iron-rich and crumbly. Lateritic soils are normally covered by a dark layer of top soil, formed from decaying organic forest matter. The lateritic soil dries, bakes and gullies badly when exposed.

The Northern Highlands are characterised by high steep mountains, shallow and stony soils. However, fertile alluvial soils are found in the river valleys ranging from sandy loams to silty clays. It is in these fertile enclaves where most crop cultivation takes place. The Northeast, as mentioned earlier, is mainly composed of sandy and lateritic soils with low fertility and not under cultivation. Laterites, quartzitic and silicious sandstones dominate the geological make-up of the Northeast with pockets of fertile alluvial deposits in shallow valleys and depressions along the Mekong River. The subsoil in the Northeast is considered more fertile than the sandy topsoil. As a result, the farmers in some parts of the Northeast use termite mounds as fertiliser since the mounds are made up of black organic subsoil (Marten and Vityakon 1986; Nuttonson 1963). Farmers also maintain soil fertility in farmlands through crop rotation and by adding animal manure (Marten and Vityakon 1986). The Central Plain soils are formed from Quaternary alluvial sediments (Kawaguchi and Kyuma 1969). This is where most of Thailand's rice is cultivated. The low and flat nature of the plain coupled with heavy clay soils (also known as Bangkok clays) is ideal for wetland paddy rice agriculture. The plains are regularly flooded during the rainy season when the water is retained by the poorly draining clayey soils. These waterlogged clay soils are not suitable for agriculture other than wetland paddy rice unless farmers invest in transforming the natural landscape by building *rongs* (Nuttonson 1963). *Rongs* are mounds surrounded by ditches usually three feet high and measuring *ca.* twelve to eighteen feet wide used for vegeculture and arboriculture. They prevent waterlogging and are built with rich fertile soils. These *rongs* require constant maintenance and fertilisation. There are other areas in the Central Plain where fruits and vegetables are intensively cultivated and these are located along the banks of the rivers and streams where the soils are composed of very fine sandy soils and in the margins of the plain where the soils are brownish silt loams and light clay loams. On the western side of the South-East Uplands, next to the granitic mountain range are hills and terraces comprised mostly of sandy soils formed by the weathering of sandstones and quartzites. The eastern side is made up of red clay (also known as Chantaburi clays) derived from dark igneous rock. Pepper was traditionally grown in the red clays of this South-East Uplands region, but has been replaced by rubber plantations, sugarcane and arboriculture. The Tenasserim Range is made up of granitic basoliths and pockets of alluvial soils.

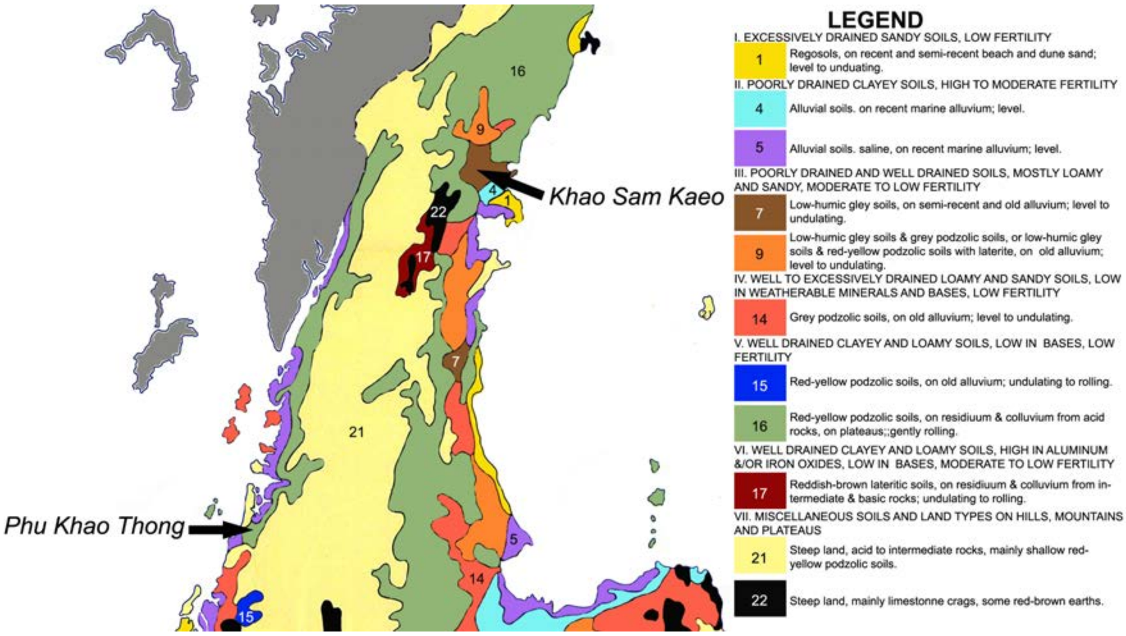


Figure 2.8: Soil map of the Southern Peninsula showing the two sites Khao Sam Kaeo and Phu Khao Thong (Map adopted from Moorman and Rojanasoonthon 1967).

Finally, in the Southern Peninsula the soils are mainly poor sandy loams and sandy clay loams. A detailed soil map by Moorman and Rojanasoonthon from 1967 shows that the soils at Khao Sam Kaeo in Chumphon province are mainly low-humic gley soils on semi-recent and old alluvium (Figure 2.8). The surface horizon is typically thin and can have a high humic content if the vegetation is natural or a low humic content when used for rice cultivation (Moorman and Rojanasoonthon 1968). Low-humic gley soils lying on semi-recent alluvial sediments (as in the Central Plains) tend to be fertile because they are not leached and weathered. Most low-humic gley soils on semi-recent and old alluvium are used for rainfed rice farming, including the soils in the Southern Peninsula (*ibid.*). Allen et al. (unpublished report) suggest that the surrounding hills at Khao Sam Kaeo may have been used for dry cultivation. However, beyond the hills where Khao Sam Kaeo is situated is an area made up of low fertile soils (low-humic gley soils and grey podzolic soils; red-yellow podzolic soils) generally found in the depressions between hill ranges. Closer to the coast there are high to moderately fertile alluvial soils (see Figure 2.8). However, Allen et al. (unpublished report) believe no broad plain (other than a narrow fringe of acidic and infertile soils) existed when Khao Sam Kaeo was an active entrepôt during the Late Prehistoric period. The east coastal plain formed long after Khao Sam Kaeo had been abandoned, as sediments and soils eroded from inland hills and were redeposited due the extensive and intensive practice of dryland agriculture (*ibid.*). Based on geomorphological studies of several test pits at Khao Sam Kaeo, Allen and Silapanth (unpublished report) also report that the soils at Khao Sam Kaeo were fertile and were stabilised and managed by man-made walls and other structures. As a comparison, at Kedah, Allen (1991) proposes that dryland cereal cultivation was undertaken on the slopes, stripping vegetation cover and causing topsoil erosion. Eventually, these inland soils created the floodplains of today.

On the other side of the coast, in Ranong province, the site of Phu Khao Thong lies in alluvial soils on recent marine alluvium. These soils are high to moderately fertile. The countryside surrounding Phu Khao Thong is steep and undulating mainly made up of red-yellow podzolic soils from acidic and intermediate rocks (Figure 2.8). These soils are low in fertility and it is therefore likely that cultivation would have taken place in the gentle hills of Phu Khao Thong and its close vicinity.

2.6 AGRICULTURE

Thailand's most important agricultural crops are rice, sugar cane, cassava and rubber. In 2009, Thailand was the seventh largest rice producer in the world (31,597,200 metric tonnes) and in value terms, rice was the highest ranking agricultural commodity in Thailand (www.fao.org). Table 2.3 shows the top 10 agricultural products of Thailand ranked by value and volume.

The major rice producing areas of Thailand are the lowlands of the Central Plain and the Northern Highlands. In 2004, the Food and Agriculture Organization (FAO) stated that a fourth of rice land was irrigated and the rest was rainfed (www.fao.org). Rice being the principal crop of Thailand is cultivated in all the six regions though in varying quantities and methods.

Rice cultivation in the Central Plain is mainly lowland irrigation (paddy fields) with some upland cultivation of corn, sugarcane and cotton in the upper and marginal plains (Kawaguchi and Kyuma 1969). In the Northern Highlands, paddy field cultivation is found along valleys, basins, recent alluvial plains and terraces. Upland crops in the

Northern Highlands include tobacco, peanuts, garlic and soybeans (Kawaguchi and Kyuma 1969; Robinson1966). Paddy field cultivation is practiced to a lesser extent in the Northeast. Other crops cultivated in the Northeast are maize, tobacco, cotton and vegetables. The Tenasserim Range and the Southeast Uplands are mostly forested. In the Southeast Uplands, rice is cultivated along the flatter areas found in coastal districts and there are rubber and pepper plantations as well in the region (Robinson 1966). In the Southern Peninsula, and as mentioned earlier, some tribes such as the Senoi have replaced foxtail millet for rice cultivation in the Southern Peninsula (Bisht and Bankoti 2004).

Rank	Commodity	Production ($1000)	Production (Metric tonnes)
1	rice, paddy	7913219	31597200
2	natural rubber	3490733	3051780
3	cassava	2298781	22005700
4	sugar cane	2259442	68807800
5	chicken meat	1735982	1218740
6	mangoes, mangosteens, guavas	1528235	2550600
7	pigmeat	1493726	971693
8	other bird eggs, in shell	1139267	395000
9	cattle meat	661967	245048
10	palm oil	560140	1287510

Table 2.3: Top 10 commodities of Thailand ranked by value and volume in 2009 (Source: FAOSTAT [faostat.fao.org]).

The Southern Peninsula was originally forested but due to economic demand for tree crops such as rubber, many lowlands have been converted to plantations (Collins et al. 1991). Rubber is the main agricultural commodity from the Southern Peninsula. Rubber plantations took over the landscape after the Second World War (Robinson 1966). Thailand is now the biggest producer of rubber in the world (The Economist 2010).

Another economic plant that has impacted the Southern Peninsula landscape is the oil palm. Approximately 90% of oil plantations in Thailand are found in the Southern Peninsula (Dallinger 2011). The lands used for oil palm plantations are classified as 'waste' lands previously used for other agricultural crops, such as for rubber, abandoned fruit orchards and rice fields. A logging ban in Thailand was enacted in 1989 and the encroachment of forests for agricultural conversion also halted when these were declared as national parks, although it appears that protected areas have sometimes been used for both rubber and oil palm plantations (Dallinger 2011). The environmental impacts of oil palm plantations include loss of biodiversity, increase in Green House Gas emissions, deforestation, oil nutrient depletion, drought and desertification (Colchester and Chao 2011), and although Thailand is less affected than other Southeast Asian countries, the flash-floods in Southern Thailand in 2011 were said to have been caused partly by oil palm and rubber plantations (Dallinger 2011). Because oil palms grow in areas with elevations lower than 300 m and require at least 1,800 mm of annual rainfall, the forests most affected by oil palm plantation encroachments would have been the lowland rain forests of Southern Thailand.

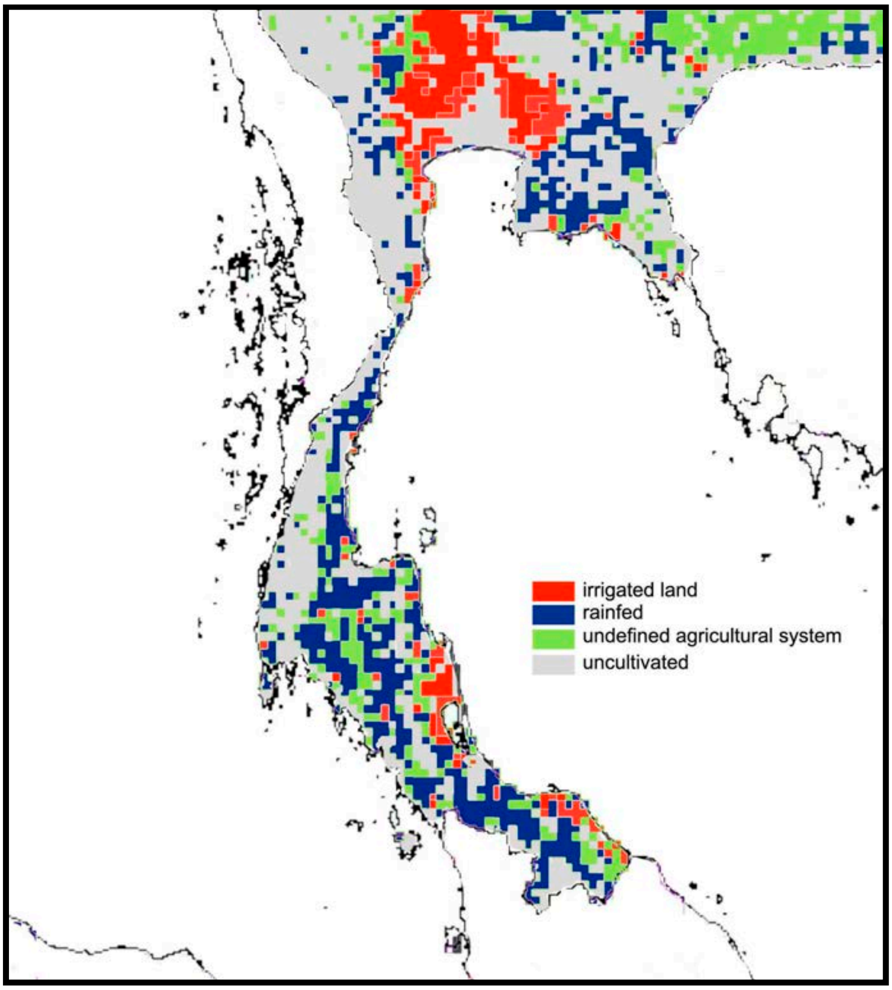


Figure 2.9: Land use in the Southern Peninsula of Thailand (Source: FAO LADA Land Use Systems Maps 2010).

It is not just rubber trees and oil palms that encroached forest zones, other high-income earning plant commodities such as mangoes, mangosteen and guavas would have caused local farmers to seek new land to convert into plantations. Many of these new lands would have been forest land, in particular the lowland rain forests. For example, *Mangifera indica* (mango) grows in evergreen and deciduous forests with altitudes up to 650 m (Santisuk and Larsen 2009); *Garcinia mangostana* (mangosteen) requires annual rainfall of 1,200 mm and grow in altitudes below 450 m (www.worldagroforestry.org); and *Psidium guajava* (guava) likewise requires high annual rainfall of up to 2,000 mm (*ibid.*). Forest encroachment is illustrated at Khao Sam Kaeo where prior to 1930, the four hills and valleys were forested areas and today, these are either rubber plantations or fruit orchards (Table 2.4).

Rice is also cultivated in this region though it is mostly rainfed. Figure 2.9 shows land use in the Southern Peninsula classified into rainfed and irrigated land. The uncultivated areas include forests, non-agrarian land and urban spaces. As mentioned under the soil section (2.5), the soils in the area of Khao Sam Kaeo are low-humic gley soils on semi-recent and old alluvium, which are generally good for rainfed rice farming.

Rainfed cultivation is the dominant agricultural system in the Southern Peninsula region. This system is normally used when there is abundant rainfall allowing the crops to be sown on non-flooded soils and this is called dryland cultivation (Fuller et al. 2011; Jacquot and Courtois 1987). Rice cultivated under this system is also termed dryland or upland rice. However, rainfed fields where flooding of bunded fields is involved is known as wetland rice cultivation. Rainfed cultivation systems may therefore be used in both dryland and wetland systems depending on their location (e.g. mountain slopes for dryland) and whether the fields are bunded or not. A point of clarification; shifting cultivation forms part of rainfed or dryland systems of cultivation but not all dryland or upland rice comes from shifting cultivation. The two elements that define shifting cultivation are ‘clearing by fire and discontinuous cropping’ (Spencer 1966). Therefore, though shifting cultivation is practiced in some areas of the Southern Peninsula, the majority of agriculture is done on permanent-fields and are rainfed.

In order to document recent local agricultural traditions, interviews were conducted in 2009, on my behalf by Chaowana Khaikaew, a Thai student from Silpakorn University. Villagers and farmers from Khao Sam Kaeo and nine localities near Khao Sam Kaeo were interviewed. Figure 2.10 shows the nine locations and Khao Sam Kaeo the area of research encircled in red.

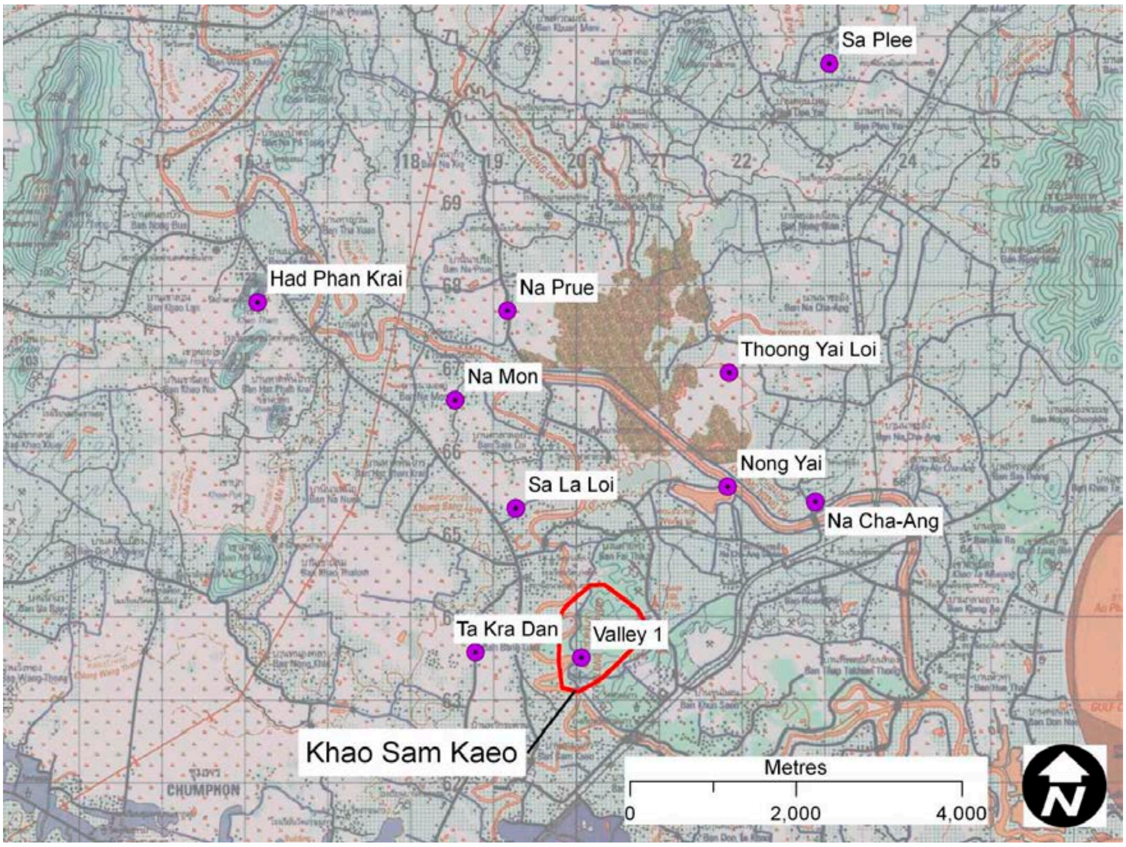


Figure 2.10: Map showing localities where interviews were conducted in 2009 in relation to the area of study Khao Sam Kaeo (courtesy of Chaowana Khaikaew). The nine locations with their coordinates are the following : Nong Yai Kam Ling: 521819; 1165569. Bang Luek Soi 32 : 520726 ; 1164604. Bang Luek : 521044 ; 1164062. Bang Luek Moo 3 : 520657 ; 1165020. Sa Pa-Lee : 523046 ; 1170675. Na Cha-Ang : 522874 ; 1165388. Thoong Yai Loi : 521834 ; 1166943. Thoong Na Prue : 519158 ; 1167692. Sa La Loi : 519259 ; 1165309. Ta Kra Dan : 518775 ; 1163571. Na Mon : 518526 ; 1166613. Had Pan Krai : 516145 ; 1167796.

The following is a summary of the interview results and Table 2.4 gives a more detailed account. In 1931, the hills of Khao Sam Kaeo were forested and Valley 1 was a peat swamp forest. Settlers planted cassava in the northern part of the area (Hill 4) in the 1930s. After the Second World War, rubber was introduced and planted on all four hills. Rice was planted in Valley 1 as it is a low-lying area prone to flooding though being replaced by coconuts and sugarcane in 1951-1960. Two companies acquired the land rights to Hills 1, 3 and 4 in the 1960s and rubber plantations dominated Hills 3 and 4. Also in the 1960s, some of the villagers settled in Hills 2, 3 and 4 and planted orchards still maintained today. The fruit trees are durian, mangosteen and pomelo. Oil palm trees were also planted in the 1960s in Valley 1.

Area	pre-1931	1930s	1940s	1950s	1960s	1970-present
Hill 1	forest	forest	rubber	rubber	rubber	rubber
Hill 2	forest	forest	rubber	rubber	rubber	rubber
Hill 3	forest	forest	rubber	rubber	rubber	rubber
Hill 4	forest	tapioca	rubber	rubber	rubber	rubber
Valley 1	peat swamp forest	meadow	rice sown for 2 yrs	coconut, sugarcane	rice, oil palm	oil palm, rubber, arboriculture
Valley 2	forest	horticulture	horticulture	horticulture	arboriculture	arboriculture
Valley 3	forest	horticulture	horticulture	horticulture	arboriculture	arboriculture
Valley 4	forest	horticulture	horticulture	horticulture	arboriculture	arboriculture

Table 2.4: Land use at Khao Sam Kaeo divided by area and period (courtesy of Chaowana Khaikaew).

The nine localities near Khao Sam Kaeo currently have rice agriculture, oil palm and rubber plantations (Table 2.5). The interviews revealed that two systems of rice cultivation are present in these localities, *na daam* and *na waan* (Table 2.6). The *na daam* cultivation system is defined as transplanted rice planted in bunded fields (Mokkamul 2006). In the sites studied in Chumphon province these were rainfed. Alternatively, broadcasted rice cultivation is called *na waan*. The main sources of water for *na waan* are the Tha Tapao River, canals and ponds. The reason for this is that *na waan* is the method used when the farmers are aiming for two harvests per year (two season rice is known as *na plang*, also written as *na prang*). Because the second cropping season is harvested during the dry season, alternate sources of water other than rain are needed hence the use of water from the river or pond.

Location	Present	Past
Na Prue	rice, palms	rice (1600 - present)
Thoong Yay Loi	rice, palms	rice (1700 - present)
Na Cha-Ang	oil palm	peat swamp forest & rice since 1700
Sa Plee	rice, oil palm & rubber	cemetery (1937), rice (1949-present)
Sa La Loi	rice	rice (1600-present)
Tha Kra Dan	oil palm	rice (1600)
Na Mon	rice	rice (1909)
Had Phan Krai	rice	ponds/meadow before rice (1809)
Nong Yai	nothing	horticulture before 1997

Table 2.5: Cultivation in the vicinity of Khao Sam Kaeo 2009 (courtesy of Chaowana Khaikaew).

Location	harvest/year	cultivation system	water source
Na Prue	na pee	na daam	rain
Thoong Yay Loi	na plang	na waan	Kam Ling canal
Sa Plee	na pee	na daam	rain
Sa La Loi	na pee & na plang	na daam & na waan	rain Tha Taphao river Nong Lum canal Ta Kan canal Thun canal
Na Mon	na plang	na waan	Na Mon pond
Had Phan Krai	na plang	na waan	Tha Taphao river Khlong pond Yaw pond Hlum Kaw pond)

Table 2.6: Cultivation systems in place in the vicinity of Khao Sam Kaeo 2009 (courtesy of Chaowana Khaikaew).

The interviews reflect the FAO data presented above. The cultivation systems are linked to the number of times rice is harvested per year. The *na waan* cultivation system is more productive for the farmers because it allowed for two harvests per year, i.e. *na plang*. However, the rainfed *na daam* system allows for only one harvest per year (*na pee*) but the quality of rice is considered superior to *na plang* rice.

2.7 PAST ENVIRONMENT

A few studies are pertinent in the reconstruction of past environments in the Thai-Malay Peninsula. These are palaeoenvironmental, palynological and geomorphological studies. In particular, Allen's geomorphological study in Kedah and Khao Sam Kaeo (1988; in preparation) and the preliminary pollen analysis of Khao Sam Kaeo by Hutangkura (2008) give us an idea of the site during the period of initial occupation *ca.* 2500 BP.

Allen's geomorphological study (in preparation) at Khao Sam Kaeo shows that the majority of the hills that comprise the site and the surrounding area are the remains of erosion that occurred in the Pleistocene (2.5 million – 10000 BP) as well as younger marine and fluvial terraces. The site also lies in an area that has remained tectonically stable for the past 10000 years allowing for sea-level reconstructions. Studies on sea-level trends in the Thai-Malay Peninsula have shown that the sea level *ca.* 2600 BP was higher than at present by around 1.5 – 1.8 m above the current level (Allen in preparation). There are two studies showing different trajectories in sea-level changes.

Geyh et al. (1979) suggests that in 4000 BP the sea-level was 5 m above present levels and continuously declined to today's sea-level. Tjia (1996) suggests a series of fluctuations spanning every 2000 years. Both studies indicate sea levels were between 2.5 to 3 m above present in 3000 BP and declined to its present level thereafter (Tjia 1996). Table 2.7 shows the results from these studies.

The coastline in the Southern Peninsula was also different from what it presently is. Khao Sam Kaeo, like many other archaeological sites in the Thai-Malay Peninsula including Kedah, was situated closer to the coast than at present. Allen's geomorphological study at Kedah demonstrated that coastal trade sites became interior sites by around *ca.* 1500 AD (Allen 1988). A coastal location for trading sites is essential for their functioning as entrepôts and a change in their physical location such as coastal progradation which result in landlocked sites can cause the decline or abandonment of said trading sites (Allen in preparation). At Khao Sam Kaeo, a nearby coastline would have provided straightforward access to the sea and therefore was well located for an entrepôt. Khao Sam Kaeo during this early period would have had access to the sea via the closer coastline and access to interior sites via the Tha Tapao River which lies alongside the prehistoric site.

Date	Straits of Malacca	Peninsular Malaysia
1500 BP	-	present level
2000 BP	1.5 metres	decline
3000 BP	3 metres	2.5 metres
4000 BP	5 metres	3.5 metres
5000 BP	-	+ 5 metres
6000 BP	-	+ 4 metres

Table 2.7: Comparison of two studies on sea level changes (Sources: Strait of Malacca by Geyh et al. 1979; Peninsular Malaysia by Tjia 1996).

The vegetation during the prehistoric period in the coastal areas of the Southern Peninsula was composed primarily of mangroves. The Satingpra pollen analysis (Stargardt 1983, fig. 28) with a base of 4000 years shows the earliest layers of the area dominated by mangroves and substituted by grass in the last period. Mangrove vegetation dominates the lower levels of most pollen studies conducted in Thailand including the preliminary palynological study by Hutangkura (2008). Samples for Hutangkura's study were taken by hand auger in two areas of the palaeo-channels (AU1 and AU2) belonging to the Tha Tapao River within the site, as well as sediments from two test pits in Hills 1 and 2 (TP4 and TP7). The results from the test pits were poor in pollen but the sampling done by hand auger shows a distinct mangrove peat layer in both samples (AU1 and AU2). The preliminary dates suggest that the final phase of the mangrove layer is *ca.* 2500 BP. This date coincides with the initial occupation recorded at Khao Sam Kaeo. The histograms (Figures 2.11 and 2.12) show a dominance of swamp and grassland pollen in the later periods. The establishment of freshwater wetlands after 2500 BP means that more land would have been conducive to rice cultivation, which would have been difficult under saline, mangrove conditions. It is likely that the freshwater environment was a contributing factor to the date of settlement at Khao Sam Kaeo.

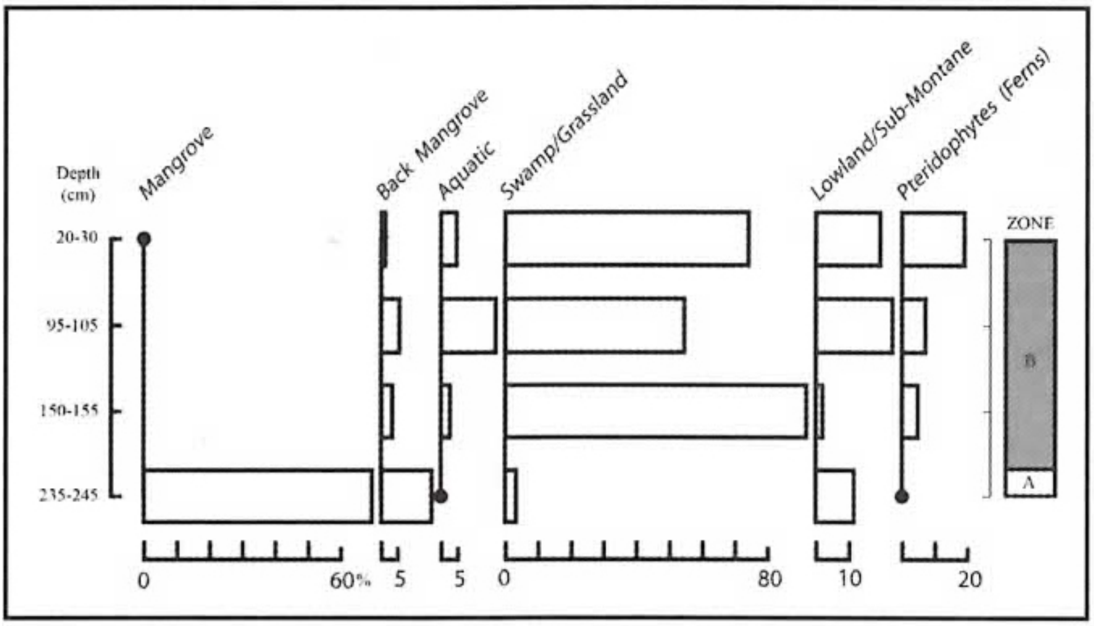


Figure 2.11: Pollen histogram of AU1 (Hutangkura 2008).

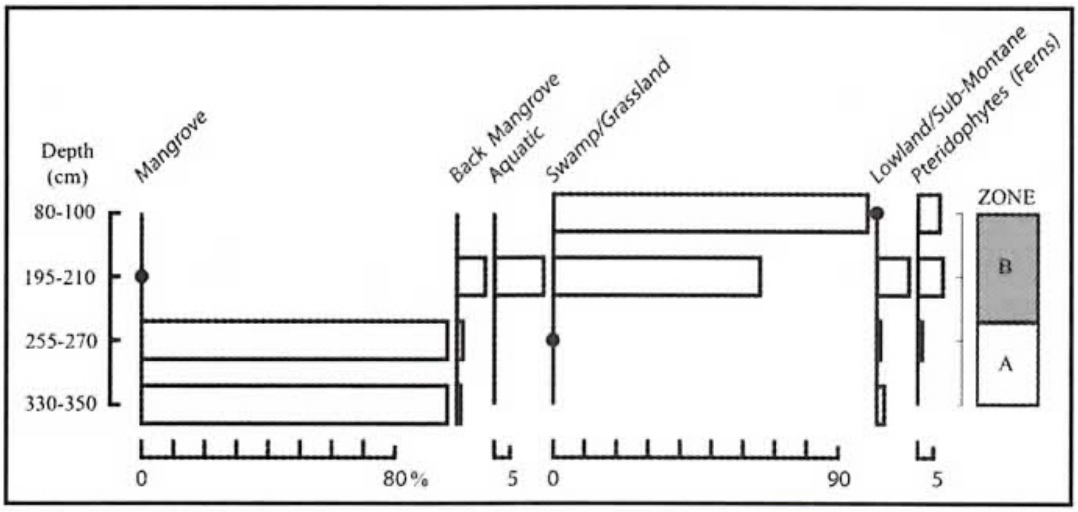


Figure 2.12: Pollen histogram of AU2 (Hutangkura 2008).

CHAPTER 3
Archaeobotany in Southeast Asia

3.1 INTRODUCTION

Childe's (1936) concept of the Neolithic Revolution sparked interest in the origins of agriculture in the archaeological world in the first half of the twentieth century. The study of agricultural origins took a major step forward as archaeologists took increasing efforts to recover traces of past agriculture via archaeobotanical techniques (Helbaek 1969; Pearsall 1989:4).

Archaeobotany emerged as a specialisation in Europe and America from the 1960s with more systematic collection and study of macroremains (Dimbleby 1967; Helbaek 1969). The introduction of the flotation technique in excavations aided in the recovery of plant remains and was first carried out at Apple Creek, Illinois by Struever in North America in 1962 and in Deh Luran, Iran by Helbaek in Southwest Asia in 1963 (Fuller 2008a; Helbaek 1969; Struever 1968). However, it was not until the 1970s that it became a routine part of archaeological sampling. From its early development and application in the Americas, southwest Asia and Europe where used regularly, it slowly became increasingly used elsewhere, such as India, during the 1980s (Fuller 2002). Finally, in the 1980s, phytolith analysis became a more widespread technique and it is now a methodology integral to archaeobotanical research (Pearsall 1989; Piperno 2006). As a result of the availability of these methodologies, archaeobotany has grown as a discipline enabling archaeologists to answer questions not only focused on origins, but climate reconstructions, environmental reconstructions, early agricultural systems, categorisation of historical landscapes, past human activities like crop-processing, exchange systems, aspects of belief systems and the construction of regional cuisines (Bowdery 1999; Fuller 2002, 2005; Paz 2001; Smart and Hoffman 1988).

In this chapter, I review the state of archaeobotany in Southeast Asia with a focus on macroremains and phytoliths.

3.2 A SHORT HISTORY OF ARCHAEOBOTANY IN SOUTHEAST ASIA

Archaeology in Southeast Asia is generally divided into Mainland Southeast Asian and Insular Southeast Asian (henceforth MSEA and ISEA respectively) archaeology.

Similarly, the field of archaeobotany has been divided into these two areas of study. The emphasis in MSEAn archaeobotany has been on the origins of agriculture and the spread of early rice farming communities (Glover and Higham 1996; Higham 2013; Gorman 1969). At the forefront have been debates on centres of rice domestication, spread of rice and the type of agricultural system that was in place (wetland or dryland). In contrast, studies in ISEA have centred on indigenous plant remains such as taro, yam and banana and their domestication (Barton and Paz 2007; Bellwood 2007; Denham and Haberle 2008; Kennedy 2009). However, in both regions, collection of hard evidence for agriculture has been lacking compared to the amount of discussion revolving around cultivation and agricultural dispersal (e.g. Bellwood 2005, 2007; Higham 1995). The majority of statements relating to agriculture in the region to date have been deduced by inference and draw on sources of evidence other than archaeobotany.

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. Sampling techniques used in Southeast Asia include dry-sieving, wet-sieving and hand-picking to flotation. However, the first three techniques used in the recovery of floral remains have the disadvantage of overlooking small-sized macroremains (Fuller 2008a; Pearsall 1989). They have often been used in conjunction with faunal remains recovery, which are, by comparison, not greatly biased by the use of a 2 mm sized mesh. Floral remains collected using these techniques have often been large-sized or found in great quantities due to their specific context (e.g. rice-filled graves) which allows for visibility with the naked eye. On the other hand, the size of the samples retrieved via flotation is dependent on the mesh size used. In Southeast Asia, these have often been larger than 2 mm where ideally they should be 0.25 mm.

Ian Glover and Chester Gorman were the first archaeologists to introduce systematic archaeobotanical techniques in ISEA and MSEA respectively back in the late 1960s (Oliveira 2008; Paz 2001). Initially, they both used dry-sieving methods in the field. Glover excavated the sites Bui Ceri Uato, Lie Siri, Uai Bobo 1, Uai Bobo 2 in East Timor forming part of his PhD thesis and retrieved plant remains such as *Cocos, Celtis* and *Coix.* Gorman conducted excavations at Spirit Cave in Thailand and found *Canarium*, and *Lagenaria* (bottle gourd) as well as several other taxa. This site was fraught with controversy over some of the identifications but Gorman continued to incorporate an archaeobotanical agenda in his other excavations due to his interest in Hoabinhian horticulture. He went on to retrieve more floral remains from Banyan Valley Cave and Tham Pa Chan. Banyan Valley Cave was originally thought to provide evidence of cultivated rice though it was subsequently considered to be wild by T. T. Chang (Yen 1982).

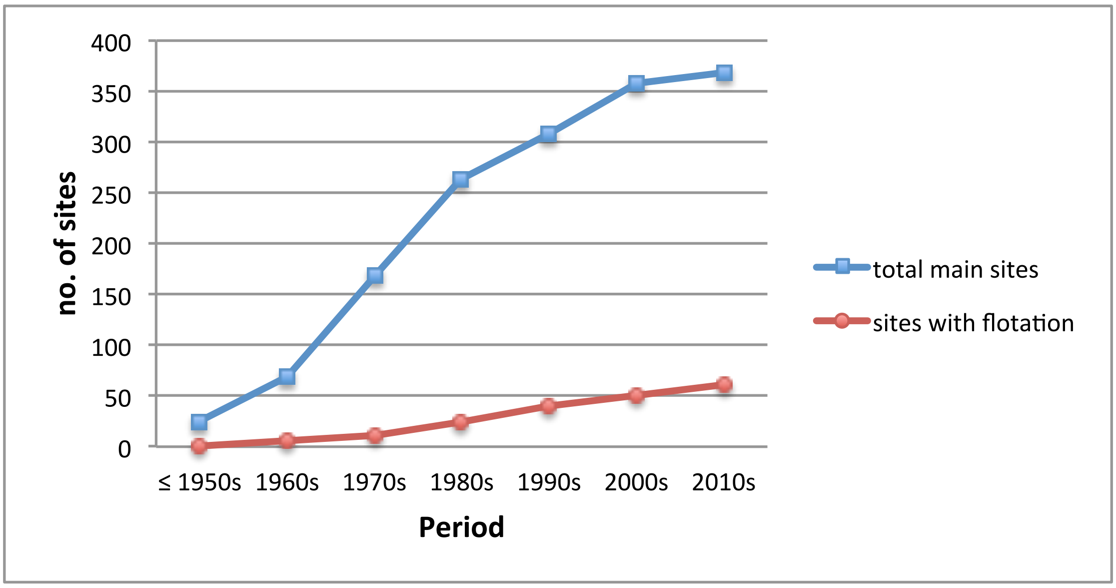


Figure 3.1: Cumulative number of Southeast Asian sites excavated and the cumulative number of sites where flotation was used as a recovery technique for plant remains. Information is based on available published data in English (compiled by Castillo).

Despite all the initial efforts by Glover in Indonesia and Gorman in Thailand, the recovery of plant remains from archaeological sites in this region did not become a routine practice (Paz 2001). In fact, flotation is still not part of the archaeological routine in Southeast Asian excavations. Figure 3.1 is a summary of Southeast Asian archaeological sites and those that have used flotation based on published data in English. Included are some sites where the author did flotation as well as some new unpublished data obtained through personal communication. This chart represents the general trend of archaeological endeavour towards more systematic archaeobotanical efforts. Of 369 sites that have been excavated (the 'main sites'), only sixty-two have used flotation to recover plant remains (the author conducted flotation in thirteen of these sites). Appendix 3.1 is a detailed table showing the sites that used archaeobotanical methodologies in Southeast Asia. A mere seventy-six sites (21%) have employed either flotation and/or phytolith sampling and twenty-one sites have employed both flotation and phytolith sampling. Thompson (1996), Paz (2001) and

Oliveira (2008) all cite the dearth of archaeobotanical studies conducted in Southeast Asia, indicating that this has remained the case through the past two decades. This state of play can be contrasted with other world regions, such as South Asia (India and Pakistan) where the first flotation was carried out in the late 1970s (Fuller 2002) and some seventy-two sites had published flotation data by 2005, with a steady rise in particular amongst Neolithic/Chalcolithic sites, and recently in south Indian sites (Fuller 2008a).

The past five decades have seen archaeological interest in early agriculture and subsistence but without commensurate interest in archaeobotanical recovery and study. Discussions on agriculture have been based on any of several lines of evidence, including retrieved plant macroremains, phytoliths, pollen, tillage tools, impressions of organic material in pottery, geomorphology or grinders. When reported, the majority of the archaeobotanical evidence was retrieved either through flotation or by examination of organic impressions (Figure 3.2). Sadly, in many instances, though archaeobotanical sampling and flotation were employed, the plant remains were not analysed (Paz 2001). Furthermore, there are several sites (Angono rockshelter, Bagumbayan, Dimolit, Panay Island, Gua Cha and Satingpra) where flotation was employed but did not yield any results.

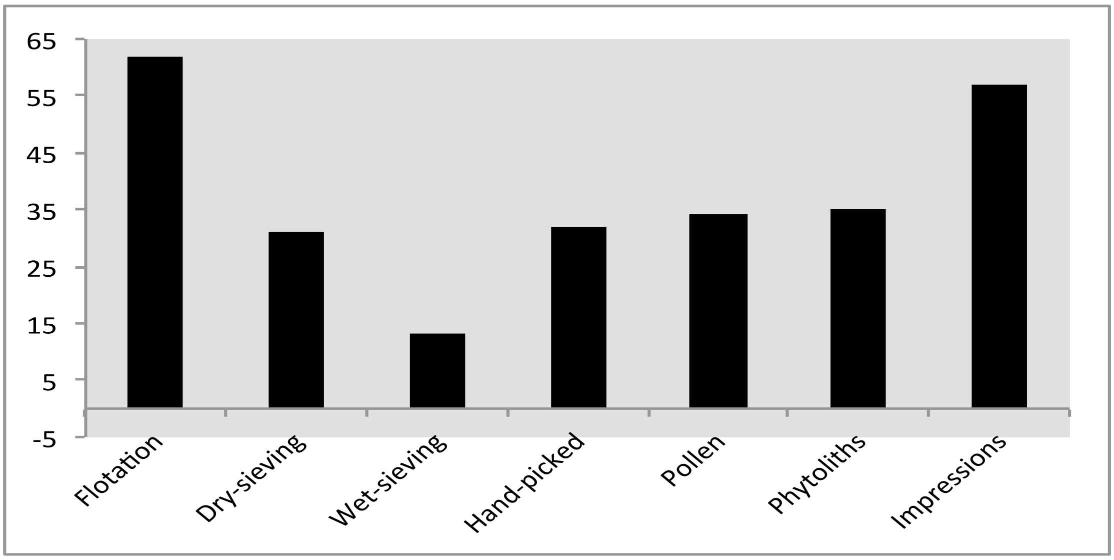


Figure 3.2: Archaeobotanical methodologies employed in SEA. Number of sites from 1950 to 2012 with archaeobotanical finds or inferences and the techniques used in their retrieval or interpretation. A total of 369 sites were considered out of which 162 sites provided references to archaeobotany or agriculture. The sites are taken from either published sources in English, personal communication or conference presentations.

The study of phytoliths was employed as an archaeobotanical methodology at a later date than macroremains analysis, but has likewise not been systematically employed in many Southeast Asian excavations. As Appendix 3.1 shows, thirty-five sites in Southeast Asia have been sampled for phytoliths and twenty-one sites employed both methodologies. It is becoming more evident that combined methodologies in the field of archaeobotany are helpful in countering preservation biases.

Most of the early writings on the agriculture of Southeast Asia revolved around rice. Given the lack of archaeobotanical sampling, inferences were based mainly on the presence of associated artefacts such as tillage tools and either rice impressions in pottery or brick from the widespread practice of tempering clays with rice husk (Nguyen 1998; Vanna 2001; Vincent 2003; Watabe et al. 1974; Yen 1982). It should be noted that the presence or absence of rice husk in pottery may have as much, or more, to do with technical considerations of ancient potters than with whether or not rice was a staple food or common crop. Obviously, if present in pottery, then rice must have been widely available to the potters, but the absence of rice from pottery does not imply an absence of rice from regional agriculture.

This study is meant to address questions of agriculture and origins of crops in a systematic manner. So far, discussions on these two topics have neglected archaeobotanical research. However, this research has prompted a number of archaeologists to consider archaeobotany as part of their excavation agenda and have started to collect and store soil samples for flotation and archaeobotanical analyis (e.g. Ban Non Wat, Khao Sai On, Non Ban Jak, Pacung, Phum Sophy, Rach Nui, Sembiran). The research done at Khao Sam Kaeo and Phu Khao Thong has begun to receive attention from other scholars in Southeast Asia and collaborations are now on their way.

3.3 SOME CONSIDERATIONS ON SOUTHEAST ASIAN ARCHAEOBOTANY

There have been a number of archaeobotanical studies in Southeast Asia which did not yield any floral remains. A reason for this lack of success is the poor preservation of organic material in tropical environments due to factors such as extreme humidity and exposure to weathering, erosion and bioturbation (Kealhofer and Grave 1999; Piperno and Pearsall 1998a; Sobolik 2003). The clay content in soils also affects the recovery process (Pearsall 1989). Another factor affecting preservation is the nature of the settlement; whether it is sedentary for an extended period of time or seasonal, shifting cultivation or less dense settlement. Finally, retrieval methods and the volumes sampled are likely to affect the extent of recovery. Khao Sam Kaeo is an open area affected by wind, erosion, rain and flooding. Nevertheless, recovery of macroremains at Khao Sam Kaeo in tropical Southern Thailand, suggests that they are often present, but in much lower density than encountered in drier or more temperate environments; this means that more archaeological sediments need to be processed making flotation difficult and slow, but not impossible. The concentration of remains from larger volumes of soil may increase the possibility of some intrusive seeds entering deposits, and this means that there is a strong need for confirming antiquity by direct AMS dating.

Further preservation bias occurs in that some plant taxa, such as domesticated banana (polyploid *Musa paradisiaca*) do not yield macroremains although wild *Musa* spp. should (Vrydaghs et al. 2009; De Langhe 2009; see Table 3.1). Other crops, made up mostly of parenchymatous tissue (such as tubers) do not leave phytolith traces, and the study of charred fragments of archaeological parenchyma is still under-developed (Hather 1999; Paz 2001, 2005). An invisible archaeological footprint does not necessarily mean the non-existence of a certain plant, and absence must be carefully assessed in light of the recovery methodologies attempted. For these reasons, combined methodologies (macroremains, phytolith analysis, palynology, diatom analysis, and starch analysis) are being used more frequently to explore archaeobotanical assemblages allowing for a more balanced and broader dataset (Piperno and Pearsall 1998b). Nevertheless the preservation of charred macroremains from Khao Sam Kaeo means that these can be used in conjunction with microremains, especially the ubiquitous phytoliths. Phytoliths have been collected at KSK and PKT and will be analysed in connection to the macroremains in the future. Harvey (2006) in her UCL PhD thesis focusing on South Asia used both macroremains and phytolith studies ensuring a wide dataset to counter preservation biases. Harvey's study also included the use of phytoliths as an alternative or complementary methodology to macroremains analysis to interpret crop-processing stages. Harvey developed crop-processing models based on crop plant components and weed seed patterns from macroremains and phytolith datasets. The limitations of macroremains in crop-processing analyses are the reliance on charring for preservation and the differential preservation of plant parts that occurs during charring (Harvey 2006; Harvey and Fuller 2005). Phytoliths can overcome some of these issues affecting macroremains since they do not require charring, are inorganic and therefore, durable. However, phytolith identification is most of the time limited to genus level.

Site	Location	Date	Evidence	Interpretation*	Reference
Ban Ang	Laos	300 BC - 300 AD	phytoliths	prob. wild bananas because they co-occur with palm phytoliths	Bowdery 1999
Batadomba Lena	Sri Lanka	36,300-34,600 cal. BP	phytoliths	use of wild bananas for non-culinary purposes	Perera et al. 2011
Beli Lena	Sri Lanka	12,000-9,300 cal. BC	macroremains	foraging of wild fruits	Kajale 1989
Bird's Head sites (Kria & Toe Caves)	New Guinea	n/a	macroremains	wild bananas	Pasveer 2003
Garua Island	Papua New Guinea	after 1100 BP	phytoliths	forest regrowth	Lentfer & Torrence 2007
Gua Chawas	Malaysia	10,000 BP	phytoliths	wild bananas	Bowdery 1999
Kot Diji	Pakistan	2000-1900 BC	phytoliths	either use of wild bananas for non-food use; or early introduction of domesticated banana	Fuller & Madella 2009 Lejju et al. 2006
Kuk Swamp	Papua New Guinea	before 10,200 cal. BP	phytoliths	wild bananas	Denham 2005
Kuk Swamp	Papua New Guinea	10,200-6,950 cal. BP	phytoliths	mixed cultivation regime with swidden	Denham 2005
Kuk Swamp	Papua New Guinea	6,950-6,440 cal. BP	phytoliths	higher frequencies of phytoliths than in previous layers indicative of banana cultivation	Denham 2005 Perrier et al. 2011
Lao Pako	Laos	300 BC - 300 AD	phytoliths	prob. wild bananas because they co-occur with palm phytoliths	Bowdery 1999
Nong Thalee Song Hong	Thailand	5,000 BP	phytoliths	forest management through periodic burnings; prob. wild bananas because they co-occur with palm phytoliths	Kelhofer 2003
Reber-Rakival	Papua New Guinea	450 BC - 600 AD	phytoliths	cultivated banana	Lentfer & Green 2004
Yuku	Papua New Guinea	ca. 3,200 cal. BC	phytoliths pollen	banana part of susbsistence regime	Horrocks et al. 2008

* Interpretations are based on references but made by Castillo & Fuller (in press).

Table 3.1: Sites in South Asia, Southeast Asia and Oceania with evidence for *Musa* sp.

The use of multidisciplinary evidence is perhaps best displayed in understanding the history of bananas. It is a fruit of great diversity because of a complex domestication process involving intra-specific and inter-specific hybridisations and somatic mutations with a history that is still being unravelled by botanists, geneticists, linguists and archaeologists (De Langhe et al. 2009). The banana underwent several stages of domestication as it was exploited, cultivated and translocated over the course of several millennia across many distinct geographical and cultural areas. In fact, when domestication began is still unknown but based on multidisciplinary evidence the first stage of domestication is estimated to be more than 4500 years ago (De Langhe et al. 2009; De Langhe and de Maret 1999). However, cultivation is a precursor to domestication and there is evidence from New Guinea indicating a minimum age of

6500 years ago for cultivation (Perrier et al. 2011). There are various sources of evidence for the existence of *Musa* in archaeological sites*:* seeds, phytoliths and starch grains. Seeds are generally found in the contexts where wild, or ‘cultiwild’ and naturalised bananas were being consumed such as in foraging sites. Evidence of domesticated banana outside its natural area of diversity is considered a proxy at the very least for human contact and in some cases for human migration (De Langhe 2009; Horrocks et al. 2009; Mbida et al. 2001; Perrier et al. 2011; Vrydaghs et al. 2009). The domesticated edible banana is by definition almost devoid of seeds. For this reason finding *Musa* seeds archaeologically in areas where it is indigenous signifies that the find is wild *Musa*. On the other hand, if the seeds are found outside the centre of primary diversity, human beings must have been responsible for their introduction (De Langhe 2009). However, naturalised *Musa* will also yield seeds and these would be difficult to distinguish from true wild bananas if found in the area of primary diversity. Seeds will not be found in contexts where the banana is already domesticated and forms part of a mode of subsistence such as vegeculture. This is because of the reduction in seeds once the banana is domesticated. The advantage of finding seeds archaeologically is that they are easier to identify to species level than phytoliths though seeds in archaeological contexts are scarce. The mode of propagation for domesticated bananas is vegetative and therefore, they do not leave archaeological traces such as seeds or pollen (Vrydaghs et al. 2009), which makes the task of finding edible domesticated bananas in prehistory a very difficult one for archaeobotanists. Accordingly, few sites claim *Musa* remains. It is because of this taphonomic bias that most archaeological reports on bananas are based on phytolith identification (e.g. Bowdery 1999; Kealhofer 2003; Mbida et al. 2001; see Figure 3.3). It is generally accepted that the Musaceae family produces distinctive phytoliths and the leaves produce genus-specific morphologies described as volcaniforms, troughs or truncated cones (Ball et al. 2006; Piperno 2006; Horrocks and Rechtman 2009). Trying to narrow down phytolith identifications to wild or domesticated status and to species level is work in progress (Ball et al. 2006; Vrydaghs et al. 2009). However, the use of phytoliths is best considered in discussions on cultivation by using quantitative and distributional analyses as well (Kennedy 2009; cf. Denham 2005).

The state of achaeobotanical research in MSEA is still in its infancy. This is especially true when comparing the quantity and quality of work done in the same field in the Middle East, Europe and the Americas. There remains a visible lack of archaeobotanical studies conducted in MSEA. With a few exceptions [Non Pa Wai, Nil Kham Haeng, Non Mak La in central Thailand (Pigott et al. 2006) and Khok Phanom Di, southeastern Thailand (Thompson 1996)], most excavations thus far have not included the systematic collection of soil samples for macroremains analysis as part of their methodology to study the agriculture. This is because the majority of projects have focused on excavating burials rather than settlement areas (Higham 1989, 2002a; Higham and Thosarat 1998; Higham and Bannanurag 1990; Glover 1983).

Studies in geomorphology and pottery have also been employed to enhance our knowledge of agriculture in Southeast Asia. Most of the early writings on the agriculture of Southeast Asia revolved around rice. It is therefore not surprising that given the lack of archaeobotanical sampling, 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). Vincent (2002, 2003) provides a summary of rice-tempered pottery in Thailand, Vanna (2001, 2002) for Cambodia, and Watabe et al. (1974) for Myanmar. Allen (1991, 2000), on the other hand used geomorphology to investigate systems of cultivation in the Thai-Malay peninsula in the early centuries AD.

Contributions to the field of archaeobotany in Southeast Asia come from scholars like Paz, Thompson and Weber. In his PhD dissertation (2001), Paz, demonstrates the importance of data quality or integrity. In past research, it was common practice to gloss over the preserved state of the plant remains studied. Therefore, both charred and un-charred (Paz uses the term untransformed) specimens were considered ancient (Paz 2001). This practice is criticised by Paz since un-charred seeds, unless waterlogged or from anaerobic layers, should be considered as modern contaminants, allowing the researcher to determine the "level of context security" (Paz 2001). Furthermore, the work of Paz consisted in testing the Austronesian hypothesis of past movements (Bellwood 1997) by examining the archaeobotanical record of several sites in Wallacea (Paz 2001). An indicator of these movements is the domesticated yam (*Dioscorea alata*) believed to be a domesticate of MSEA. The presence of domesticated yam in ISEA could signify Austronesian migrations and dispersals. The earliest dates Paz secured for the presence of domesticated yam in ISEA is 1500-2000 cal. BC at Madai-1, Malaysia supporting the hypothesis of an early introduction by at least this early age (Paz 2005). However, more archaeobotanical investigations are needed to determine whether domesticated yam is present or absent in deposits dating prior to the Austronesian movements of people (*ca.* 2200 BC) to properly test the Bellwood hypothesis. Rice was originally believed to also be an indicator of Austronesian movements (Bellwood 1997) but Paz did not discover any rice in his study sites and it is now widely accepted that rice may have been dropped from the original crop package introduced from Taiwan (Bellwood 2013).

Thompson (1996) is perhaps the most cited scholar in Southeast Asian archaeobotanical studies for her comprehensive work in Khok Phanom Di. The research comprised of macroremains analysis, including wood. She was able to infer from the presence of certain seeds and wood types, the environments and vegetation zones present. She also furthered our understanding of morphological manifestations of domesticated rice by studying rice spikelet base scars. To date, this method of discerning whether rice is domesticated or wild by examining the spikelet base scar is the most accurate (Fuller et al. 2010). Thompson also showed that domesticated rice was present in the coastal site Khok Phanon Di *ca.* 2000-1500 BC and was probably cultivated in nearby swamps dependent on natural flooding. The work in Khok Phanom Di also proved that preservation of plant remains in open sites does occur in humid Asian environments. Another important contribution by Thompson in the interpretation of archaeobotanical data is the detailed discussion and documentation of rice crop-processing in Thailand.

The archaeobotanical study conducted by Weber in the Khao Wong Prachan Valley has also helped in our understanding of agriculture and subsistence in the region. Weber et al. (2010) demonstrate that foxtail millet was grown a millennium prior to the adoption of rice in the Khao Wong Prachan Valley. In a region where archaeologists have been obsessed with rice, the Khao Wong Prachan Valley study has been pivotal in pursuing other lines of inquiry regarding the agricultural regime present in Prehistoric Thailand. Weber et al. also indicate the mode of cultivation was dryland with the study of the weed assemblage.

The present study derives elements from the above stated archaeobotanical works of Paz, Thompson and Weber. A methodology was developed to determine context security of plant remains, crop-processing stages were inferred from the rice assemblage, examination of rice spikelet bases was used to determine the domestication status of rice and the weed assemblage was crucial in determining past agricultural regimes.

Archaeobotanical analysis in Southeast Asia is still lagging behind other regions of the world even though there has been some development in both MSEA and ISEA in the field of archaeobotany since the 1960s, specifically coming from key studies using macroremains (Oliveira 2008; Paz 2001; Thompson 1996; Weber et al. 2010). Together with these studies, this dissertation is important as it provides more archaeobotanical evidence from prehistoric Southeast Asia necessary in the formulation and revision of our understanding of past agricultural and subsistence regimes. Weber et al. (2010) found that millets were the staple diet before rice in Neolithic and Bronze Age central Thailand showing that multiple phases in Southeast Asian agriculture existed. More archaeobotanical studies such as the present one are needed to provide higher resolution regarding the presence of multiple agricultural phases and crop dispersal movements and directions. Lastly, this study also shows the use in the Late Prehistoric Period of potential local domesticates. Exploration of outward dispersals of local domesticates is uncommon in discussions of Southeast Asian archaeobotany since the focus has almost always revolved around introductions.

CHAPTER 4
Materials and Methods

4.1 SOURCE DATA

Several sources of information were used in the preparation of this research. The main body of information is archaeobotanical and botanical data collected from the sites of Khao Sam Kaeo and Phu Khao Thong. Macroremains, phytoliths and modern plants that form part of the reference collection were gathered during the period of study from 2007 to 2009. However, the results from the phytolith study are not included in the dissertation. The other sources of data are from charring experiments (Chapter 6) and written references. Each of these sources will be discussed in the following sections and for simplicity, the sections will be subdivided to discuss details of each site where applicable.

Three limitations were encountered in this study: preservation of plant remains, identification problems and the dearth of archaeobotanical studies in Southeast Asia. However, my work at Khao Sam Kaeo proves that archaeobotanical research can be done successfully in a humid and difficult environment. On-going identifications are also paving the way for future work to be done in Southeast Asia and specifically in the Southern Peninsula of Thailand. The results from this study will hopefully form part of future work revolving intra and inter-regional discussions on agriculture.

4.2 MACROREMAINS

Macroremains form the main corpus of study in this dissertation for both sites, KSK and PKT. The sampling strategy in both sites was based on the same aims and research questions. For consistency, the archaeobotanical methodology was the same although variations did occur between sites, which are mentioned when significant. Most time was spent at KSK, PKT was surveyed towards the end of KSK fieldwork. The period of time spent doing fieldwork and focusing on flotation, retrieval of phytoliths and modern botanical specimens is as follows:

Year	time spent in the field
2007	1 month
2008	1.5 months
2009	1.5 months

Khao Sam Kaeo

Khao Sam Kaeo was excavated over a period of five years, 2005-2009, and sixty test pits (TP) were sampled. The dimensions of the test pits were 2x2 metre squares. Six sections were also sampled and these are designated with 'S' instead of 'TP' in the databases. Sampling was aimed to recover plant remains representative of the entire site and not specific contexts or features only. It is for this reason that whenever a new test pit was opened, it was sampled for archaeobotanical remains. At KSK, time constraints required us to discard some of the soil samples collected for archaeobotanical studies. This is not considered an issue in the analysis of the remains since 365 samples were collected from KSK. This number was considered too high for one person to sort and identify and so the number of samples analysed was narrowed down further, as is discussed in the data quality section.

The rationale for excavating specific areas of the site was determined by the site's limitations (e.g. looting) and the Franco-Thai Project's research questions during each particular field season. There were areas of the site that were inaccessible to the team due to destruction of the area from looting activities or lack of permission from the land owners. This is the reason why there are fewer samples from Hill 2. Research questions concentrated on determining the role of KSK in regional and inter-regional exchange networks and examine the social structure and cultural changes of different social groups involved in trans-Asiatic networks through the organisation of craft systems at the site (Bellina and Silapanth 2006). In addition to these research questions, the project's objectives in 2009 were aimed to address palaeo-environment issues. In particular, the project aimed to define whether local cultivation was practiced in this early urban site or whether it was exclusively used as an exchange entrepôt.

sampling soil

The soil collection strategy was bulk sampling. The aim was to collect a standard amount of soil in every excavation level. If all years are taken into account, the average amount of soil collected is thirty-one litres per layer. In 2007, the average amount of soil collected was 4.8 kg (≈4.8 l). It was decided to increase the amount of soil floated in the following years because of the low amount of seeds yielded in the 2007 samples. It is generally considered good practice to collect larger samples if preservation is considered a problem. The amount of soil collected in the years 2008 and 2009 was increased to average forty litres (Appendix 4.1). Almost 12,000 litres of soil were floated in the four years of research. The breakdown of volume of soil floated, test pits sampled and samples collected are found in Table 4.1.

Year	test pits sampled	no. of samples	volume of soil floated (litres)
2006	3	6	-
2007	18	72	339.6
2008	29	147	6275
2009	13	140	5380
TOTAL	63	365	11,994.6

Table 4.1: Total amount of soil and samples collected at Khao Sam Kaeo for macroremains analysis. The soil collected in 2007 has been converted from weight to volume using 1 litre of soil ≈ 1 kg of soil. The original weight collected in 2007 was 339.6 kg. Unfortunately, there were no records of how much soil was floated in 2006; also, weight measurements for 2 samples were not recorded in 2007.

Excavation levels at KSK are known as 'US' (unité stratigraphique), the French term for stratigraphic unit, as the excavations were under Franco-Thai direction and the *'chef de mission*' was the French archaeologist Dr. Bérénice Bellina. The initial aim was to collect soil samples from all stratigraphic layers (US) of the test pits opened in order to obtain chronological information. However, collection from all layers was not always possible due to time constraints and logistical issues during fieldwork. Also, following the sampling strategy laid out by Popper and Hastorf (1988), samples were taken from less productive deposits as a control measure. This means all US levels from test pits selected were sampled when it was possible. This was done to have chronological resolution but also to provide stratigraphic information.

The soil collected was placed in clean rice sacks and was not dried prior to flotation. Moreover, the soil samples were collected straight from the test pits without previous dry-sieving. This is important as it lessens contamination and loss of material. Figure 4.1 shows the locations of the test pits sampled per year at KSK.

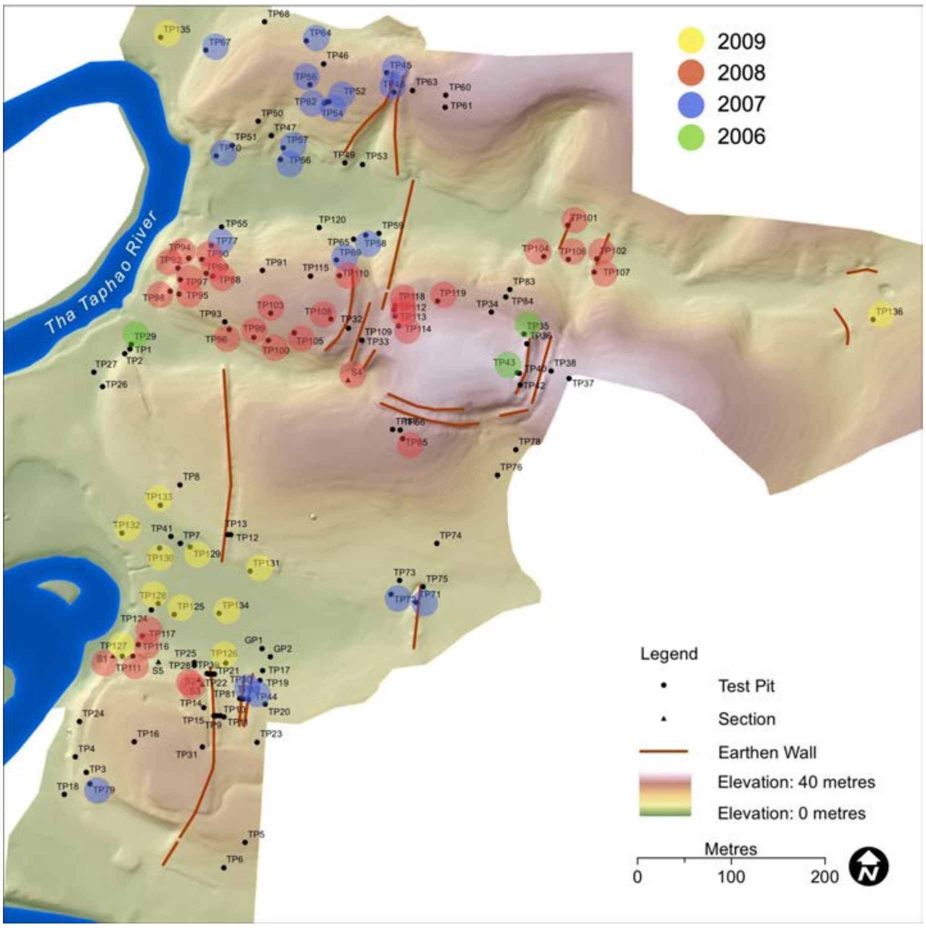


Figure 4.1: Map showing the locations of soil samples collected for macroremains analysis (Map courtesy of Julie Malackie).

retrieval of plant remains

The recovery technique employed in both sites KSK and PKT was bucket flotation. The technique involves placing a quantity of soil in a bucket, adding water and stirring it by hand to break down the soil and allow the charcoal to break free and float. After stirring the soil, it is allowed to settle for around two to three minutes and the suspended sediments are then poured into a 250 μm mesh bag to catch the floating charred remains. The process is repeated at least three times or until all the visible charred material is poured off into the mesh bags. This method is considered very time consuming and labour intensive. Other archaeobotanists opt for flotation machines. At KSK there were sufficient workers to make bucket flotation methodology worthwhile. I was in charge of flotation during the three seasons of excavation at KSK which made the flotation technique uniform. Standardising the recovery method results in less variation in the retrieval of remains, especially loss of plant remains (Wagner 1988). Figure 4.2 shows the team at KSK doing bucket flotation and the 250 μm mesh bags drying.

Figure 4.2: Images of the team at Khao Sam Kaeo doing flotation and the mesh bags drying. (Photographs by author).

Flotation areas were set in different locations each year depending on the availability of water. Water supply was always a problem on-site and several sources were used including the Ta Thapao, streams and stored water from nearby households. All source water was strained through a 250 μm mesh bag to prevent contamination. This is a reason for not examining the fine fraction of <250 μm in the lab.

The tasks of pouring soil and water into buckets and stirring to break down the sediments were mostly relegated to the workers. The job of pouring the floating remains into mesh bags was mainly done by this researcher. Many plant remains sink to the bottom even when charred and it requires some skill to pour these into the mesh bag

(Wagner 1988). Finally, after all the charred remains were extracted (or at least this was believed to be the case), the heavy fraction was wet sieved to retrieve larger fragments including glass and stone.

The individual mesh bags were then air dried, bagged and shipped to London for analysis. The bags were not sorted on site and all flotation remains including roots were left in the bags. Roots are important indicators of bioturbation and the proportion of roots per sample was noted down in the lab in order to determine the level of contamination in each sample (see Chapter 6 - modern contaminants and context security section).

sorting and data quality

Table 4.1 shows the total volume of soil collected and floated during the course of four years and the resulting number of samples. The soil floated yielded 365 samples. Floated samples were weighted and the volume determined. The proportion of roots in each sample was estimated as a percentage of volume. Samples were then sorted and identified down to 0.5 mm size by the author of this dissertation. Several low-powered microscopes at the Institute of Archaeology, UCL archaeobotany laboratory were used including the Leica EZ4D. Some authors suggest 'scanning' or examining only a fraction of the bigger samples in order to get around budgetary constraints and to save time (Toll 1988). I decided that it was better to concentrate on quality data (see below) and sort the entire sample even if time consuming rather than scan or subsample. This decision is based on the low seed density of the samples due to preservation issues at KSK. Subsampling might lead to further biases or no results. Some samples contained very few plant remains; there are fifteen samples with fewer than ten plant remains.

Not all samples were sorted and identified due to time constraints as well as other practical considerations. A data quality system was therefore introduced to narrow down the samples to be analysed with grades 1 and 2 considered the most appropriate samples to answer the research questions. Therefore, most samples sorted and identified came from these two groups. Samples from grades 4 and 5 were rejected. It is recommended that samples not recovered in a satisfactory method be rejected from the dataset (Wagner 1988). Appendix 4.2 shows the data quality grade of each test pit.

The following are the criteria applied to the samples collected:

1 samples from test pits with conventional and AMS radiocarbon dating or OSL dating and associated artefacts
2 samples from test pits containing associated artefacts or having other information from specialists such as geomorphology
3 samples from test pits with no associated artefacts but with interpretations
4 samples from test pits that have structures or those with fluvial deposits
5 samples from test pits that have been disturbed, heavily eroded or difficult to interpret, were rejected from dataset

To date, a hundred and one samples were sorted from Khao Sam Kaeo. However, after applying the quality criteria only eighty-eight samples have been used in the archaeobotanical study. The number of specimens (NSP) totalled 11,497.

Phu Khao Thong

Phu Khao Thong was sampled for archaeobotanical remains only and the test pits were opened only for this purpose. The mission surveyed PKT in 2006 and 2007 and also conducted interviews. In 2008 and 2009, the mission again visited PKT and this time two sections and five TPs were opened and sampled. S3 was only sampled for phytoliths. In 2008, the samples came from two sections of looting pits. In 2009, 2x2 m TPs were opened. As at KSK, a standard amount of soil was collected at every US though the average amount of soil at PKT was 10 litres. The TPs were opened at different levels of the hill to avoid erosion biases. Less soil was sampled at PKT for several reasons; no proper excavation took place on the site, the purpose of gathering the material was to compare with the main site KSK. During the two years that PKT was visited, 188 litres of soil were collected and floated. The breakdown of volume of soil floated, test pits sampled and samples collected are found in Table 4.2.

Year	test pits sampled	no. of samples	volume of soil floated (litres)
2008	2	4	60
2009	4	13	128
TOTAL	6	17	188

Table 4.2: Total amount of soil and samples collected at Phu Khao Thong for macroremains analysis.

The soil was floated using the same methodology stated above except there were no workers to assist. Again, though time-consuming, this has the advantage of less variation. Finally, the samples were bagged and sent to UCL where 11 samples were sorted to 0.5 mm and identified. The number of specimens (NSP) totalled 10,663.

4.3 PHYTOLITHS

At Khao Sam Kaeo, soil samples averaging 100 g were collected from 2007 to 2009 from thirty-three test pits yielding a total of 195 samples. The collection of phytoliths took place after excavations had finished with a few exceptions including special features. One section from the test pit showing stratigraphic units (US) was chosen and a vertical column was cut into the section measuring approximately fifteen cm deep. Phytolith soil samples were collected from the fresh resurfaced soil at every layer starting from the bottom upwards to avoid contamination.

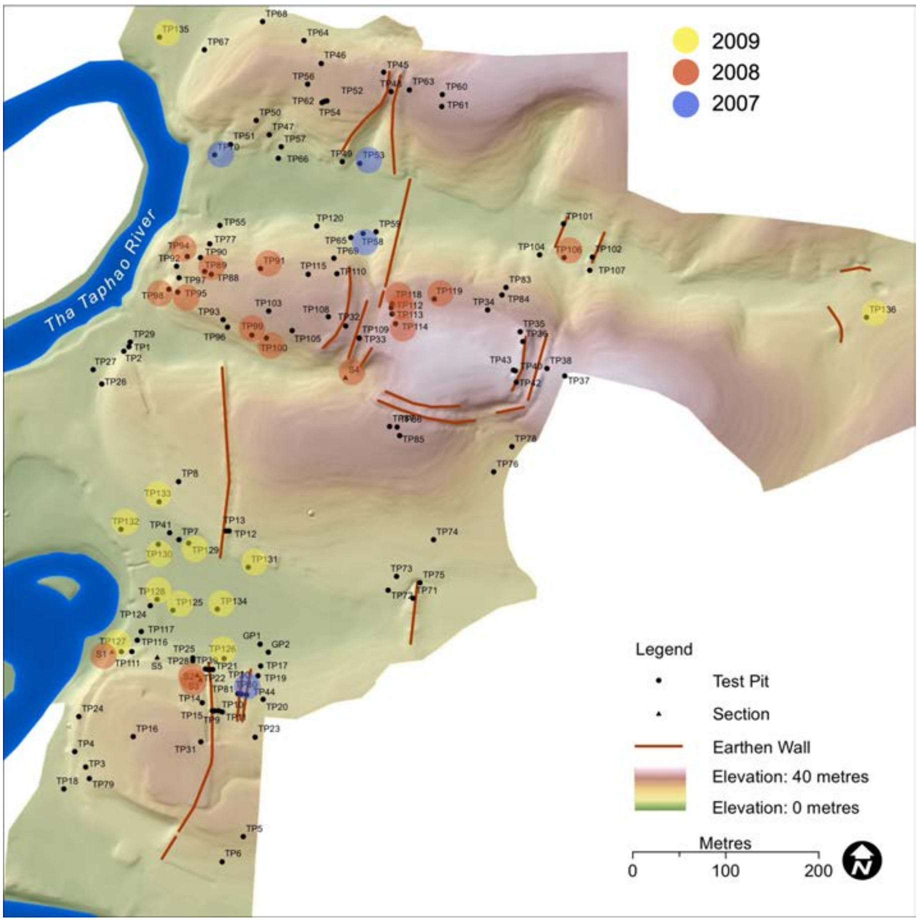


Figure 4.3: Map showing the locations of soil samples collected for phytolith analysis (Map courtesy of Julie Malackie).

Year	test pits sampled	samples collected
2007	5	28
2008	15	26
2009	13	141
TOTAL	33	195

Table 4.3: Total amount of soil and samples collected at Khao Sam Kaeo for phytolith analysis.

The initial intention was to sample for phytoliths from the same contexts where the macroremains were collected but fewer phytolith soil samples (Table 4.3) were taken compared to macroremains soil samples. Figure 4.3 shows the locations of the test pits sampled for phytoliths.

The bagged soil samples were shipped to London for processing and identification. The soil samples were processed using the 'Phytolith protocol' set by Rosen (1999). To date 68 samples have been processed. The data quality system applied to the macroremains will be applied to the rest of the phytolith soil samples and only those with grades 1-3 will be processed and analysed. Appendix 4.2 summarises the archaeobotanical sampling done at Khao Sam Kaeo.

4.4 IDENTIFICATION CHALLENGE

Identification problems were a limitation encountered during the course of this study. Most published and on-line reference material used as seed identification guides concentrate on flora found in Europe, the Middle East and the Americas (Digital Atlas of Economic Plants, Digital Seed Atlas of the Netherlands, GRIN, Seed Identification Handbook, Seed Identification Manual). The absence of reference material for Southeast Asia makes the task of identifying certain seeds to species level difficult and sometimes only allows for a reliable Family or Genus identification. Furthermore, published archaeobotanical studies from mainland Southeast Asia do not include a complete set of images of the seeds identified (e.g. Thompson 1996; Weber et al. 2010). The Flora of Thailand has yet to publish volumes on Asteraceae, Piperaceae, Poaceae and Polygonaceae amongst others.

Seed identifications were done in the laboratory at the Institute of Archaeology, UCL. Seed measurements and photographs were initially done with the low-powered microscope Leica EZ4D. If the plant part was too small to be properly identified with a low-powered microscope, or if there were specific features that needed more magnification, the Hitachi S-3400N SEM at the Institute was used. The specimens used in the SEM were all mounted on studs with double sided conductive adhesive discs and silver paint. When identifications were not possible, an image and description of the plant remain was made. Appendix 6.14 is the compiled list of identifications and descriptions.

Identifications were also made with the help of specialists. Prof. Dorian Fuller checked my work regularly and also helped narrow some of the unidentified specimens to genus or species level. Dr. Wolfgang Stuppy, the seed morphologist from the Royal Botanic Gardens Millennium Seed Bank at Kew dedicated one day to look at some difficult samples. At the time I asked Dr. Chalermpol Suwanphakdee for his help, he was in the process of writing-up his PhD dissertation specialising in the Family Piperaceae. He kindly looked at my Piperaceae specimens. In Thailand, I visited Dr. Siriporn Zungsontiporn and Panarat Charoenchai from the Weed Science Group in the Department of Agriculture who provided me with fresh samples of *Spilanthes paniculata* and *Spilanthes acmella.*

The Latin names (scientific names) are used in the appendices. However, the common names are also used in discussions of certain plants though at their first mention, the Latin name is also written. When identifications are tentative the prefix 'cf.' is used.

4.5 REFERENCE COLLECTIONS

In 2008, a modern botanical reference collection was started. Flora from Khao Sam Kaeo and the surrounding area, as well as from the province of Ranong in the West Coast of the Southern Peninsula were collected. Reference collections that focus on the Southeast Asian flora, including weeds, do not exist in London. As a consequence, a modern reference collection was started. The specimens are still in the process of being identified and Appendix 4.3 shows this work in progress. This reference collection is intended to help in the identification of macroremains and phytoliths. Identification criteria are still not fully developed in these areas of study in Southeast Asia. Sub-samples of some flora were selected targeting plant parts known to produce phytoliths (e.g. leaves). These were charred in a muffle furnace at 500°C for 2½ hours. They were then directly mounted onto slides and fixed with Entellen. However, these are not included in this dissertation.

The reference collection at the Institute of Archaeology was used to narrow down identifications to Family or Genus level. The Economic Botany Collection at Kew Gardens was also employed to take the Piperaceae samples to Species level through the kind help of Dr. Mark Nesbitt.

4.6 CHARRING EXPERIMENTS

The charring experiments are dealt with in two chapters (Chapters 5 and 8). Chapter 5 provides a summary of published results from charring experiments conducted by other authors, a description of the methodology used in charring experiments conducted by the present author and general observations. Chapter 8 provides the results and interpretation of the charring experiments conducted by the author. The charring experiments were conducted in order to understand some of the preservation bias that exists in archaeological plant remains. Real fire was used instead of the commonly used muffle furnace. At least three of the samples used in the Primtech08 experiments have been found in KSK and PKT. These are *Vigna radiata* (mungbean), *Oryza sativa* (rice) and *Setaria italica* (foxtail millet).

4.7 OTHER REFERENCES

Other sources of information include written and on-line resources dealing with environments, agricultural systems, identifications and descriptions of plants and seeds. The following two tables include some of the general references used. More specific references are quoted throughout the dissertation when a particular species is described or discussed. Also, species-specific references are found in Appendix 6.14.

4.8 A FINAL NOTE ON TROPICAL ENVIRONMENTS and SAMPLING

It has often been mentioned that macroremains sampling is not worth doing in tropical climates or in the Neotropics. It is wrongly assumed that plant remains in humid and hot environments cannot withstand the constant wet and dry cycles or the exposure to microorganisms in these environments (Hageman and Goldstein 2009). This pervasive belief probably contributed to the rapid development and continued use over macroremains of phytolith analysis in the New World Tropics (Pearsall 1989; Piperno 1995). However, it is demonstrated in this dissertation that using the proper methodology and sampling strategy in the wet tropics can yield adequate macroremains. Field archaeologists should routinely collect samples from excavations, not only for macroremains analysis, but also for phytolith and pollen analysis. At KSK and PKT, soil samples were collected for future research in microremains as well.

Burkill, I. H.	1966	A dictionary of the economic products of the Malay Peninsula, Kuala Lumpur.
Cappers, R.T.J.	2006	Roman foodprints at Berenike : archaeobotanical evidence of subsistence and trade in the eastern desert of Egypt, Los Angeles, Calif. : Cotsen Institute of Archaeology.
Cappers, R.T.J., Bekker, R.M., Jans, J.E.A.	2006	Digital Seed Atlas of the Netherlands, Barkhuis Publishing, Eelde, The Netherlands.
Cappers, R.T.J., Neef, R., Bekker, R.M.	2009	Digital Atlas of Economic Plants, Barkhuis Publishing, Groningen, The Netherlands.
Fuller, D.Q.	2006	A Millet Atlas: Some Identification Criteria.
Fuller, D.Q., Harvey, E.L.	2006	The archaeobotany of Indian Pulses: identification, processing and evidence for cultivation, Environmental Archaeology 11, 219-246.
Galinato, M. I., K. Moody & C. M. Piggin	1999	Upland Rice Weeds of South and Southeast Asia, Makati City: International Rice Research Institute.
Gunn, C.R., Ritchie, C.A.	1988	Identification of Disseminules Listed in the Federal Noxious Weed Act, U.S. Department of Agriculture, Technical Bulletin Number 1719.
Jones, S., Taylor, J., Ash, F.	2004	Seed Identification Handbook: Agriculture, Horticulture & Weeds, National Institute of Agricultural Botany, Cambridge.
Mabberley, D. J.	2008	Mabberley's plant-book : a portable dictionary of plants, their classification and uses. 3rd ed., completely rev. Cambridge: Cambridge University Press.
Martin, A. C. & W. D. Barkley	2000	Seed Identification Manual, New Jersey: The Blackburn Press.
Moody, K.	1989	Weeds reported in rice in South and Southeast Asia, International Rice Research Institute, Los Baños, Laguna.
Neef, R., Cappers, R.T.J., Bekker, R.M.	2011	Digital Atlas of Economic Plants in Archaeology, Barkhuis Publishing, Groningen, The Netherlands.
Noda, K., C. Prakongvongs & L. Chaiwiratnukul	1985	Topography of the seeds and leaves of tropical weeds; with scanning electron microscope. Project manual No.2, Bangkok: National Weed Science Research Institute Project.
Noda, K., M. Teerawatsakul, C. Prakonvongs & L. Chaiwiratnukul	1985	Major Weeds in Thailand, Bangkok: Department of Agriculture.
Ochse, J. J.	1931	Vegetables of the Dutch East Indies: edible tubers, bulbs, rhizomes and spices included, survey of the indigenous and foreign plants serving as pot-herbs and side-dishes, Amsterdam: Asher.
Paz, V.J.	2001	Archaeobotany and Cultural Transformation: Patterns of Early Plant Utilisation in Northern Wallacea. University of Cambridge, PhD Thesis.
Soerjani, M., A. J. G. H. Kostermans & G. Tjitrosoepomo	1987	Weeds of rice in Indonesia, Jakarta: Balai Pustaka.
van der Veen, M.	2011	Consumption, trade and innovation: exploring the botanical remains from the Roman and Islamic ports at Quseir al-Qadim, Egypt, Frankfurt am Main: Africa Magna Verlag.
Zhang, Z.P., Hirota, S.	2000	Chinese Colored Weed Illustrated Book, Institute for the Control of Agrochemicals, Ministry of Agriculture, P.R.China, and the Japan Association For Advancement of Phyto-Regulators.
Zohary & Hopf	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 : Oxford University Press.
		Handouts from the ‘Practical Surgery’ course at the Institute of Archaeology, UCL run by Dorian Fuller
		Flora of China
		Flora of Thailand

Table 4.4: General references used for seed identifications, use of plant and ecology.

website	sitename	description
http://ars-grin.gov/cgi-bin/npgs/html/index.pl.ars-grin.gov/cgi-bin/npgs/html/index.pl	GRIN Taxonomy for plants	this is one of the most complete on-line resources used for querying information on particular taxa. Provides information on common names, economic uses, distributional ranges and images.
http://data.gbif.org/welcome.htm	Global Biodiversity Information Facility	information on species, including occurrence records and links to other databases
http://ecocrop.fao.org/ecocrop/srv/en/home	Ecocrop	tool to identify plant species for given environments and uses
http://econ.eldoc.ub.rug.nl/index.php?lang=en	Digital Atlas of Economic Plants	contains the same images in the book. The photographs are of very high quality and include seeds, fruits, roots, tubers and other plant parts. It contains many economic plants from Southeast Asia
http://efloras.org/	eFloras	Contains subsites including Flora of China, Flora of Taiwan and Flora of Pakistan
http://flora.huh.harvard.edu/china/ or http://www.efloras.org/flora_page.aspx?flora_id=2	Flora of China	list or treatise of Chinese plants, includes illustrations
http://forestryimages.com/	Forestry Images	four major website interfaces that provide images on species of economic concern
http://idtools.org/id/citrus/citrusid/	Citrus ID	includes general overviews of the morphology of cultivated citrus
http://irri.org	International Rice Research Institute	provides information on rice, also has books that can be downloaded for free
http://issg.org/database/welcome/	Global Invasive Species Database	information on invasive alien species
http://kew.org/herbarium/keys/fm/key.html	Interactive Key to Seed Plants of Malesia & Indo-China	identification system for plants in the Malesiana region (Malaysia, Brunei, Singapore, Indonesia, Philippines, East Timor and Papua New Guinea).
http://mansfeld.ipk-gatersleben.de/pls/htmldb_pgrc/f?p=185:3:0:::::	Mansfeld's World Database of Agricultural and Horticultural Crops	
http://nationaalherbarium.nl	Nationaal Herbarium Nederland	includes information on tropical plants and weeds, on-line keys and databases
http://nationaalherbarium.nl/Riceweedsweb/	Weeds of Rain Fed Lowland Rice Fields of Laos and Cambodia	
http://plants.usda.gov/wetland.html	USDA Wetland Indicator Status	list of plants that are found in the wetlands in the US
http://plantsystematics.org/	Plant Systematics	provides images and can be searched easily by species name. However, the images show flowers and leaves rather than seeds
http://proseanet.org/prosea/eprosea.php	Plant Resources of South East Asia	species-based information databank
http://seeds.eldoc.ub.rug.nl/	Digital Seed Atlas of the Netherlands	contains the same images in the book. The photographs are of very high quality and include seeds, fruits, roots, tubers and other plant parts. It is however an identification guide for plants found in Europe.
http://web3.dnp.go.th/botany/Botany_Eng/index.aspx	Office of the Forest Herbarium	a good source for Thai plant names though written in Thai script and a bibliography for vascular plants in Thailand. It contains very few illustrations and does not necessarily show the seeds. Lastly, it gives the complete list of 'Flora of Thailand' so far published.

Table 4.5: Main on-line resources used.

CHAPTER 5
Preservation Bias

5.1 INTRODUCTION

The definition of charred remains in the Oxford dictionary is '(an object) that becomes blackened as a result of partial burning'. This partial burning reduces organic matter to carbon-rich residues that preserve over long periods of time. Carbon is relatively inert in soil and therefore, microorganisms that break down organics do not affect charred remains. In some instances, these charred remains retain their structure. Charred remains also make good specimens for conventional and AMS radiocarbon dating (www.archaeologywordsmith.com).

Accordingly, archaeological botanical remains are normally found in carbonised form (Lone et al. 1993; Renfrew 1973), though these remains may also be desiccated or waterlogged, depending on the environment in which they are found. In Khao Sam Kaeo (KSK), most of the macroremains recovered were charred with only a few waterlogged and silicified remains retrieved. On the other hand, only charred remains were found at Phu Khao Thong (PKT). Charred seeds can retain their original shape and features which allow archaeobotanists to identify them in the lab on the basis of morphological and sometimes anatomical characters. But charred remains may be found in varying states of preservation so it is sometimes impossible to identify them if no defining features are present. Identification may only be possible to genus or likely family level, although some taxa and states of preservation can be assigned to species or subspecies. Carbonisation can also cause changes to the size and proportions of seeds which may be misinterpreted, especially when trying to deduce the domestication status of certain crops in which wild counterparts are generally smaller than the domesticated forms.

When dealing with material remains, archaeologists take into consideration issues of preservation as well as formation processes. Preservation affects the morphological details of artefacts and biological remains. These issues are also encountered in archaeobotany. Differential preservation is also one of the biggest challenges faced by palaeoethnobotanists (Popper and Hastorf 1988). Certain plants and plant parts preserve better than others due to their physical properties and site-formation processes such as type of soil, humidity and depth of deposit (*ibid.*). Formation processes can result in fragmentation and destruction. It is important to understand what effects the charring of seeds has on archaeological remains. Charring changes the shape and size of plant remains and also causes fragmentation. Charring experiments help determine preservation biases and changes in seed morphology during carbonisation. It is for this reason that studies have been conducted to understand some of these issues and compare the results of the experiments to archaeological remains. However, most of these studies have so far concentrated on crops originating in the Old World. The study presented here differs from its predecessors in that it deals with Asian crops with origins in India, China and Southeast Asia. It aims to produce data that could aid archaeobotanists working in the areas of South, East and Southeast Asia to assess preservation biases and issues on morphology changes.

This chapter and Chapter 8 discuss the charring experiments conducted in September 2008 at West Dean, East Sussex during the Experimental Archaeology course held for incoming undergraduate students also known as ‘Primtech’ (henceforth these experiments will be known as the Primtech08). Unlike most published charring experiments, the experiments presented here were done with the use of real fire (henceforth 'fire'). The objective of these charring experiments was to replicate the charring processes that occur naturally. The alternative is a muffle furnace where the experiments are highly controlled. It is impossible to reproduce the exact conditions that a seed would have undergone in terms of charring but experiments using fire simulate the charring process more faithfully than the use of a muffle furnace, although they allow for less precise control of temperature and atmosphere conditions. Archaeobotanical assemblages have survived through different formation processes including seeds falling into hearths, house fires, burning cultivation fields, burning fuel and cooking accidents. None of these activities involve controlling any of the variables in the way that a muffle furnace experiment does.

Most published data are on charring experiments carried out in the muffle furnace with the purpose of addressing certain taphonomic issues including seed shrinkage and distortion during carbonisation (Bowman 1966; Smith and Jones 1990) as well as differential preservation (Boardman and Jones 1990). In archaeobotany, charring experiments are conducted in order to simulate conditions that resulted in the carbonisation of crops as in the past. Some of the variables and parameters in these experiments remain constant whilst others are changed in order to observe the effects of such variances. Variables normally taken into consideration are temperature, length of exposure, oxidation or reduction and moisture content. The first section of this chapter discusses some of the previous work done on charring experiments and is followed by the methodology, general observations and overall results of the fire experiments done at Pimtech08. The specific results and interpretation of the Primtech08 experiments together with discussions using archaeological data from the two sites Khao Sam Kaeo and Phu Khao Thong are found in Chapter 8 (Charring Experiments: Interpretation).

5.2 OTHER EXPERIMENTS and RESULTS

Table 5.1 is a summary of some of the published data from charring experiments indicating the species charred, methodology and main results. The majority of published experiments were conducted mainly to estimate shrinkage, changes in size and proportions of seeds as well as distortions (Bowman 1966; Braadbaart 2008; Garton 1979; Lone et al. 1993). Others have focused on differential preservation and the conditions which allow seeds to preserve (Boardman and Jones 1990; Märkle and Rösch 2008; Wright 2003; Yang et al. 2011). Shrinkage is of particular interest when trying to distinguish between domesticated crops and wild species (Jupe 2003). Although most studies were not intended to gain knowledge of the chemical transformation or to discover the changes in internal structure of the seeds, Bowman's (1996) studies on carbonised seeds examined internal structure changes as well as measured distortion amongst other changes. Another important aspect in charring experiments is the method of heating. Most have used ovens or muffle furnaces (Boardman and Jones 1990; Chuenwattana 2011; Lone et al. 1993; Märkle and Rösch 2008; Mason 1988; Wright 2003) with a few using real fires (Jupe 2003; Sievers and Wadley 2008; Yang et al. 2011). Some studies have experimented with oxidising or reducing (oxygen-poor) conditions (Boardman and Jones 1990; Braadbaart 2008; Chuenwattana 2011; Märkle and Rösch 2008; Wright 2003). The plant taxa used have ranged from Near Eastern crops (Boardman and Jones 1990; Bowman 1966; Braadbaart 2008; Jupe 2003; Lone et al. 1993; Mason 1988) to New World cultivars (Wright 2003) while others have experimented with Asian cereals and pulses (Chuenwattana 2011; Garton 1979; Märkle and Rösch 2008; Yang et al. 2011).

Lone et al. (1993) conclude that charring causes size and proportions to vary for both cereals and pulses although the main morphological characteristics can remain well preserved and discernable. Both Bowman (1966) and Braadbaart (2008) observe a decrease in grain length and an increase in width, thickness or breadth relative to length as a consequence of charring. Thus while shrinkage occurs overall, shrinkage is more pronounced in length, such that seeds tend towards a more spherical shape after charring. Braadbaart (2008) also states such changes to differ little between husked and dehusked cereal grains. He also observed the formation of protrusions generally occurring at higher levels in dehusked grains compared to those with glumes. These protrusions are the starchy mass of the grains that ooze out during carbonisation. Distortions in seeds seem to be greatly affected by moisture content as seen in New World crops (Wright 2003). However, fire experiments by Sievers and Wadley (2008) showed that charring took place regardless of oil or moisture content when plant remains were buried in sand 5 cm below the surface where the fire was made. Jupe (2003) on the other hand found that the variance in size of some pulses differed according to different charring regimes including the use of the muffle furnace and open fires.

Increased grain size is a commonly recognised characteristic used to differentiate between wild and domesticated cereals (Fuller and Allaby 2009). However, charring experiments have shown that this may be a difficult criterion to use by itself because shrinkage occurs through charring. Likewise, there is huge variability in the sizes of domesticated crops and therefore there is no definitive size to determine domestication status. For example, as Motuzaite-Matuzeviciute et al. (2012) discuss, the immature grains of the cereal broomcorn millet preserve well, retain characteristic features and so because of their small size may be confused with wild millet.

Braadbaart (2008) attempted to approximate fire conditions by using a tube oven. The tube oven was pre-heated before the seeds were placed in order to approximate how wheat grains would have dropped into a fire (Braadbaart 2004). However, this type of experiment is still heavily controlled and any conclusions on differential preservation are limited by the constant conditions of the laboratory, which are likely to be a poor analogue for ancient fires.

Authors	Species	method	results
Abdel-Magid 1989	*Sorghum vulgare* *Sorghum arundinaceum* *Pennisetum americanum* *Setaria verticillata* *Echinochloa pyramidis* *Triticum aestivum* *Hordeum* sp.	100-110°C for 3-4 hours reducing conditions	↑ in breadth & thickness, ↓ in length though ↓ in breadth of *S. arundinaceum* %age varied with species
Boardman & Jones 1990	*Triticum monococcum* *Triticum dicoccum* *Triticum spelta* *Triticum aestivum* *Hordeum vulgare* grains, straw nodes, glume bases and rachis internodes used	muffle furnace at 250-550°C from 30 minutes - 15 hours; reducing & oxidising conditions; all specimens were dry	grains have highest survival rate followed by glumes; oxidising conditions result in faster carbonisation than reducing conditions; broader survivability band under reducing conditions carbonisation starts at *ca.* 250°C after 1.5 hours (for grains) & 2-2.5 hours (for straw)
Bowman 1966	*Triticum aestivum* *Triticum compactum* *Triticum spelta* *Triticum durum* *Triticum dicoccum* *Triticum monococcum* *Hordeum distichum* *Hordeum vulgare* *Hordeum nudum*	3 ovens: muffle furnace, glass annealing oven & electric oven 150-550°C for 20 minutes - 16 hours variables: moisture content (0-18.2%)	↑ in breadth & thickness, ↓ in length carbonisation occurs between 200-250°C carbonisation causes splitting, oozing & blistering esp. at ↑ temperatures though less distortion occurs w/ hulled grain wheat grains unrecognisable at 550°C
Braadbaart 2008	*Triticum dicoccum* *Triticum aestivum* with & without glumes	tube oven at max 600°C for 60 minutes anoxic	↑ in width, ↓ in length formation of protrusions
Chuenwattana 2011	*Oryza sativa* sticky and plain varieties	muffle furnace: 250-450°C for 2-6 hours reduction vs. oxidation	↓ in length, ↑ in width & thickness at 250°C but ↓at ≥300°C oxidation produces ↑ degree of destruction than reduction possible to distinguish between processed & unprocessed rice carbonisation w/out distortion *ca.* 250°C, at 450°C all grains reduced to unidentifiable state
Garton 1979	*Oryza sativa indica* *Oryza sativa japonica* *Oryza sativa javanica* dehusked and husked grains were used for all	thermogravimetric kiln variables: moisture content, temperature & rate of heating	rice grains unrecognisable after 320°C different races react differently to heating regime; only *japonica* survive w/o distortion slow rate of heating to 300°C grains are smaller overall but an ↑ in width may occur if grains are not distorted most grain dimension ratios are similar between charred & fresh grains non-glutinous rice preserves more intact than glutinous rice husks are fragile after charring
Helbaek 1970	*Lens culinaris*	400°C, no time stated dry lentils used	↓ size, thickness practically unchanged
Jupe 2003	*Pisum sativum* *Lens culinaris*	muffle furnace: 300-400°C for 1-3 hours;	muffle furnace: rate of charring not related to seed size

	Cicer arientinum dried specimens used	reducing condition real fire: fire fuelled for 90-180 minutes with highest temp reached at 850°C	real fire: ↑ temp caused survival rate ↓; lentils had overall the highest survival rates followed by peas then chickpeas
Lone et al. 1993	*Triticum* spp. (5 species) *Hordeum vulgare* *Oryza sativa* (husked) *Avena* spp. (2 species) *Phaseolus aureus* *Lens culinaris* 2 species of wood	electric oven at 200°C for 12 hours	all cereals: length of grain ↓, breadth ↑; morphological features well preserved both pulses: ↓ in both length and breadth; seed coat wholly or partly lost awns lost in most *O. sativa;* husk detached in 80% of China cultivar & 35% of Noon Beoul cultivar *Phaseouls* seed coat lost in 70-80% of seeds
Märkle & Rösch 2008	*Setaria italica* *Panicum miliaceum* *Papaver somniferum* *Linum usitatissimum* *Cannabis sativa* (dehusked and whole seeds were used for *S. italica* & *P. miliaceum*)	muffle furnace at 180-750°C for 1-4 hours; reduction vs. oxidation	reducing conditions enlarge temp. range for carbonization w/o destruction though *P. miliaceum* does the opposite ↓ chances of carbonisation: *P. somniferum* Good chances of carbonisation: *L. usitatissimum* and *C. sativa*
Mason 1988	*Triticum aestivum* *Hordeum sativum* ssp. *hexastichum* both hulled	muffle furnace at 100-350°C for 40 minutes - 4 hours; gradual ↑ in temperature; freshly harvested & dried grains oxidising conditions	gradual heating produces better preserved grains experimental charring did not resemble archaeological samples
Motuzaite-Matuzeviciute et al. 2012	*Panicum miliaceum* dehusked and at 6 stages of maturity	muffle furnace at 235 & 335°C for 1 hour oxidising conditions	grains at various stages of maturity can withstand charring
Renfrew 1973	*Triticum aestivum* *Hordeum vulgare* *Avena sativa* *Secale cereale*	gas oven at 200°C for 12 hours	all cereals: length of grain ↓, width ↑, thickness variable
Sievers & Wadley 2008	*Bridelia mollis* *Elephantorrhiza burkei* *Strychnos pungens, Rhus pyroides, Xanthocercis zambesiaca* *Mundulea sericea, Vangueria parvifolia* *Ximenia caffra*	open fires with reducing conditions max temp above ground reached 670°C max temp 5 cm below surface was 328°C	all seeds w/in the fire were destroyed seeds from 5 cms below surface at center of fire appeared carbonised regardless of moisture or oil content, at 10 cms below they were dehydrated & at the perimeter they were unaffected
Wright 2003	*Amaranthus hypochondriacus* *Chenopodium berlandieri* *Cucurbita pepo* (rind) *Helianthus annuus* *Lagenaria siceraria* (rind) *Nicotiana rustica* *Zea mays*	muffle furnace at 100-700°C for 5-50 minutes variables: reduction vs. oxidation, temperature, duration of exposure, moisture content	*ca*. 300°C for 50 min to produce specimens w/ potential to survive & be identified >700°C at 50 min: all consumed specimens in reducing conditions endure better & moist specimens survive better than when dried.
Yang et al. 2011	*Setaria italica* *Panicum miliaceum* both with seedcoat	drying oven at 50°C or 100°C for 3h, 200°C, 250°C or 300°C for 0.5,1,2,4 or 8h field fire: fire pit 15 cms deep was burnt for 45 min and samples were: 1)	OVEN: foxtail millet length ↑ at 100°C for 3h but length, width & thickness ↓ at 200°C for 1h; L, W and Th ↑ after 250°C (for both caryopsis & embryo) broomcorn millet length & width↓

	buried in a hole 3-5 cms below fire stack, 2) placed at bottom of fire stack, 3) distributed around fire stack, 4) placed in centre of fire stack	at 200°C for 1h; badly deformed after 250°C both foxtail & broomcorn deformed & partially ashen after 300°C FIELD FIRE: samples at bottom of fire were carbonised & mostly intact; samples around fire burst & many incinerated; samples in centre of fire mostly burnt to ash

Table 5.1: Summary of results from various charring experiments. Increases and decreases in length, width and thickness are all in absolute values.

The study by Märkle and Rösch (2008) includes some species used in my own experiments, *Setaria italica* (foxtail millet) and *Panicum miliaceum* (broomcorn millet), permitting a comparison of certain effects. Their results show that millet seeds have a popcorn effect even though the seed shape is ultimately retained as the ooze comes out from one point. Under oxidizing conditions, foxtail millet starts to carbonise at 220°C and length of time heated is not a determinant whereas broomcorn millet needs slightly higher temperatures to carbonise and is affected by the length of time heated. Destruction occurs after 1 hour at 400°C and 335°C for 4 hours for broomcorn millet and 500°C for 1 hour and 400°C for 4 hours for foxtail millet. The temperature ranges withstood by broomcorn millet before destruction are less than that of foxtail millet and this again was evident in reducing conditions. In a separate study by Wright (2003), it was observed that there is a narrow window for carbonisation to take place while seeds retain their identifiable state. This was also true in Yang et al.'s (2011) experiment using foxtail and broomcorn millets. Wright's study is concerned with preservation biases and considers the species and part of the plant charred to be one of three important factors that affect the carbonisation process. Garton (1979), experimenting with rice, observed that husk has a high chance of preservation. On the other hand, Boardman and Jones (1990) examine both the preservation and the survivability of the cereal plant components including the grain, straw and glumes in wheat. Their observations examine the point at which these different plant components turn to ash or are too distorted to be identifiable. The results show that wheat grains have the highest survival rate followed by glumes. They also observed, like Chuenwattana's (2011) study on rice, that when the wheat grains are husked or surrounded by chaff, preservation is good and there is less distortion. Finally, an important conclusion drawn from Boardman and Jones is that because survivability of grains exceeds that of the other plant components such as glumes and chaff, it is difficult to establish the crop processing stage of particular archaeological specimens. A way to ascertain the presence of chaff and straw would be to also conduct phytolith analysis because the silica remains from these plant parts should, in theory, be preserved archaeologically (see Harvey and Fuller 2005).

In several experiments (Boardman and Jones 1990; Bowman 1966; Garton 1979; Märkle and Rösch 2008), carbonisation seems to take place between 200-250°C and the temperature at which seeds become unidentifiable depends on the species (550°C for wheat, 335-500°C for millets, 320°C for rice). Glumes also seem to play a role in the charring process. When whole seeds (with glumes) of both foxtail and broomcorn millet were charred the general observation was that the glumes protect the grains and slightly higher temperatures are needed for carbonisation to occur (Märkle and Rösch 2008). For rice, husked grains survived better at higher temperatures and a faster rate of heating than naked grain (Garton 1979). In the case of wheat, less oozing, splitting and changes in grain dimensions occurred when spikes as opposed to naked grains were used (Bowman 1966). According to Märkle and Rösch, ‘glumes do not impede carbonization but rather promote it'. Partial reduction is also a contributing factor in the preservation of rice grains to an identifiable state according to Garton (1979). Therefore, husks probably create a reducing atmosphere for the grain (Fuller, pers. comm.). In field fires conducted by Yang et al. (2011), they found that both foxtail and broomcorn millet samples were carbonised and retained their morphology when they were in a reduced environment. The samples were either buried three cm below the fire pit or were placed at the bottom of the fire pit.

An important conclusion made by Bowman (1966) concerns the changes in size and dimensions of carbonised grains vis a vis uncarbonised specimens. Because carbonisation promotes distortion, he warns that grains of one species may appear to look like another species. The MSc dissertation by Chuenwattana (2011) also illustrates the difficulties in distinguishing charred remains of two varieties of rice, sticky and non-sticky. The distinguishing feature between the two varieties is not grain shape but rather opaqueness in sticky rice. Once charred the differences (i.e. grain opaqueness) which distinguish one variety from the other are not discernable. Her work does however show that it may be possible to distinguish rice that has been burnt in the husk and burnt naked. Before rice is cooked, it is dehusked (also referred to as milled) and if most of the rice finds are identified as husked grain, a possible conclusion is that rice was used for non-food uses such as offerings or an accidental fire that affected stored husked rice spikelets. An example of this is at Ban Don Ta Phet where husk and husked rice were found in a bronze bowl from a burial [sf.3441/context 324/BDTP 1984-85] (Glover 1990). Although the Ban Don Ta Phet bowl containing rice has not been interpreted as an offering, it does not appear to be someone's meal either. In Thailand, rice is normally stored husked in the '*yung*' or storage house to prevent insects from feasting on them. An interesting point which Chuenwattana noted for both sticky and non-sticky husked rice is that charring did not cause the same amount of distortion as in dehusked grains and therefore, the distinctive grooves were still visible. These grooves help identify charred remain fragments as rice.

The Primtech08 experiments presented in the following section of this chapter and in Chapter 8 were done with 'real fires.' Most experiments reviewed in the preceding section used a muffle furnace suitable for the aims of those studies but not when differential preservation is the main point of inquiry. A muffle furnace cannot properly simulate conditions that may have occurred in prehistory during fire events because a fire has flames whereas carbonisation using a muffle furnace occurs because of hot air (Märkle and Rösch 2008). Furthermore, fluctuations in temperatures occur in fires but are hard to replicate using a muffle furnace. Jupe (2003) conducted charring experiments using both a muffle furnace and an open fire addressing both the issues of size change and seed survival. Much of his work using a fire was followed as the methodology for the Primtech08 experiments. Sievers and Wadley (2008) approximate conditions that lead to charring using fires simulating a hearth although they buried the specimens before the fire was lit. Unlike Sievers and Wadley, the Primtech08 experiments were not pre-buried.

5.3 METHODOLOGY

The fire Primtech08 experiments were done with the intention of conducting future charring experiments using the muffle furnace as well. The main reason for a combination of methods is that experiments using a furnace yield results on the changes in the morphology of seeds, whereas, fire experiments give an indication of preservation bias analogous to archaeological finds. However, time was limited and further experiments using the muffle furnace will be done in the future.

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Oryza sativa	25	25		
Oryza sativa (dehusked)			25	25
Vigna radiata	25	25	25	25
Glycine maxima	25	25	25	
Coix lachryma-jobi	25	25		
Setaria italica	25	25		
Setaria italica (dehusked)			25	25
Panicum miliaceum	25	25		
Panicum miliaceum (dehusked)			25	25
total	150	150	125	100

Table 5.2: Seed counts of each species, whole and hulled, for each experiment.

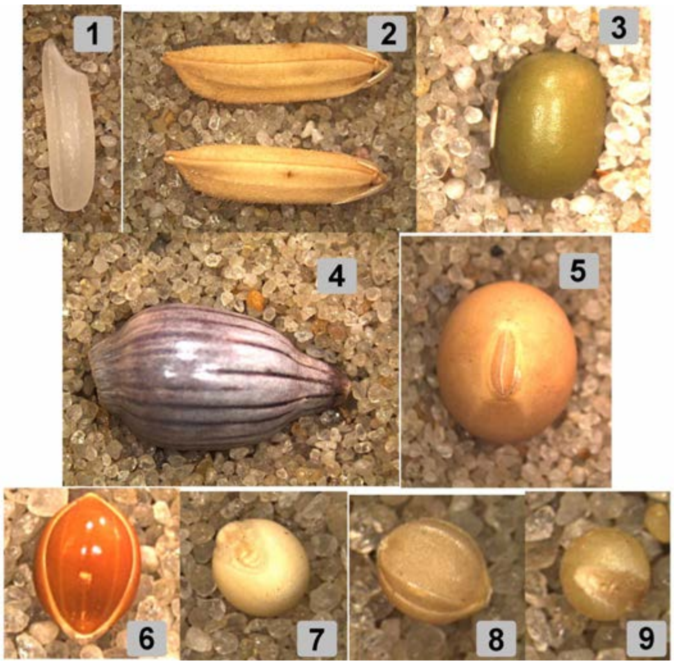
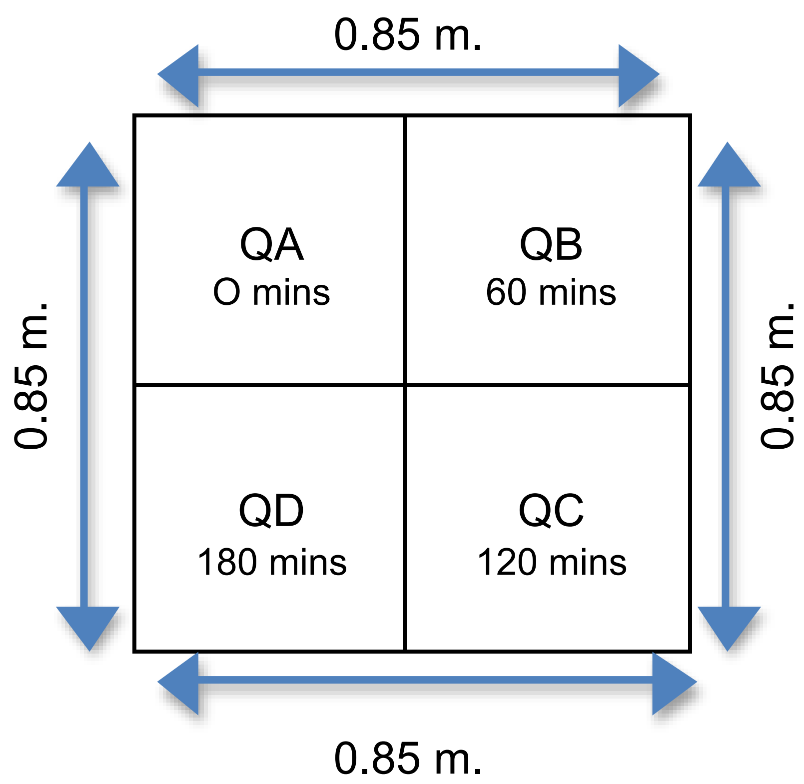


Figure 5.1: The images are not to scale. 1) *Oryza sativa* (rice) naked, 2) *Oryza sativa* (rice) husked, 3) *Vigna radiata* (mungbean), 4) *Coix lachryma-jobi* (job's tears), 5) *Glycine max* (soy bean), 6) *Panicum miliaceum* (broomcorn millet) husked, 7) *Panicum miliaceum* (broomcorn millet) naked, 8) *Setaria italica* (foxtail millet) husked, 9) *Setaria italica* (foxtail millet) naked (Images by author).

Four experiments were conducted over two days. Table 5.2 shows the species and seed counts for each experiment. A sample size of twenty-five seeds per species per quadrant was used. The specimens used for this research concentrate on South, Southeast and East Asian species, these being the most likely crops to be found in Late Prehistoric sites in Peninsular Thailand. The seeds used for the experiment were bought in markets in Asia and Asian supermarkets in London. These were *Vigna radiata* (mungbean), husked and dehusked *Oryza sativa* (rice), husked *Coix lacryma-jobi* (jobs' tears), *Glycine max* (soybean), husked and dehusked *Setaria italica* (foxtail millet) and husked and dehusked *Panicum miliaceum* (broomcorn millet). Three of these crops, *Vigna radiata*, *Oryza sativa* and *Setaria italica*, have so far been identified in archaeological contexts in KSK and PKT. Figure 5.1 are photographs of the specimens used in the Primtech08 experiments before charring.

The samples were not measured for moisture content and nor was it considered a variable though all seeds were dry specimens. All seeds were measured before charring. When the fire was already going, all were buried under the soil to create anoxic conditions though this was a difficult task. Temperatures were measured using a thermocouple every thirty minutes. Two sets of experiments were conducted: Experiments 1 and 2 included mungbean, soybean, and husked cereals; and Experiments 3 and 4 included mungbean and dehusked cereals except job's tears in both Ex3 and Ex4 and soybean in Ex4. The dehusking of cereals used in Ex3 and Ex4 was done manually.

The following diagram shows the division of the area into four quadrants with the time when the new samples where added:



In the first set of experiments (Ex1 and Ex2), the temperature was read in each quadrant as well as in the middle. In the second set of experiments (Ex3 and Ex4), the temperature was only read in the middle of the square. The control variable for all experiments was time. The fire was continuously fed in an effort to maintain temperatures between 600-800°C, though all feeding was stopped once the seeds in quadrant QD were placed, which occurred three hours after the start of the experiments. Temperatures fluctuated all throughout the experiments and on several occasions the thermocouple did not work properly. The highest temperature reached was in Ex3 at 909°C one hour after the start of the experiment. Figure 5.2 plots the temperature readings of the four experiments. The rest of the experiments reached temperatures above 800°C.

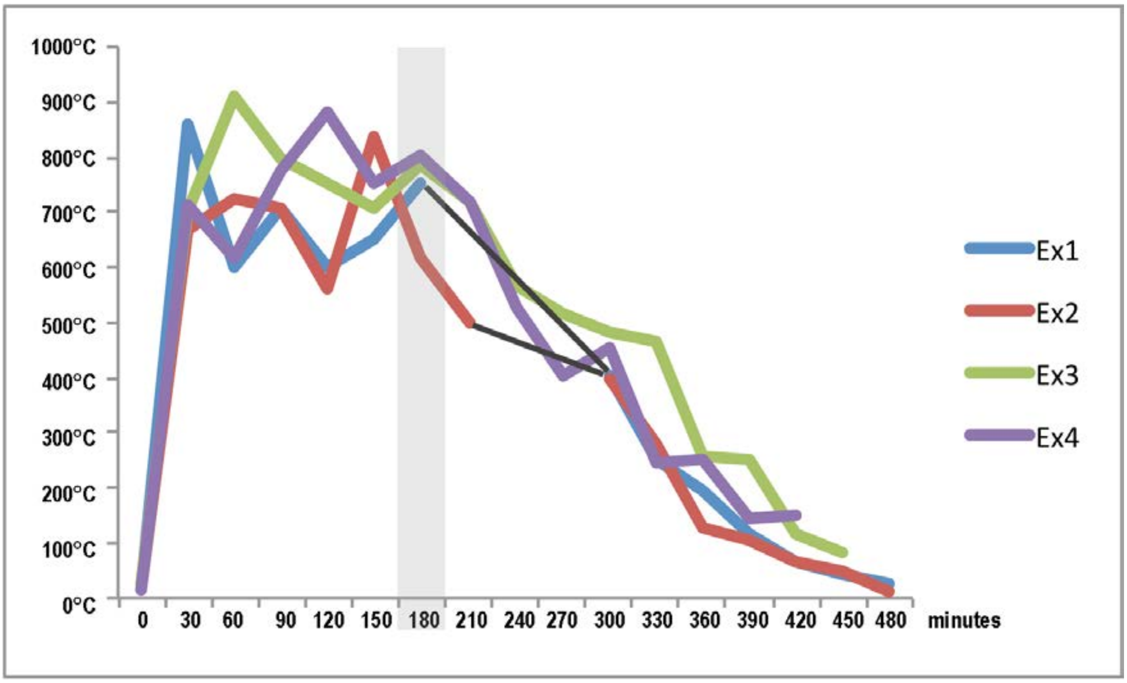


Figure 5.2: Graph showing the temperatures recorded with the thermocouple. The temperature readings shown here were taken from the middle of the square. The shaded area shows the time when after 180 minutes feeding the fire stopped. The straight black lines are estimated readings when the thermocouple did not work.

Each fire was allowed to die naturally. Once the experiments cooled, samples from each quadrant were scooped out and bagged. Bucket flotation was used to retrieve the charred specimens. This method follows archaeobotanical recovery methods in the field. However, one limitation in doing flotation is that any seeds not charred would sink to the bottom of the bucket and therefore, not be collected. The samples were then air dried and sieved to different sizes to aid the sorting and identification. The size of the British standard sieves used were >4 mm, 2-4 mm, 1-2 mm and 0.5-1 mm. Samples from all experiments were sorted to 0.5 mm except for Ex3A and Ex3B which were discarded because of an error in their retrieval from the fire pits. The decision to sort to 0.5 mm is based on the premise that no identifiable seeds of the types burned or their components would be found below 0.5 mm. Likewise, in the archaeobotanical studies of KSK and PKT, samples were only sorted to 0.5 mm. As a control, a few subsamples were taken and sorted from the <0.5 mm fraction and though some parenchymatous fragments were found, they are too small to be narrowed down to genus level. After sorting, the samples were identified, counted and measured. Data in this study were analysed statistically in terms of destruction of seeds and shrinkage per taxa (section 5.5 and Chapter 8).

5.4 OBSERVATIONS

During the processes of charring, bagging, floating, sorting and identifying the seeds, certain observations were made. Some of these observations are similarly encountered during the retrieval and analysis of KSK and PKT archaeobotanical remains.

- ***Human error.*** Human error was the biggest limitation when conducting the experiments. There was a mix-up with the bags from Ex3A and Ex3B when gathering the charred remains and bagging them. Because of this mix-up, these experiments were discarded. Sorting, especially the fine fraction, had to be done twice in case some of the husk was missed out in the first sweep.
- ***Uncharred seeds.*** During the flotation stage, it is probable that the uncharred seeds sank to the bottom and were not retrieved. This may be the reason why there are very few uncharred seeds in the experiments (ExIA n=3). For this reason, unlike controlled experiments using a muffle furnace, uncharred vs. charred seeds will not be considered. One could also assume that there would be a lower percentage of retrieved charred remains in the last two experiments (less time in the fire) compared to the first two experiments. However, this trend is not seen in the experiments. One reason could be the complete destruction of more plant remains in the first two experiments. The more prolonged exposure to the fire could render them to ash.

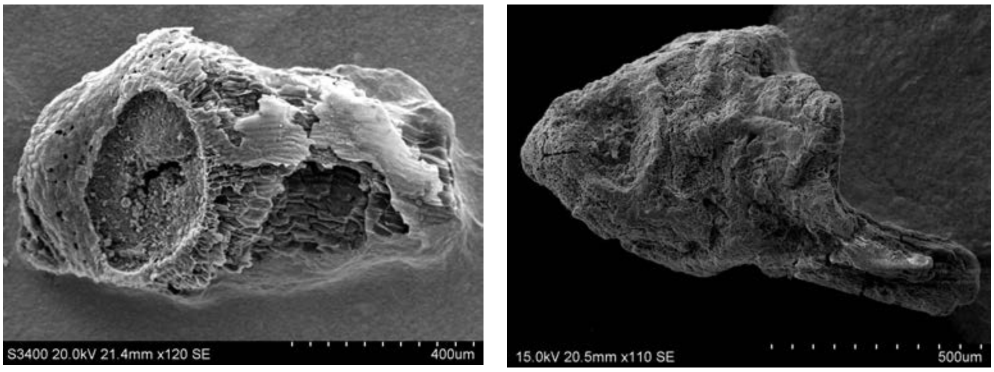


Figure 5.3: SEM images of rice spikelet bases found in the 0.5-1 mm fraction. (Left: Ex1A; Right: KSK_tp43_us4) [Images by author].

- ***Fine fraction.*** The fine fraction from 0.5-1 mm is mostly, if not wholly, composed of rice husk, rice spikelet bases, millet husk and job's tears' utricle. One also finds parenchymatous fragments which are too small to be identifiable. A similar result is found when sorting archaeological samples with respect to the seeds represented in the charring experiments. The rice spikelet bases found in this range of 0.5-1 mm have very little husk still attached to them resembling the archaeological rice spikelet bases found at KSK and PKT (Figure 5.3).
- ***Rice spikelet bases.*** The biggest difference in the preservation state between the charring experiments and archaeological material is that in the Primtech08 experiments, all the rice spikelet bases found in the >1 mm fraction had a substantial amount of husk still attached to them. On the other hand, none of the rice spikelet bases from the archaeological sites KSK and PKT had any husk still attached to them (Figure 5.4). The husk probably detached from the spikelet bases in the archaeological material as a result of post-depositional factors.

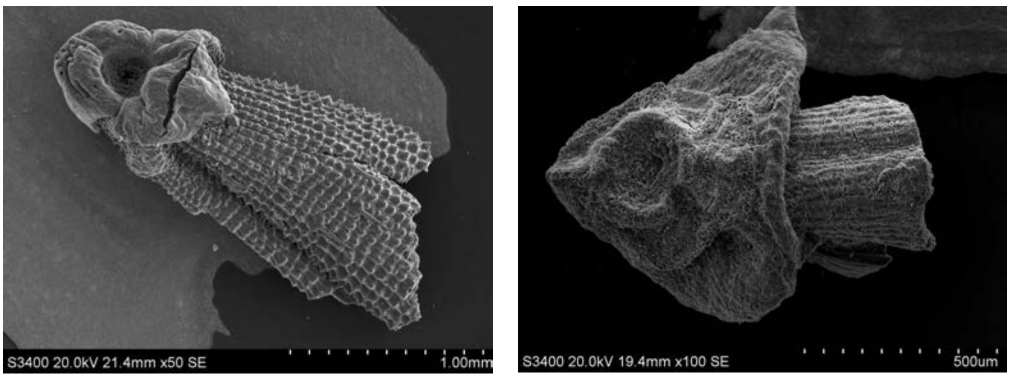


Figure 5.4: SEM images of a typical charred rice spikelet base from Primtech08 experiment 1A (L) and from Khao Sam Kaeo tp128 us11 (R). (Images by author).

- ***Millet husk.*** Of the two millets charred, *Setaria italica* and *Panicum miliaceum,* the most distinctive husk is the rugose and punctuate lemma of *Setaria italica* (Figure 5.5). The palea of *Setaria italica* is not as punctuated especially when charred, while the husk of *Panicum miliaceum* is smooth making the palea of these two millets difficult to differentiate when charred (Figure 5.6). The *Panicum* husk remained very shiny even after charring with slight vertical stripes visible with the SEM but not with a low-powered microscope (Figure 5.7). This shine may be lost because of post-depositional factors and therefore not a reliable characteristic to be observed in archaeobotanical remains. However, remains found at Nørre Sandegaard in Denmark by Helbaek are described to have a glossy palea (Renfrew 1973; orig ref Helbaek 1952C, 108).

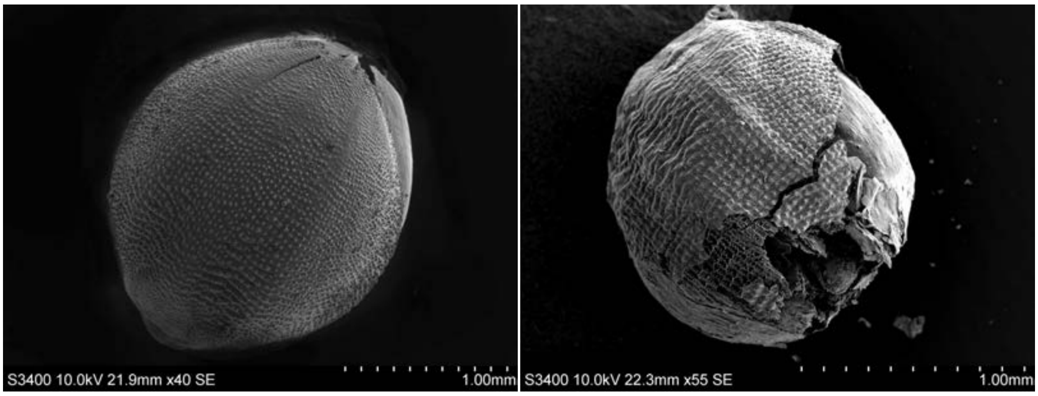


Figure 5.5: SEM images of the lemma of a modern uncharred (L) and charred (R) *Setaria italica* showing the distinctive punctuate texture. (Images by author).

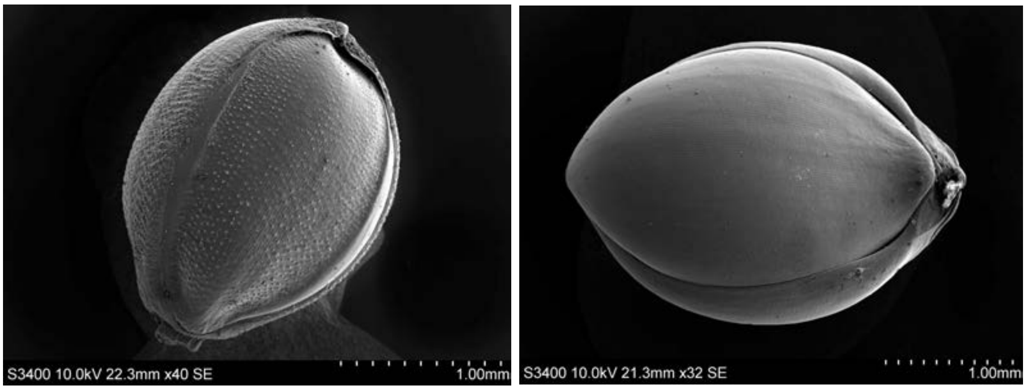


Figure 5.6: SEM images of palea of modern uncharred *Setaria italica* and *Panicum miliaceum* showing vertical stripes. Although this pattern is more distinctive in *Setaria italica* with some punctuate texture, the pattern was not seen in the charred remains. (Images by author).

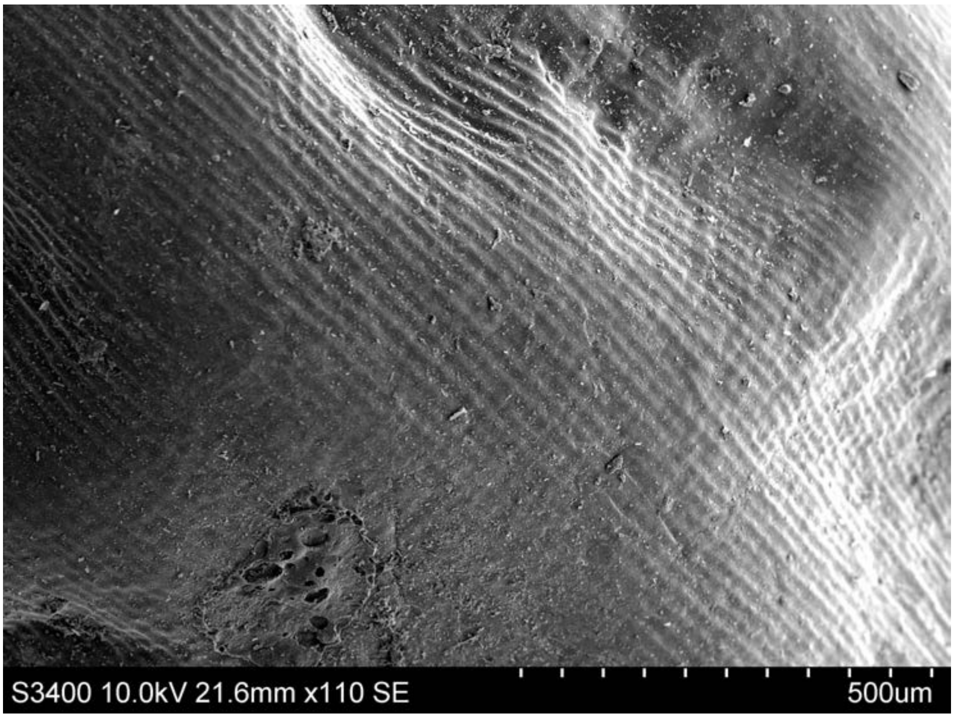


Figure 5.7: A close-up SEM image of the lemma of a modern charred *Panicum miliaceum* showing characteristic vertical stripes. (Image by author).

- ***Rice husk.*** In some instances, rice husk seems to lose the protruding tubercules found on the external side and therefore ends up looking more like wood (Ex2B). Small fragments could easily be overlooked and considered wood.
- ***Parenchyma.*** There are parenchymatous fragments which seem to be of *Oryza sativa* but because of their small size it is very difficult to identify. These were mostly from the 0.5-1 mm fraction.

5.5 OVERALL RESULTS

Because so many factors are involved in the preservation of seeds through charring no given charring experiment represents a complete analogue for archaeological carbonized grains. So results from charring experiments should not be interpreted as absolute values but rather they indicate relative outcomes, relationships or patterns. Therefore, the statements in this section and in Chapter 8 are broad and the interpretations mostly discuss possible relations and biases of species when charred under fire conditions.

5.5.1 Absolute frequencies

There are two main measurements used by palaeontologists/archaeozoologists to estimate taxonomic abundances, these are the number of identified specimens (NISP) and minimum number of individuals (MNI). These two measures can also be applied to archaeobotanical remains. NISP in archaeozoology is defined as *'the number of skeletal elements (bones and teeth) and fragments thereof - all specimens - identified as to the taxon they represent* (Lyman 2008).' NISP values are absolute frequencies. MNI is the number of individuals represented in an assemblage. NISP has the inherent weakness of interdependence in values because of fragmentation and it is often suggested that MNI be used to solve the problem of specimen interdependence (Lyman 2008). Fragmentation may cause the NISP to over-represent the number of individuals whereas MNI would under-represent them. I have decided to use NISP values since one of the aims of charring experiments is to ascertain the relative visibilities of different species including their component parts or fragments. This is because the actual number of individuals (ANI) is known a priori as these are the number of fresh specimens used in each experiment and the upper limit of MNI is the ANI. So it is hard to establish from which individual specimen the fragments come. MNI would prove a futile exercise. Finally, Lyman (2008) advises the use of NISP values for archaeological work to determine taxonomic abundances and this advice is followed in Chapters 6, 7 and 8 when dealing with the archaeobotanical remains. The NISP values from the charring experiments are found in Table 5.3.

	1A	1B	1C	1D	2A	2B	2C	2D	3C	3D	4A	4B	4C	4D
Vigna radiata	11	22	16		21	25	26	15	5	9	3		6	
Oryza sativa caryopsis	7	14	3			22	44	23						
Oryza sativa husk (w/o sb)	12	61	18	8	34	102	146	120						
Oryza sativa spikelet base*	8	18	4		1	16	17	11						
*Oryza sativa***	14	24	6		1	30	56	32						
*Coix lachryma-jobi****	8	23	10		10	25	24	22						
Coix lachryma-jobi utricle	77	271	142	76	105	414	433	683						
Glycine max	1	21	7	7	5	23	27	20	10	11				
Setaria italica	1	22	5		13	21	16	8			3	1		
Setaria italica husk		9	6		3	14	21	9						
Panicum miliaceum	7	21	1	1	1	19	13	6		2	14	1	2	
Panicum miliaceum husk	1	16	2			59	31	22						

* *Oryza sativa* spikelet bases includes those attached to caryopsis
** *Oryza sativa* excludes husk but includes spikelet bases
*** *Coix lachryma-jobi* does not include the utricle counts

Table 5.3: Number of Identified Specimens (NISP) / absolute frequencies. The values include whole seeds and fragments.

The total number of charred plant remains in each experiment does not appear to have a common trend (Table 5.5) with one exception. The total amount of charred plant remains is higher when the seeds burned are husked or have a hard utricle or bract sheath (as in the case of job’s tears). This holds true for all experiments even when the tabulation includes only the species used in all experiments, therefore excluding job's tears and soybean (Table 5.6). The apparent reason for this is that it appears that there are more plant components to be found if the cereals are husked and as is shown in other experiments (discussed in the preceding section), cereals which are husked survive better when they come into contact with fire. Furthermore, Boardman and Jones (1990) concluded that preservation of grains is better when surrounded by chaff. Boardman and Jones also mention a lower degree of grain distortion when husked grain is charred. Several other experiments show that glumes protect the seed (Bowman 1966; Garton 1979; Märkle and Rösch 2008). Indeed, this seems to be the case in the Primtech08 experiments.

	1A	1B	1C	1D	2A	2B	2C	2D
Vigna:Oryza caryopsis	100:64	100:64	100:19			100:88	59:100	65:100
Vigna:Oryza caryopsis & sb	79:100	92:100	100:38		100:5	83:100	46:100	47:100
Vigna:Oryza all	42:100	26:100	67:100		60:100	19:100	13:100	10:100
Vigna:Coix	100:73	96:100	100:62		100:48	100:100	100:92	68:100
Vigna:Glycine	100:9	100:95	100:44		100:24	100:92	96:100	75:100
Vigna:Setaria	100:9	100:100	100:31		100:62	100:84	100:62	100:53
Vigna:Panicum	100:64	100:95	100:6		100:5	100:76	100:50	100:40
Oryza caryopsis:Oryza sb	88:100	78:100	75:100			100:73	100:39	100:48
Oryza caryopsis:Oryza husk	58:100	23:100	17:100			22:100	30:100	19:100
Oryza:Coix	100:57	100:96	60:100		10:100	100:83	100:43	100:69
Oryza:Glycine	100:7	100:87	86:100		20:100	100:77	100:48	100:62
Oryza:Setaria	100:7	100:92	100:83		8:100	100:70	100:29	100:25
Oryza:Panicum	100:50	100:87	100:17		100:100	100:63	100:23	100:19
Coix:Glycine	100:12	100:91	100:70		100:50	100:92	89:100	100:91
Setaria:Panicum	14:100	100:95	100:20		100:8	100:90	100:81	100:75
Oryza husk:Setaria husk		100:15	100:33		100:9	100:14	100:14	100:8
Oryza husk:Panicum husk	100:8	100:26	100:11			100:58	100:21	100:18
Oryza husk:Coix utricle	16:100	22:100	13:100	10:100	32:100	25:100	38:100	18:100
Setaria grain:Setaria husk		100:41			100:23	100:67	76:100	89:100
Panicum grain:Panicum husk	100:14	100:76	50:100			32:100	42:100	27:100
			3C	3D	4A	4B	4C	4D
Vigna:Glycine			50:100	82:100				
Vigna:Setaria					100:100			
Vigna:Panicum				100:22	21:100		100:33	
Setaria:Panicum					21:100	100:100		

Table 5.4: Comparison ratios.

	Total ALL charred	Total charred ex husk	Total husk & utricle	Total charred large seeds*	Total charred small seeds**
1A	132	42	90	20	22
1B	490	133	357	66	67
1C	213	45	168	33	12
1D	92	8	84	7	1
2A	193	51	142	36	15
2B	732	143	589	73	70
2C	793	162	631	77	85
2D	937	103	834	57	46
3C	15	15	-	15	0
3D	22	22	-	20	2
4A	20	20	-	3	17
4B	2	2	-	1	2
4C	8	8	-	6	2
4D	0	0	-	0	0

* large seeds include *Vigna radiata, Coix lachryma-jobi* and *Glycine maxima*
** small seeds include *Oryza sativa, Setaria italica* and *Panicum miliaceum*

Table 5.5: NISP of charred remains including all species used in the experiments. Experiments 1A, 1B, 1C, 1D, 2A, 2B, 2C and 2D used husked cereal whereas experiments 3C, 3D, 4A, 4B, 4C and 4D used naked cereal.

	Total ALL charred	Total charred ex husk	Total husk
1A	46	33	13
1B	175	89	86
1C	54	28	26
1D	9	1	8
2A	73	36	37
2B	270	95	175
2C	309	111	198
2D	212	61	151
3C	5	5	-
3D	11	11	-
4A	20	20	-
4B	2	2	-
4C	8	8	-
4D	0	0	-

Table 5.6: NISP of charred remains including only the species used in all four experiments. Excludes job's tears and soybean. Total number of fresh specimens per experiment would be equal for all at n=100. Experiments 1A, 1B, 1C, 1D, 2A, 2B, 2C and 2D used husked cereal whereas experiments 3C, 3D, 4A, 4B, 4C and 4D used naked cereal.

5.5.2 Relative frequencies

Only seeds or plant components that can be counted as unique units are used in the relative frequencies found in Table 5.7. Relative frequencies are discussed throughout Chapter 8. However, some general conclusions are that a higher percentage of rice spikelet bases preserve relative to whole grains; when dehusked grain was charred

(Experiments 3 and 4), no rice grains preserve or they are in such a deteriorated state to render them unrecognisable; and at least one soybean was preserved in all experiments.

	1A	1B	1C	1D	2A	2B	2C	2D	3C	3D	4A	4B	4C
Vigna radiata whole	6 24%	20 80%	14 56%		7 28%	24 96%	24 96%	14 56%	2 8%	7 28%	2 8%		3 12%
Oryza sativa whole	5 20%	13 52%	1 4%			12 48%	17 68%	10 40%					
Oryza sativa spikelet base	8 32%	18 72%	4 16%		1 4%	16 64%	17 68%	11 44%	-	-	-	-	-
Coix lachryma-jobi whole	8 32%	23 92%	8 32%		10 40%	23 92%	24 96%	22 88%	-	-	-	-	-
Glycine max whole	1 4%	21 84%	3 12%	4 16%	1 4%	23 92%	24 96%	18 72%	6 24%	5 20%	-	-	-
Setaria italica whole	1 4%	16 64%			13 52%	19 76%	13 52%	6 24%			3 12%		
Panicum miliaceum whole	7 28%	16 64%	1 4%			16 64%	9 36%	5 20%		2 8%	11 44%	1 4%	2 8%

Table 5.7: Number of identified specimens for whole charred seeds and rice spikelet bases. Relative frequencies are below the NISP values. Experiments 1A, 1B, 1C, 1D, 2A, 2B, 2C and 2D used husked cereal whereas experiments 3C, 3D, 4A, 4B and 4C used naked cereal. Relative frequencies in this table refers to the recovered remains compared to the total number of seeds that were used in the charring experiment.

5.5.3 Shrinkage factors

Table 5.8 shows the measurements of the different taxa used in the Primtech08 experiments, including fresh and charred samples. Only whole seeds were measured but some were too distorted and therefore not measured. For example, all the fresh job's tears seeds had an intact utricle but the charred specimens had fragmented utricles (Figure 8.3). For this reason, the difference in measurements between fresh and charred specimens of job's tears are not comparable and have been left out of these discussions on shrinkage. Discussions below revolve around the three species found in the study sites KSK and PKT, namely rice, foxtail millet and mungbean.

General observations from the Primtech08 experiments were similar to charring experiments conducted by other authors, such as a decrease in the length of cereals (Abdel-Magid 1989; Bowman 1966; Braadbaart 2008; Chuenwattana 2011; Lone et al. 1993; Renfrew 1973) and a decrease in the size of pulses (Helbaek 1970; Lone et al. 1993). All cereals except one population of foxtail millet decreased in length. Both pulses mungbean and soybean decreased in size. Abdel-Magid (1989) noted that the percentage of variation was different for each species and it is similarly the case for the Primtech08 experiments. However, whereas the width and thickness of cereals increased in the published charring experiments (Abdel-Magid 1989; Bowman 1966;

Braadbaart 2008; Chuenwattana 2011), this was not the case in the Primtech08 experiments. Generally, thickness increased for most cereals except for dehusked broomcorn and foxtail millets, but width generally decreased. Perhaps one of the reasons for these discrepancies is the difference in methodology. The Primtech08 experiments were done in an open fire whereas the charring experiments mentioned above used muffle furnaces. At higher temperatures, such as those reached in the Primtech08 experiments, cereals have a tendency to distort and some eventually turn to ash. It is believed that the shrinkage values from the Primtech08 experiments cannot be used as a corrective factor adjustment applied to modern fresh samples. Therefore, discussions on shrinkage derived from the Primtech08 experiments are regarded as general tendencies. Fuller and Harvey (2006) applied a shrinkage correction factor to modern measurements of uncharred specimens of -20% for pulses and -10% for cereals. Fuller and Harvey formulated the shrinkage correction factor for cereals and pulses based on a good fit between the scatter plots of archaeological seed measurements and those from modern seed measurements after adjustment (Fuller pers. comm.). This corrective factor was applied to modern measurements found in Chapters 6 and 7 rather than those from the Primtech08 experiments because of the wide range of shrinkage found in the Primtech08 experiments even within the same species. Furthermore, the Primtech08 experiments were aimed primarily to understand the preservation bias that occurs between different species and only secondarily, to determine morphological changes including shrinkage.

Husked rice decreased relatively more in length and width compared to rice that had lost its husk during charring. The charred dehusked rice measurements in Table 5.8 were of rice that was placed husked in the experiments but lost their husk during charring. These measurements were compared to those from dehusked fresh rice measurements to calculate the shrinkage factor. This was done because none of the fresh dehusked rice used in the experiments (Ex3 and Ex4) survived. Interestingly, there is a 25.21% increase in the thickness of rice that lost its husk, and an explanation for this is that once rice loses its husk, there is no protective layer to limit the distortion. On the other hand, charred husked rice had negligible thickness shrinkage (-0.10%).

	length				width				thickness			
	max	min	mean	% shrinkage	max	min	mean	% shrinkage	max	min	mean	% shrinkage
Coix lachryma-jobi												
fresh (n=100)	13.69	8.56	10.63		7.32	4.90	6.19		6.55	4.45	5.25	
carbonised w/ urticle (n=10)*	6.49	4.94	5.54		5.99	4.44	4.89		3.85	2.32	3.11	
carbonised (n=5)	5.30	3.60	4.40		4.70	4.00	4.30		3.40	1.50	2.70	
Oryza sativa (dehusked)												
fresh (n=114)	8.16	5.81	7.16		2.44	1.61	2.11		1.88	1.42	1.65	
carbonised (n=10)**	7.72	6.32	6.98	-2.49%	2.64	1.60	2.08	-1.57%	2.42	1.67	2.06	25.21%
Oryza sativa												
fresh (n=200)	11.74	8.85	10.53		2.89	2.29	2.62		2.33	1.41	1.98	
carbonised (n=18)	9.77	6.67	8.31	-21.05%	3.52	1.78	2.37	-9.68%	2.55	1.23	1.98	-0.10%
Vigna radiata												
fresh (n=198)	5.64	3.68	4.68		4.24	3.01	3.68		3.84	2.97	3.45	
charred no testa (n=9)	4.64	2.37	3.58	-23.47%	3.40	2.70	3.10	-15.76%	4.00	3.30	3.60	4.30%
charred w/ testa (n=99)	6.50	3.31	4.36	-6.80%	4.10	2.05	3.06	-16.84%	4.00	2.16	3.19	-7.58%
Glycine max												
fresh (n=135)	7.96	5.94	7.10		6.70	4.35	5.94		7.27	6.04	6.70	
carbonised (n=66)	9.55	3.77	6.83	-3.77%	6.78	3.11	4.98	-16.09%	5.67	2.41	4.09	-38.91%
Panicum miliaceum												
fresh (n=188)	3.53	2.93	3.20		2.58	1.71	2.27		2.19	1.55	1.81	
carbonised (n=13)	3.10	2.00	2.40	-25.00%	2.30	1.60	1.90	-16.18%	2.20	1.80	2.00	10.51%
Panicum miliaceum (dehusked)												
fresh (n=188)	2.68	2.00	2.43		2.50	1.79	2.14		1.98	1.11	1.65	
carbonised (n=27)	2.49	1.51	1.99	-18.23%	2.31	1.57	1.96	-8.60%	2.19	0.98	1.59	-3.73%
Setaria italica (China)												
fresh (n=190)	2.45	1.93	2.25		1.95	1.37	1.73		1.74	1.13	1.44	
carbonised (n=51)	2.52	1.51	1.84	-18.09%	2.14	1.32	1.64	-5.09%	1.90	1.00	1.46	1.40%
Setaria italica (China, dehusked)												
fresh (n=190)	1.87	1.37	1.66		1.76	1.14	1.55		1.48	0.67	1.22	
carbonised (n=9)***	2.20	1.08	1.74	4.80%	1.83	1.26	1.59	2.83%	1.52	0.92	1.26	3.01%
Setaria italica (India, dehusked)												
fresh (n=170)	2.83	2.19	2.50		1.72	1.24	1.57		1.52	0.95	1.27	
carbonised (n=4)	1.72	1.40	1.53	-38.79%	1.92	1.45	1.59	1.16%	1.36	0.93	1.21	-4.90%

* a lot of frgmentation, so measurements are not accurate
** no dehusked rice charred in the experiments, these were husked when charred but comparable to the dehusked rice grains because they derive from the same population and were manually dehusked.
*** these are from experiments 1 and 2 so were originally husked but come from the same population as those used in Experiment 3 that were manually dehusked.

Table 5.8: Measurements of the fresh and charred specimens at Primtech08. All measurements done with the Leica EZ4 D stereo microscope.

Foxtail millet showed differences between two populations used in the experiments, Chinese and Indian foxtail millets. Dehusked Chinese foxtail increased in length, width and thickness, whereas the dehusked Indian foxtail decreased in length and thickness but increased slightly in width. The explanation for this is that the Indian foxtail was placed into the fire already dehusked whereas the Chinese millet were husked when placed in the fire but lost their husk when charred, similar to the rice specimens discussed above. Therefore, the husk must have protected the grains before burning off. Furthermore, only four of the charred Indian foxtail grains were preserved which is a very small sample. Foxtail millet and rice showed a similar tendency to have a relatively higher percentage of shrinkage in the length and width of husked grain than the dehusked specimens. For foxtail millet, this comparison can only be made with the Chinese samples because no Indian husked samples were used in the experiments.

All the mungbeans used in Primtech08 had a testa. Some of the mungbeans lost their testa as a result of charring and these showed a relatively higher percentage of length shrinkage compared with mungbeans that retained their testa. This is partly because lacking the testa makes the specimens smaller. The decrease in width was similar in both mungbeans with and without testa but thickness increased in mungbeans without testa and decreased in those with testa. Contrary to Helbaek (1970) who found thickness practically unchanged in charring experiments with one pulse, lentils, the Primtech08 experiments showed there was variability in the thickness of charred pulses, especially in soybean.

5.5.4 Temperature

As discussed above, in the experiments conducted with the muffle furnace, it was generally the case that grains become unidentifiable due to deterioration between 320°C and 550°C depending on the species. Also, carbonisation generally took place between 200-250°C with reducing conditions positively influencing the charring process. Hillman (1981) observed that plant remains preserved either when exposed to gentle heating (200-400°C) or at higher temperatures only when the plant remains were buried in ash. In the fire experiment conducted by Sievers and Wadley (2008), the specimens placed in reducing conditions survived even though the fire temperatures reached 670°C. Likewise, the Primtech08 experiments, higher temperatures were reached compared to the muffle furnace experiments of other authors and yet the specimens managed to be charred and survive. All Primtech08 specimens were in a reduced atmosphere. It is not yet clear to me why specimens under reducing conditions seem to survive better at higher temperatures in fire experiments than in controlled muffle furnace experiments, but it may be that the actual temperature of seeds is more variable in real fires and does not reach the highest temperatures reached in the fire overall, whereas the air temperature in muffle furnaces is consistent.

5.6 ARCHAEOLOGICAL DATA and PRESERVATION BIAS

Specific results from the charring experiments presented above and their interpretation are discussed in detail in Chapter 8 (Charring Experiments: Interpretation). The reason for presenting the data in this manner is to incorporate the results from the sites KSK and PKT. This allows for an understanding of the archaeological data using the experimental work done at Primtech08. Some conclusions on preservation bias in the archaeological record are presented in Chapter 8 with respect to KSK and PKT.

CHAPTER 6
Khao Sam Kaeo

6.1 SITE DESCRIPTION

As early as the second century BC the Thai-Malay Peninsula appears in a Chinese Han text as an overland route to the Indian Ocean (Jacq-Hergoualc'h 2002; Wheatley 1961). It was strategically located between South Asia on the west and Han China and the Insular Southeast Asian maritime world to the east. Khao Sam Kaeo (here after KSK) is situated at the narrowest point of the Thai-Malay Peninsula. It is the earliest known urban settlement in Southeast Asia which was engaged in trans-Asiatic exchange networks (Bellina 2002; Bellina and Silapanth 2006;Bellina-Pryceand Silapanth 2008). With several communities represented and craft specialisation in the form of glass working, stone bead production, metalworking and pottery (Bellina and Silapanth 2006;Bellina-Pryce and Silapanth 2008;Lankton et al. 2006;Pryce et al. 2008). Whilst some items originated from India, China and Southeast Asian locations, others were produced in KSK using transferred technologies. KSK provides data on the beginning of a long-lasting cultural exchange that linked South Asia and Southeast Asia, that process is traditionally referred to as Indianisation (cf. 'localization' [Wolters 1999]) and which is recognised from the fifth century AD when a fair part of Southeast Asia was fully Indianised.

KSK consists of four hills located in the Na Cha Ang subdistrict, Chumphon province. The site is located at longitude 99.18499511° and latitude 10.5282973° with the hilltops averaging an altitude of 30m above sea level. It is surrounded by lowlands and flanked to the west by the Tha Tapao River. Although an early port city, KSK was not a coastal site but had access to the sea via the Tha Tapao River (Bellina in press). Settlements have been found on the plateaus, the gentle hill slopes, the foot of the hills and on the riverbank. Both domestic and industrial areas have been identified, as well as communal habitation terraces. Several types of structures can be found at the site including terraces, floors, postholes, walls and drainage systems. Figure 6.1 is an example of a domestic area with some of these structures represented.

Extensive work has been done by Dr. Bellina and her team of specialists to understand the organisation of the site. The spatial analysis of the artefacts in the four hills shows two differentiated areas with a south-north division. The two areas correspond to different communities of people occupying the hills. Hills 1 and 2 form the southern area and is the area attributed to local populations with the presence of a few artisans (at the bottom of Hill 2) working glass and stone ornaments. Hills 3 and 4 form the northern area and correspond to foreign populations composed of other Southeast Asian groups, South Asians and possibly East Asians (Figure 6.2). The evidence for this is discussed below.

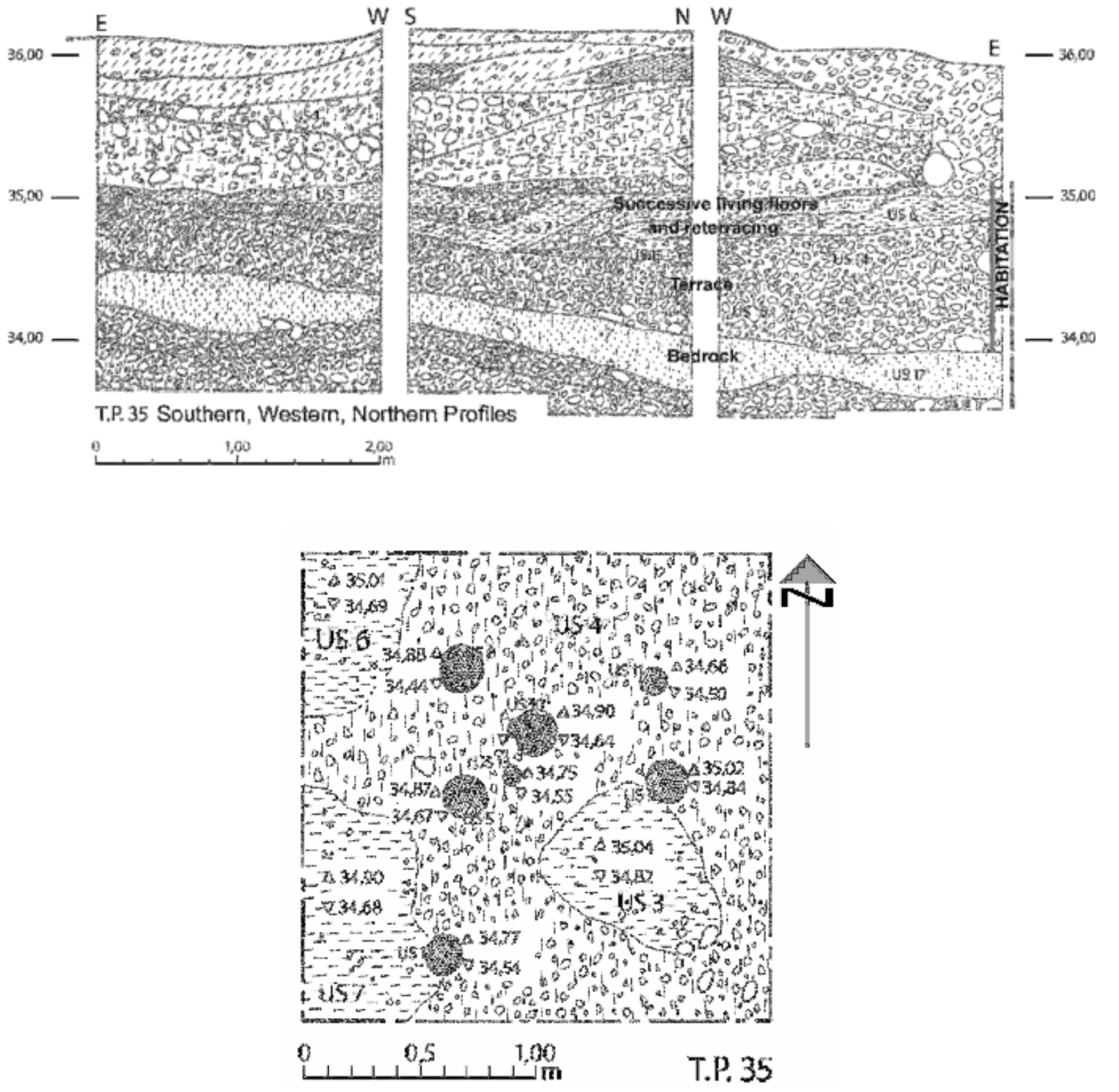


Figure 6.1: Section drawings of TP35showing the habitation layers made of successively built floors on top of a man-made terrace. The lower drawing is from the habitation layers US3, US6 and US7 from TP35 showing postholes and fireplaces (Section drawings by V. Bernard).

KSK was excavated over a period of five years and the archaeological team was composed of several specialists (Table 6.1). Through each of the specialist studies, the social organisation of KSK and its role as a port and entrepôt has been established. The artefacts show that KSK contributed to a network of exchange known as the 'maritime silk road.' The maritime silk road is part of a world systems network that extends east to China and west to India via the Indian Ocean and beyond to the Red Sea and the Mediterranean. This extensive network is illustrated through the studies conducted by the specialists and are briefly discussed below.

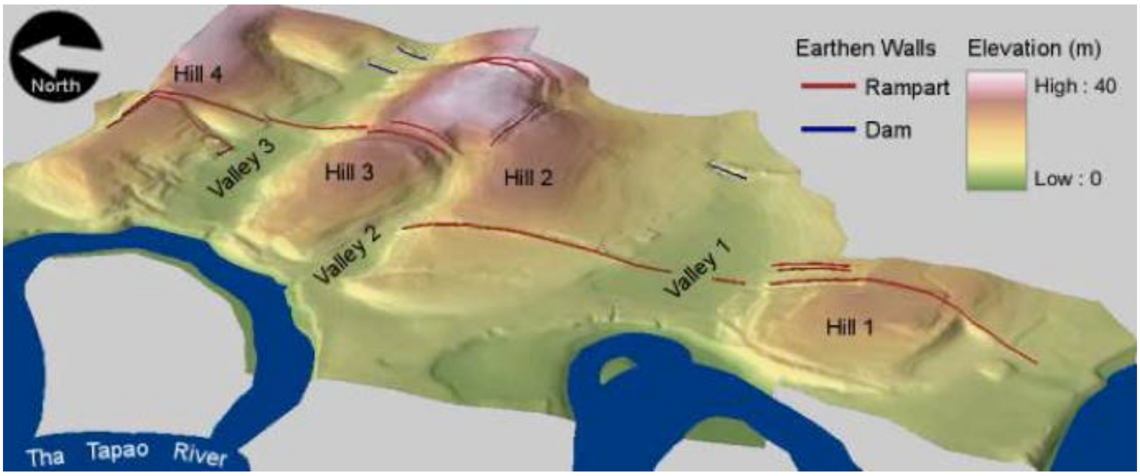


Figure 6.2: Map of KSK showing the four hills that comprise the settlement area flanked to the west by the Tha Tapao River (Map by J. Malakie).

Archaeobotany	Cristina Castillo
Archaeometallurgy	Lynn Biggs Mercedes Murillo-Barosso Dr. Oliver Pryce
Ceramics	Dr. Phaedra Bouvet Dr. Sophie Peronnet Aude Favereau
Geomorphology	Dr. Jane Allen Praon Silapanth G. Epinal
GIS	Julie Laclair Malakie
Glass	Dr. Laure Dussubieux Dr. James Lankton (Md)
Stone	Dr. Berenice Bellina
Topography	Vincent Bernard

Table 6.1: List of specialists that worked at KSK.

6.1.1 The material artefacts

Glass

Dussubieux and Bellina (in preparation) believe that during the period dating from the second century BC to the fifth century AD, a well-established network involving the exchange and use of raw glass and finished glass products was in place in an area covering South Asia and Southeast Asia. KSK contributed to this flourishing period in the glass industry as revealed by the glass finds dating from the fourth to the second century BC when these exchange networks started to emerge.

The glass assemblage shows that KSK had a glass workshop in Hill 2 specifically using green glass (Dussubieux 2009). Raw glass, glass waste and finished artefacts in the form of bracelets and lapidary beads were found in abundance in Hill 2 (TP29). Lapidary beads involve similar stone-knapping and polishing techniques used for stone bead manufacture. Lapidary beads have been found elsewhere in Thai prehistoric sites, including Ban Don Ta Phet and Ban Chiang, and is a technique attributed to South Asia. It is believed that translucent green glass raw material was brought into KSK where it was worked into bracelets and lapidary beads (Dussubieux and Bellina in preparation). The 'chaine operatoire' of these glass beads, called lapidary beads, used techniques commonly used in stone bead production and these techniques are considered highly skilled Indian technologies (Dussubieux and Bellina in preparation). These types of glass beads are found specifically at the bottom of Hill 2 during the earliest occupation period of KSK. Had Indian craftsmen travelled to, settled at and working in KSK from the onset of occupation? Or were these specialised skills transferred to the local populations during the early occupation period of KSK?

Finished glass and glass production were identified at KSK. There is evidence for glass bracelet, drawn and lapidary glass bead production. However, KSK was not a primary glass producer and instead raw glass was imported. The composition analysis shows that only a small quantity of glass can be attributed to South Asian origins (Lankton et al. 2008). The origin of most of the glass remains unknown and is work in progress for the glass specialists. However, some composition analysis of the different coloured glass show possible origins in south India and Sri Lanka (for mixed alkali glass producing red and orange beads) and the Sassanian Near East (for v-Na-Ca glass) because of similarities in glass made in these areas. The m-Na-Al 3 glass present at KSK has also been traced to northeastern India as the source, where lapidary techniques used in glass probably originated from (Dussubieux and Bellina in preparation).

Stone

Bellina's extensive study on the stone industries present at KSK has revealed four types of production. Her analysis included a stylistic and technological approach. These four types can be summarised as follows:

Production type 1- The South China Sea siliceous type of production is characterised by Indian raw materials and skilled technologies with South China stylistics. The facetted lapidary worked glass ornaments are probably Indian in origin as mentioned above and it is hypothesised that at the onset of occupation, there were a few highly skilled Indian craftspersons working in KSK (Bellina et al. in preparation). This type of production is mainly found in the southern part of the site. Bellina has also identified similar artefacts with this type of production in the South China Sea cultural sphere including Ban Don Ta Phet in central Thailand, Sa Huỳnh sites in south Vietnam and in Tabon Caves in the Philippines (Glover and Bellina 2011; Bellina 2003,2007)

Production type 2 - The South China Sea jadeite typology includes artefacts made of nephrite and green mica with an East Asian technique and similar style as production type 1. The shapes include the *lingling'o*, also found in the Philippines and Vietnamese Sa Huỳnh sites, and the bicephalous (two-headed) ornament. The two-headed animal ornament has also been found in the prehistoric burial site Ban Don Ta Phet though in that case in carnelian. Hung and Iizuka's study (in preparation) shows that the nephrite analysed (n=12) was sourced from eastern Taiwan but worked in KSK. Nephrite from Taiwan has also been found at Giong Ca Vo, a Sa Huỳnh site located in southern Vietnam. Other jade production workshops using Taiwanese nephrite have been identified in Pinglin, eastern Taiwan, Trang Kenh in northern Vietnam and northern and southern Philippines. The mica is similar in chemistry to Mindoro (Philippines) raw material. The South China Sea jadeite ornaments and their raw materials were found in the northern part of the site (Hills 3 and 4) and an insignificant amount in the southern part of KSK.

Production type 3 - The South Asian-related siliceous ornaments are made of Indian raw materials, skilled technologies and style. The craftspersons were probably of Indian origin or trained by them (Bellina in preparation). The raw materials are carnelian, agate, jasper, rock crystal, amethyst and garnet. The Indian style is well defined by the number of auspicious and religious symbols that have been identified. These symbols have similar comparisons in South Asia ranging in dates between *ca.* fifth-second century BC. South Asian symbols include the mythological beast *makara*, the sacred goose *hamsa,* the symbol of the three jewels the now-termed *triratna* and the paired fish *mina-yugala* to name a few (Figure 6.3). Many of these symbols have later been integrated in the iconographic repertoire in Buddhism, Hinduism and Jainism. These objects were mostly found in Hills 2 and 3.

Figure 6.3: Stone artefacts from KSK in the form of auspicious symbols. From left to right: carnelian *makara*, carnelian *triratna* and rock crystal *mina yugala* (Photographs: *makara* by author, others by Bellina).

Production type 4 - The last type is characterised by a later Southeast Asian low quality production. This type is difficult to define because of the small number of samples but it made up of siliceous medium quality stone which is of lower quality compared to the other three types of production and the typology is mostly large rounded beads and some flat agate pendants. These were only found in Hill4.

Metal

On stylistic grounds, the gold ornaments found at KSK show similarities with other objects retrieved elsewhere in Southeast Asia and South Asia, once again demonstrating the links this entrepôt had with other sites. These sites extend from China (Shendingling, Guigang), Vietnam (Oc Eo and the Sa Huỳnh site of Giong Ca Vo), the Philippines (Palawan Island sites), Burma (Pyu sites), Pakistan (Taxila) as well as other sites in the Southern Peninsula of Thailand (Sawi in Chumphon province and Tha Chana in Surat Thani province) (Pryce et al. in preparation). Iron smithing, particularly secondary smithing, took place at KSK though the iron was probably imported as no evidence for smelting on-site was found. The bronze artefacts show a variety of stylistic influences from South Asia, Vietnam (Dong Son) and China (Western Han) and an equal variety of material sources. Furthermore, it has been posited by Pryce et al. (*ibid.*) that it is possible that craftspersons of South Asian origin may have been responsible for some of the locally produced Southeast Asian-type material using South Asian techniques, in particular ferrous technologies. This belief is consistent with some of the above discussions on the origin of some of the other material culture at KSK.

Other metal finds of significance include a complete Han bronze mirror (Figure 6.4), a mirror fragment and two Han bronze seals. A similar Han mirror has also been found at Chawang in peninsular Thailand (Péronnet et al. in preparation). But the bronze Dong

Son drums found in Hill 1 are considered to be some of the best evidence for exchange networks at KSK (Figure 6.5). These Dong Son drums originated from the Dong Son cultural tradition of northern Vietnam and have also been found in other parts of southern Thailand, Burma, Cambodia, Indonesia, Malaysia, Laos, southern China and central and southern Vietnam (Bellina and Silapanth 2006; Calo 2009).

Figure 6.4: The complete Middle Western Han bronze mirror found at KSK called *xing yun jing* (mirror with stars and clouds)[Photograph by author].

Figure 6.5: Dong Son drums found in KSK (Photographs by Bellina).

Pottery
There was an abundance of pottery sherds at the site which were grouped according to technology used, i.e. the '*chaine operatoire*' and according to morpho-stylistic criteria. There was a corpus of Fine Ware found to be similar to pottery from Arikamedu and other coastal sites along the Bay of Bengal ranging from Bengal to Tamil Nadu in South Asia including, to cite only a few, rouletted and knobbed ware (Bouvet 2011, Figure

6.6). It has therefore been argued that these finds are a result of contact and exchange between the KSK population and South Asia. Another group of pottery that also illustrates the links with South Asia is the group named 'KSK Black Polished Ware' which has been compared to the Northern Black Ware (NBP) of South Asia on morpho-stylistic grounds by Bouvet (*ibid.*). Interestingly, this group is characterised by the high amount of rice husk used as temper. The Indian-related wares have a higher concentration on Hills 3 and 4. This is evidence of Bellina's interpretation that the site is divided into quarters with different populations settled on different parts of the site.

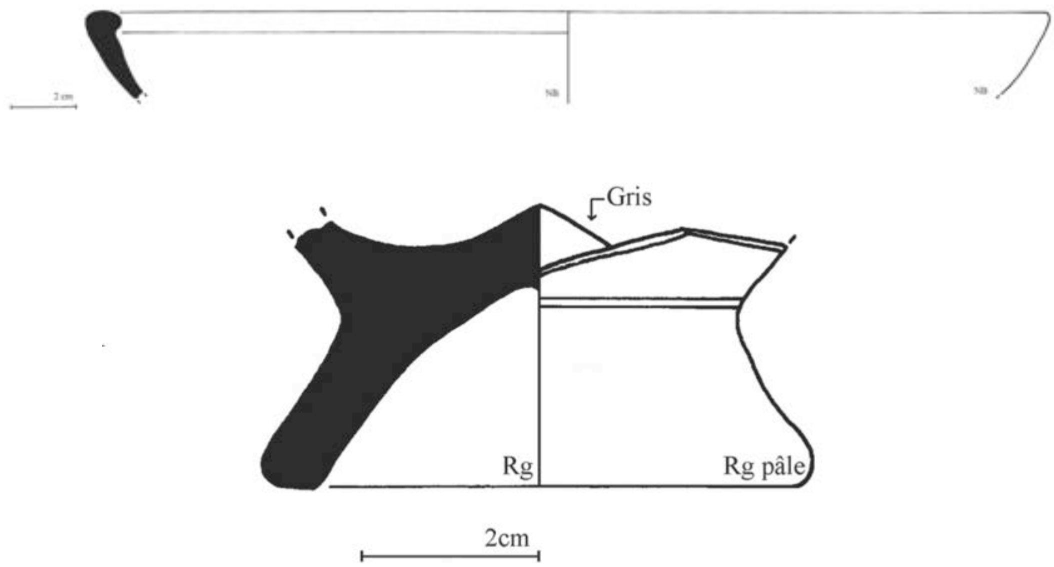


Figure 6.6: Examples of rouletted and knobbed ware from KSK. Top: Rouletted ware of the *KSK Fine Wares 1* group TP68 US8; Bottom: Knobbed ware of the *KSK Fine Wares 1* group TP66 US6 (Drawings by Bouvet).

Han-style pottery has also been identified in KSK and the corpus is considered the largest outside China (Figure 6.7). The number of sherds totalled eighty-four and came from both excavations and surveys concentrated in Hill 3 (Péronnet et al. in preparation). These sherds have been identified as belonging to the Western Han Dynasty tradition. Western Han pottery has been found mostly in tomb sites located in south and east China as well as in north and central Vietnam and also in Tha Cha Na in peninsular Thailand (*ibid.*). Unlike the vast amount of pottery and other material objects of Indian origin, the Chinese artefacts have been found in lower quantities. One possible explanation by Péronnet et al. is that the Chinese objects were brought in as part of tribute and not trade.

Figure 6.7: Han pottery sherds found at KSK (Photographs by Péronnet).

<u>**6.1.2 Early Globalisation**</u>

The links with South Asia and East Asia are well documented at KSK as illustrated by the material culture found throughout the site. Some artefacts from KSK can be compared with similar types in both India and China, such as rouletted ware and Han ceramics respectively. KSK also forms part of a network with other Southeast Asian sites as seen by the similar artefact types found in central Thailand, southern and central Vietnam and the Philippines. Flat hexagonal beads made of carnelian and agate have been found at KSK but also at Leang Buidane in Talaud Islands, Indonesia and Tabon caves in the Philippines, respectively (Glover and Bellina 2011). Glass ear pendants in the shape of a comma, knobbed bronze vessels and iron-socketed billhooks (n=1 at KSK) have also been found in both KSK and BDTP (*ibid.*).

Early interactions between India and Southeast Asia during the period 500 BC and 500 AD have been documented in abundance. In fact, the book titled 'Early Interactions between South and Southeast Asia' (Manguin et al. 2011) is a compilation of essays providing evidence of this early network in Vietnam, Thailand and Indonesia. There is also evidence in the Andaman coast of Thailand of Roman beads and carnelian intaglios probably making their way to Thailand through India during the first-second centuries AD (Chaisuwan 2011).

In the west, there are various trading ports documenting early exchanges between the Red Sea and India. Berenike and Myos Hormos dating to *ca.* third century BC and the first centuries AD respectively show ample evidence of trade linking the Red Sea to both India and the Roman Empire (Cappers 2006; van der Veen 2011). The Indian Ocean trade during the Roman period is also documented by the '*Periplus Maris Erythrae'i'* dating to the first century AD. World systems is briefly discussed in the Introduction and the Conclusion.

6.2 CHRONOLOGY

Thirty-three samples have been dated from the site using conventional and AMS radiocarbon techniques. Charcoal, wood, organic material found in pottery and plant parts comprise the material sampled. Nineteen AMS dates have been obtained so far and fourteen were from conventional radiocarbon dating. The laboratories used for radiocarbon dating were the Waikato Radiocarbon Dating Laboratory in New Zealand and the University of Oxford Radiocarbon Accelerator Unit in the United Kingdom. Ten archaeobotanical samples from KSK were sent to the Oxford Radiocarbon Accelerator Unit for AMS radiocarbon dating although only two results were obtained with four samples failing due to no or low yield of carbon, and four samples being withdrawn because the lab believed the samples would not yield any results. The complete list of samples sent together with the justification for having them dated is found in Appendix 6.1.

The conventional and AMS radiocarbon dates from KSK have reliably placed the chronology of the site in the Late Prehistoric period between the fourth to first centuries BC. Three dates extend the age of the site to the sixth and fifth centuries BC (WK-16804, WK-21177, WK-2582). The two samples that yielded very early dates (WK-18766: 7577-7356 cal. BC and WK-18767: 5616-5474 cal. BC) were taken from the upper layers of the bedrock forming the embankments and therefore do not represent the date of occupation for the site. The other very early date corresponds to an occupation period prior to the Metal age and is from a burial in TP29 from US15, 18 and 19 (WK-18763: 1744-1537 cal. BC). The late dates (WK-16800, WK-23275, WK-23272, WK-

23274, WK-23276 and OxA-26627) have all been rejected as they are deemed to represent contaminated samples (Bellina and Bernard in preparation).

KSK is among the best-dated Late Prehistoric sites in Southeast Asia and with the site of Ban Non Wat in northeast Thailand (Higham and Higham 2009) helps anchor the Late Prehistoric chronology of Southeast Asia, mainly the Bronze and Iron Age. Table 6.2 is a compilation of the uncalibrated and calibrated dates obtained from all samples sent, the context where they came from and the source material used for samples.

Lab no.	TP	US	source	C14 uncal	Calibrated 1-sigma (68.2%)	Calibrated 2-sigma (95.4%)	context
WK 16798	1	18		2182±49 BP	358-176 BC	384-108 BC	Prod glass+stone
WK 16800	7	4		437±65 BP	1414-1617 AD	1333-1639 AD	Prod glass+stone
WK 16801	7	8		AMS: 2258±33 BP	389-234 BC	396-207 BC	Prod glass+stone
WK 16802	7	10		2236±45 BP	382-210 BC	392-201 BC	Prod glass+stone
WK 16803	9	3		2188±47 BP	359-194 BC	386-113 BC	occupation before Wall 1
WK 16804	9	5		2316±45 BP	412-235 BC	515-209 BC	occupation before Wall 1
WK 16805	15	4		AMS: 2217±33 BP	361-209 BC	382-202 BC	occupation before Wall 1
WK 18762	29	5,6,7		1507±47 BP	443-616 AD	433 - 640 AD	Prod glass (end)+stone
WK 18763	29	15,18,19		AMS: 3367±30 BP	1727-1621 BC	1744-1537 BC	occupation, prior prod glass
WK 18764	35	3		AMS: 2227±32 BP	371-210 BC	386-203 BC	occupation Hill 3 + Prod. Stone
WK 18766	35	17		8412±48 BP	7545-7384 BC	7577- 7356 BC	burning prior occupation top Hill 3
WK 18767	40	7		6568±42 BP	5551-5482 BC	5616-5474 BC	within Wall 8
WK 18768	41	13		AMS: 2234±31 BP	379-211 BC	389-204 BC	Prod glass (beginning)+stone
WK 18769	43	5		AMS: 2223±31 BP	365-209 BC	383-203 BC	occupation Hill 3 after Wall 15 before Wall 8 + Iron working
OxA20824	52	4	sherd	C14	47 BC - 20 AD	96 BC - 59 AD	Hill 4
WK 21175	57	11	bones	AMS: 2152±39 BP	352-114 BC	359-57 BC	cremation pot in Valley 3
WK 21176	66	13		2203±58 BP	361-202 BC	394-111 BC	early occupation, N edge Valley 3
WK 21177	69	24		AMS: 2295±32 BP	401-262 BC	406-211 BC	early occupation, Hill 3 - N slope
WK 21178	77	2		AMS: 2184±35 BP	356-193 BC	376-165 BC	late occupation, Hill 3 W Plateau + metallurgical activities
WK 23275	102	11		AMS: 157.5±0.5 BP	1744-1936 AD	1677-1940 AD	structure and repair of dam
WK 23272	111	14	charcoal	AMS: 136±35 BP	1680-1939 AD	1669-1945 AD	
WK 23274	116	4		276±37 BP	1522-1664 AD	1490-1950 AD	platform
WK 23273	116	9		AMS: 2222±34 BP	365-209 BC	383-203 BC	occupation Hill 1
OxA 19996	117	4	sherd	2206±25 BP	358-205 BC	367-200 BC	occupation Hill 1
OxA 19997	117	4		2257±26 BP	388-234 BC	395-209 BC	occupation Hill 1
OxA 19998	118	5		2189±27 BP	354-200 BC	363-178 BC	occupation Hill 3 East, habitation, 4th level of occupation
WK 25484	125	9	charcoal	AMS:1610±30 BP	410-532 AD	393-539 AD	Valley 1 - post-occupation period
WK 25483	125	11	charcoal	AMS: 2112±30 BP	191-93 BC	339-47 BC	Valley 1, KSK occupation period
WK 2582	125	13	wood	AMS: 2280±33 BP	397-236 BC	402-209 BC	Valley 1, pre-occupation
WK 23277	S1	9	charcoal	AMS: 2230±35 BP	376-210 BC	388-203 BC	occupation Hill 1
WK 23276	S1	14		AMS: 167.1±0.5 BP	1678-1776 AD	1669-1944 AD	
OxA-26626	128	11	*Oryza sativa*	AMS: 2109±26 BP	176-92 BC	199-52 BC	cultural layer
OxA-26627	130	5	*Piper longum*	AMS: 1.20185±0.00316 BP	1898-1902 AD	1896-1904 AD	3rd cultural layer

Table 6.2: Conventional and AMS radiocarbon dates from KSK.

The AMS radiocarbon dating of prehistoric seeds was intended to obtain direct dating of crop remains in order to establish the antiquity of the earliest occurrence of certain crops in peninsular Thailand. The two AMS dates derived from the archaeobotanical samples at KSK are from a grain of rice and a fragment of long pepper infructescence.

The AMS result of the rice grain (TP128 US11) is199-52 cal. BC which falls within the established chronological time frame of KSK. This AMS date is currently the earliest date for rice in the south of Thailand although this does not mean that rice was not present earlier. The test pit and stratigraphic layer where the rice grain came from is a secure context with no modern inclusions or fungal sclerotia present in the sample. US layers 12 to 7 from TP128 all correspond to a period of occupation and contained pottery sherds and glass beads.

The date of the long pepper fragment is problematic as the date obtained is 1896-1904 cal. AD. However, this date is rejected on the grounds that it is probably contaminated. Factors that affect contamination include bioturbation and looting. Archaeology in the Southern Peninsula of Thailand is mainly limited by the weather (the period suitable for excavation is two to three months per year during the dry season) and the high incidence of looting. KSK has been heavily affected by looting which has left the site with pitted and uneven surfaces, and it is therefore possible that ancient stratigraphies have been disturbed. In addition the tropical climate promotes vigorous plant growth increasing the potential for bioturbation to move carbonized seeds through the sediment. Great care has been taken in the analysis of archaeobotanical samples to minimize the likelihood of interpretation based on intrusive material. The level of contamination was determined by quantifying the proportion of uncharred modern contaminants, fungal sclerotia and roots found in the samples. The interpretation of modern inclusions is discussed in the next section. Although the date for long pepper is modern, the context from which the sample came (TP130 US5) is secure and the stratigraphic level is relatively deep in the test pit. This test pit has eight stratigraphic layers andUS5 lies below another layer also considered secure (Bellina rapport 2009). TP130 US5 has very low modern contamination (0.17% modern seeds and n=2 fungal sclerotia). Furthermore, it is a rich context comprising other economic crops, specifically rice and parenchymatous fragments, as well as pottery sherds. On this basis, the AMS date for the long pepper is rejected though it is considered of utmost importance to date other samples of long pepper in the future to ascertain its prehistoric date.

6.3 CONTEXTS

Only the test pits from which archaeobotanical samples were taken and subsequently analysed are described below. The contexts for each of the test pits have been collated using mainly the interpretations by Bellina and Bernard (in preparation) but also site reports and individual specialist reports. Appendix 6.2 provides a summary for each test pit.

TP29 is located at the base of Hill2 and corresponds to a glass working and hard stone production area. The associated artefacts include glass bracelet fragments and knapped and heated stone material. Rice is the only cultivar present in all three samples studied.

TP35 lies in Hill 3 and corresponds to an area of habitation showing terraces and successive living floors some of which show signs of repair or re-terracing. Excavations also revealed fireplaces and postholes. This TP is possibly of a house in the Indian quarter as suggested by the associated artefacts found, consisting of an unfinished agate bead and ceramics. An AMS date of 386-203 cal. BC (WK18764) came from US3. Archaeobotanical remains from this TP include rice remains (one grain and four spikelet bases).

TP43 is situated between two ramparts in Hill 3 and provides evidence for iron-smithing activities, specifically US5 which has an AMS date of 383-203 cal. BC (WK18769). There is some evidence of rice.

TP52, TP54 and TP62 are TPs located in Hill 4 that lie side by side and were opened in order to estimate the dimensions of habitation platforms. All three TPs had three levels of platforms with associated artefacts that were very eroded. The platforms were estimated to measure *ca.* 3.2m^2. The C14 date from TP52 US4 corresponded to 96 BC-59 cal. AD (OxA20824). The archaeobotanical remains include the cash crop long pepper in TP52 and TP54, and cf. *Citrus* rind in TP62.

TP57 located on Valley 3 at the foot of Hill 4 contained a funerary urn with the cremated remains of two children. The bones yielded an AMS date of 359-57 cal. BC (WK21175) corresponding to US11. It lies in close proximity to human occupation and is interpreted as an area frequented by people. This test pit is rich in archaeobotanical remains, specifically US12 and US16 which have evidence of rice and mungbeans although US12 also contained foxtail millet. This TP is in the area where Bellina believes foreign populations settled and this may be confirmed by the presence of mungbean and foxtail millet because these cultivars are of foreign origin.

TP66 has been interpreted as a communal structure showing a succession of reinforced floors built with compacted gravel in order to stabilise the floor. This TP is located in Valley 3 near the base of Hill 4. The associated artefacts include glass fragments, beads and tubes. Sherds from knobbed ware classified under the *KSK-Fine Wares 1* group have also been found in this TP and are considered to belong to an Indian tradition (Bouvet 2011). Han ceramic sherds have also been identified. The C14 date shows an early occupation phase of 394-111 cal. BC (WK21176). This TP contained rice remains.

TP67 is located in Hill 4 and is interpreted to have had nearby occupation. Sherds of the *KSK-Fine Wares 1* group of rouletted wares and jars which are comparable to the Arikamedu type 6 jars, were found in this TP. The archaeobotanical evidence included rice, long pepper and *Citrus* sp. rind.

TP69 is a habitation area in the west of Hill 3 with a succession of terraces where the first terrace is cut into the bedrock and repaired over time. There are also postholes present and a pit probably corresponding to a burial or a funerary deposit. Sherds and a glass bead were found. Of particular interest is the presence of sherds classified as *KSK-Black Polished Wares* which are very similar in terms of morpho-stylistic criteria to *Northern Black Polished Ware (NBP)* from the Indian subcontinent. The *KSK-Black Polished Wares* are considered to belong to an Indian tradition by Bouvet (2011). US24 yielded an AMS date of 406-211 cal. BC (WK21177). Several mungbean fragments and a rice fragment were found in this test pit. The archaeobotanical remains from this TP accord with Bellina's view that the foreign populations, including South Asian presence, are found in Hill 3. It is argued in section 6.5.3.4 that the mungbean was brought in by South Asians.

TP77 is located in Hill 3 and yielded a large amount of slag and moulds used in metallurgic activities. Other associated artefacts include sherds belonging to the *KSK-Fine Wares 1* group from jars comparable typologically to Arikamedu type 6 jars (Bouvet 2011). The late occupation level US2 also corresponds to metallurgical activity and yielded a date of 376-165 cal. BC (WK21178). The archaeobotanical analysis shows a conspicuous lack of economic plants.

S1 is a section that was cleared on the bank of the Tha Tapao River in Hill 1. The profile of the section shows a series of habitation floors, a drainage system, glass working (raw glass and glass tubes) and siliceous stone production (unperforated etched bead fragment, garnet, agate and carnelian beads). The AMS date from US9 corresponds to 388-203 cal. BC (WK23277). There is evidence for rice.

TP105 located in Hill3 is a possible habitation structure with postholes dug into the bedrock. The associated artefacts are glass beads and sherds including Han pottery. There is evidence for pigeon pea and long pepper.

TP110 corresponds to habitation with terraces and is located in Hill 3. The associated artefacts include beads and sherds including Han pottery. There is evidence for long pepper.

TP116 lies at the border of Valley 1 situated in a low-lying area showing the limits of the waterline. It is a habitation area built with successive platforms and postholes. At least two platform layers are present with associated artefacts including sherds and carnelian. The platforms are built on a previous occupation layer that was flooded. The limit of the flooding is foundinUS9 and dates to 383-203 cal. BC (WK23273). The archaeobotanical assemblage contains rice remains.

TP117 located at the base of Hill 1 provides some evidence of glass working in the form of glass fragments and glass waste. The presence of platforms and postholes also provides evidence for habitation. There is also what appears to be a cremation or funerary deposit in the form of an empty jar that was placed in a hole cut into the bedrock. US4 yielded a date of 395-209 cal. BC (OxA19997). US8 corresponds to the posthole infill and is very rich in archaeobotanical remains with evidence for rice, long pepper, ricebean and rind.

TP118 located in Hill 3 is a habitation area with a copper workshop. Several platforms were uncovered as well as postholes. US5 yielded a date of 363-178 cal. BC (OxA-

19998). The archaeobotanical assemblage from one sample (US13 terrace) yielded very poor results.

TP125 located in Valley 1 is similar to TP128 as it has evidence of a mangrove habitat (US13 and US14) followed by human occupation (US10 to US12). Only one archaeobotanical sample was examined from this TP belonging to the post-occupational phase of the site (US7) and mainly yielded wetland weeds from the Cyperaceae and Najadaceae families. There was no evidence of economic crops. The three major phases of the TP were dated; the pre-occupation phase in US13 yielding an AMS date of 402-209 cal. BC (WK-2582), the KSK occupation phase in US11 dating to 339-47 cal. BC (WK-25483) and a post-occupation phase in US9 dating to 393-539 cal. AD (WK-25484).

TP128 situated on the edge of Valley 1 was formed by fluvial deposition from the Tha Tapao River. The geomorphological study suggests there may have been some human activity that influenced the formation of the soils in the test pit. Archaeobotany provides strong evidence of human activity as rice predominates the assemblage. US11 has the highest frequency of rice and also has one horsegram and a mungbean fragment. The only dated rice grain from KSK is from US11 of this TP and yielded an AMS date of 199-52 cal. BC (OxA-26626). Prior to the occupation of KSK, this TP suggests that Valley 1 had a mangrove habitat (US15 to US13), followed by an occupation period (US12 to US7) which yielded sherds, glass and a gold fragment.

TP130 is located in Hill 2. It has been interpreted as a location near human occupation as it has cultural deposits such as sherds. The geomorphology shows that a layer including US4 supported vegetation (Allen in preparation). The archaeobotanical assemblage is very rich and is comprised predominantly of rice with high frequencies in US4 to US8. US8 is considered to be the first cultural deposit. Also present in the TP is foxtail millet and high frequencies of parenchyma, some long pepper, the only evidence of cotton and a few more pulses, possibly weedy. Unfortunately, the only date for this TP came from long pepper in US5, which yielded a modern date which has been rejected as discussed in section 6.2.

TP132 located in a flat zone of Hill 2 near the Tha Tapao River has been interpreted as a succession of habitation structures and a glass workshop. There are floors built with soil and gravel extracted from the bedrock, rebuilt floors and a fireplace showing habitation. The associated artefacts include finished carnelian beads, glass beads and sherds. The glass workshop is represented by the amount of glass fragments, flakes and raw material found in US9 to US17. The associated artefacts corresponding to the different layers indicate an early use of the area as a glass workshop (i.e. raw glass and flakes) followed by habitation structures from US3 to US8 (i.e. finished ornaments). US17b has been identified as a potential rubbish dump because of the large assemblage of sherds and melted glass debris. Rice is present starting from US7 to the lowest layer US17b though there is an increase in the frequency of rice remains at the deepest layer (Figure 6.8). This TP also yielded horsegram (Fabaceae family) in US3and a few more Fabaceae seeds.

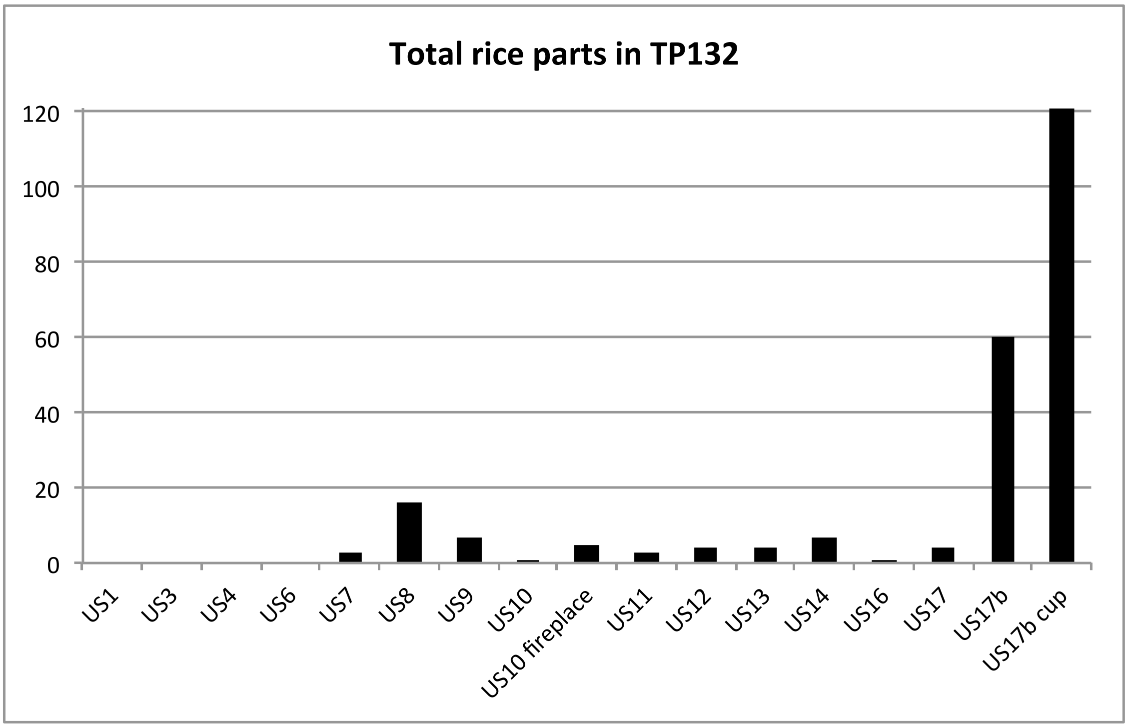


Figure 6.8: Bar graph showing the frequency of rice in TP132 and the greater frequency in US17b.

TP135 is located in the lowlands close to the Tha Tapao River and west of Hill 4. Geomorphology suggests that the soils were formed through fluvial deposition and overland flooding. The archaeobotanical assemblage is interesting in that US8 has evidence of rice and high frequencies of Asteraceae weeds normally associated with dryland rice cultivation.

TP136 is located *ca*. 300m from the site in a gently sloping plateau which is presently a rubber plantation. The geomorphological study indicated that this area potentially was cultivated though the archaeobotanical record in charred remains is poor. If this TP represents part of the agricultural hinterland that supported the KSK population, phytoliths would perhaps be a better methodology to use since macroremains would not necessarily preserve unless the fields were burned after harvest and possibly yielding some charred remains.

6.4 DATASETS

To date, a hundred and one samples have been sorted and identified from Khao Sam Kaeo. However, after applying the quality criteria as discussed in Chapter 4only eighty-eight samples have been used in the archaeobotanical study. The number of specimens (NSP) totalled 11,497 with a total number of identified specimens (NISP) of 10,622 (Table 6.3). The NISP excludes modern plant parts and fungal sclerotia. There were four sterile test pits.

	Total
NSP	11,497
NISP	10,622
No. of samples	88
Plant parts per litre MEAN	8.74
Plant parts per litre MIN	0
Plant parts per litre MAX	184.77
No. of taxa* MODE	3
No. of taxa* MIN	0
No. of taxa* MAX	20
* excludes unidentified plant parts, fungi sclerotia, parenchyma & modern seeds	

Table 6.3: Summary statistics of the botanical dataset in KSK. The complete list is found in Appendix 6.3.

The tables that follow in this chapter use total frequencies or presence/absence. Ratios are frequently used in discussions to compare samples with different sizes suggesting variations are a result of preservation or deposition (Weber 1991). The ubiquity index based on presence/absence analysis is also given in most discussions where it is defined as *'the percentage of samples from a given assemblage which contains a specific taxon'* (*ibid.*) The term 'ubiquity' is somehow a misguided term since ubiquity is defined as omnipresence or found everywhere. Perhaps 'presence index' would be a more accurate term, or 'presence-analysis,' the original term coined by Hubbard (1976) where presence-values ranged from 0% for taxa absent from all samples to 100% when a taxon was ubiquitous. However, the term ubiquity is used regularly in palaeoethnobotany and is therefore also used in the present study for consistency. The term presence-analysis in this study is used to denote the total number of occurrences and ubiquity is the percentage of these occurrences.

Family	no. of samples	ubiquity (n=88)	ID
Amaranthaceae	3	3.41%	104
Asteraceae	60	68.18%	7a, 7b, 14, 21, 61
Brassicaceae	1	1.14%	31
Caryophyllaceae	1	1.14%	118
Cleomaceae	2	2.27%	37
Commelinaceae	2	2.27%	63, 99
Convolvulaceae	3	3.41%	32, 52
Cyperaceae	5	5.68%	15, 33, 41, 115, 117
Euphorbiaceae	1	1.14%	97
Fabaceae	11	12.50%	6a, 6b, 30, 48, 49, 50, 56, 58, 59, 60, 71
Hydrocharitaceae	1	1.14%	93, 94
Malvaceae	2	2.27%	43, 47
Myrtaceae	8	9.09%	8, 8c
Najadaceae	1	1.14%	68
Oxalidaceae	1	1.14%	28
Phyllanthaceae	1	1.14%	62
Piperaceae	16	18.18%	13a, 13b, 66
Poaceae	45	51.14%	1a, 1b, 2a, 2b, 2c, 2d, 3a, 3b, 4, 5, 34, 42, 46, 57, 65, 67, 70a, 70b, 78, 105, 127
Polygonaceae	10	11.36%	10, 74, 91
Pontederiaceae	1	1.14%	72
Portulacaceae	2	2.27%	92
Ranunculaceae	1	1.14%	106
Rosaceae	3	3.41%	54, 90, 100
Rutaceae	10	11.36%	35, 40
Solanaceae	2	2.27%	55

Table 6.4: Families to which identified samples belong to in KSK, the number of samples containing them, the ubiquity index and the identification nos. of samples belonging to said Family group.

The plant parts have been sorted and grouped into 112 identifications: Family, Genus and Species, or types when identifications have not been possible. A total of twenty-two species, thirty-four genera and twenty-five family groups were identified (Table 6.4 and 6.5). When a plant part or an identical group of plant parts are sorted and described but not identified to Family level, these are designated as 'types' of which there are twenty-six. Likewise, if a plant part is identified to Family or Genus and several distinct types are recognised, the term type followed by a letter is added (e.g. *Rubus* sp. type A). Identification codes 0a and 0b represent a large amount of indeterminate or unidentified plant parts (n=3,089 or 26.87% of the total assemblage in seventy-four samples). The difference between unidentified and the 'types' mentioned above is that the 'types' have enough diagnostic features to allow an identification even if the author was unable to provide one. This is a task for a future endeavour.

Family	Genus	Species	ID
Amaranthaceae	*Alternanthera*	*Alternanthera* cf. *sessilis*	104
Asteraceae	*Acmella*	*Acmella paniculata*	7
	Calendula	*Calendula arvensis*	21
	cf. *Eupatorium*		61
	Mikania	*Mikania* cf. *cordata*	14
Brassicaceae	*Brassica*		31
Caryophyllaceae			118
Cleomaceae	*Cleome*	*Cleome viscosa*	37
Commelinaceae			82
	cf. *Cyanotis*		63
Convolvulaceae	*Ipomoea*		32
			52
Cyperaceae	*Cyperus*	*Cyperus* cf. *pulcherrimus*	41
		Cyperus cf. *pygmaeus*	15
	Rhynchospora	*Rhynchospora corymbosa*	33
	Scirpus		115
			117
Euphorbiaceae			97
Fabaceae	*Cajanus*		58
			59
	Lablab		49
	Macrotyloma	*Macrotyloma uniflorum*	30
	Vigna	*Vigna* cf. *umbellata*	56
		Vigna radiata	6a
			48
			50
	type A		60
	type B		71
Hydrocharitaceae	*Blyxa*	*Blyxa aubertii*	93
	Ottelia	*Ottelia alismoides*	94
Malvaceae	*Gossypium*		47
			43
Myrtaceae			8
Najadaceae	*Najas*	*Najas graminea*	68
Oxalidaceae	*Oxalis*		28
Phyllanthaceae	*Phyllanthus*	*Phyllanthus urinaria*	62
Piperaceae	*Piper*	*Piper* cf. *longum*	13
			66
Poaceae	*Brachiaria*	*Brachiaria mutica*	105
	Eleusine	*Eleusine indica*	34
			65
	Oryza	*Oryza sativa*	1, 2a
			2b
			2c
			2d
			3
			78
	Panicum		42
			67
			127
	Setaria	*Setaria italica*	5
			4
	type A		46
	type B		57
	type C		70a
	type D		70b
Polygonaceae	*Rumex*		10
	type A		91
	type B		74
Pontederiaceae	*Monochoria*	*Monochoria hastata*	72
Portulacaceae	*Portulaca*	*Portulaca* cf. *quadrifida*	92
Ranunculaceae			106
Rosaceae	*Rubus*	type A	54
		type B	90
		type C	100
Rutaceae	*Citrus*		35
			40
Solanaceae	*Solanum*		55

Table 6.5: The Families, Genus and Species groups identified in KSK.

Table 6.4 shows that the Family groups most represented in the samples are Asteraceae, Poaceae, Piperaceae, Fabaceae and Rutaceae. As will be discussed in the section dedicated to weeds (6.5.6), the high representation of Asteraceae is correlated to the high representation of Poaceae, specifically rice. The assemblages represented by the other three top Family groups namely Piperaceae, Fabaceae and Rutaceae are mostly coming from cultivars. This means that the archaeobotanical assemblage at KSK originated from human activity and is a representation of human subsistence in prehistoric times.

6.5 RESULTS and DISCUSSION: An ecological and agricultural interpretation

6.5.1 The Resource Base

TAXA	Common name	Domestication centre of origin	Date of domestication
CEREALS			
Oryza sativa japonica	rice	China (Yangtze Basin)	5000-4000 BC
Oryza sativa indica	rice	South Asia	2000 BC
Setaria italica	foxtail millet	Northern China	6000 BC
PULSES			
Cajanus sp. *(if Cajanus Cajan)*	pigeonpea red gram	South Asia: Eastern India / Orissa	by 1400 BC
cf. Lablab (if *Lablab purpureus)*	hyacinth bean	East Africa	transferred to India before 1600 BC
Macrotyloma uniflorum	horsegram	South Asia: Indian peninsula and/or Western India	2600-2000 BC
Vigna radiata	mung bean green gram golden gram	South Asia: Indian peninsula and/or Northwestern India	2600-2000 BC
Vigna umbellata	rice bean	Southeast Asia	unknown
CASH CROPS			
Citrus maxima	pomelo	Southeast Asia	unknown
Gossypium arboreum (on geographical / dating grounds most likely *arboreum)*	tree cotton	South Asia: Pakistan (if *G. arboreum; G. herbaceum* is of African origin)	6000-5000 BC
Piper longum	long pepper	Greater Assam region	unknown

Table 6.6: Seed crops identified at KSK, the regions of origin and dates of domestication (Sources: Blench 2008; Dalby 2002; Fuller 2011a, 2011b, 2008; Fuller and Harvey 2006; Liu et al. 2009; Niyomdham 1991).

The macroremains identified so far have yielded five domesticated crops and several wild/weedy species (Table 6.6). There are also three cash crops, two broadly identified to genus level and the other, to species level. I use the term 'cash crops' following the unconventional definition by Fuller and Stevens (2009) [after Sherratt 1999] of *'cultivars that do not directly contribute towards subsistence, either because they are used for another purpose like craft production or which when produced in quantity they are traded.'* Approximately twenty-eight types of weed are represented in the assemblage though exact identifications are still forthcoming for most. Appendix 6.4 is the list of taxa found at KSK, their frequencies, their presence-values and their ubiquity. Only samples from data qualified with grades 1 to 3 are presented in Appendix 6.4 and interpreted in this chapter.

6.5.2 Modern contaminants and context security

In his article 'Formation processes of the archaeobotanical record,' Miksicek (1987) provides a summary of the difficulties encountered when doing archaeobotanical research. Site formation processes affect archaeobotanical interpretations and it is therefore good practice to understand how the plant remains ended up in one's sample. In past studies of plant remains, the rule of thumb was to only consider carbonised seeds as ancient. Miksicek discusses faunal and floral bioturbation as nonhuman agents in the introduction of seeds into sites and samples. The agents of faunalturbation are normally burrowing animals such as earthworms, ants and rodents. Floralturbation is normally caused by roots pushing material downwards and decayed roots leaving cavities that are filled up at a later period. It is important to identify modern seeds so that these do not form part of discussions of ancient plant use, but these modern seeds can be useful in interpreting context security and should be sorted and counted like all the other plant remains.

In KSK and in PKT, several steps were taken to identify the context security for each sample (or layer). The first step takes place during fieldwork. When doing bucket flotation, all the material that floats to the surface, including roots, is collected. These samples are bagged without removing any of the modern material. Once the samples are in the laboratory, their weight and volume is noted and whilst doing so, the proportion of roots in the samples is written down. When sorting the samples, all seeds including modern ones are counted and stored. Likewise, the presence of fungal sclerotia is noted as these are considered contaminants. The context security is then determined by looking at the proportion of modern seeds in each sample as a percentage of all seeds in that sample. This determines the contamination level. If roots and fungal sclerotia are also present, the level of contamination is deemed to be high and one has to understand the reasons why this may be the case. In order to define the context security for the macroremains samples, it is essential to review the proportion of modern inclusions in each sample set. As discussed in Chapter 4, bioturbation and looting activities limit this study. It is anticipated that stratigraphic layers closer to the surface (the modern period) would contain a higher number of modern seeds. Likewise, stratigraphic layers where roots were found in abundance; where postholes act as deposit collectors from upper layers and highly disturbed areas would be expected to yield higher quantities of modern seeds. Another explanation for modern material found in the samples is that windblown seeds make their way into the soil during excavation or flotation.

Percentages of modern seeds to total counted plant parts is used to determine high levels of inclusions (>15%). At KSK, fifty-six samples contained modern plant parts (ubiquity index of 84.09%). The total number of modern plant parts is 680, this accounts for 5.92% of the NSP. Results from KSK show that the majority of samples containing modern inclusions greater than 15% come from the upper layers or have high levels of bioturbation as evidenced by the proportion of roots found in the sample. Table 6.7 summarises modern inclusion quantities at KSK.

Fungal sclerotia (Figure 6.9) also occur in twenty samples. In this study their presence has a low degree of correlation with bioturbation (Pearson's Correlation Coefficient: 0.2362). Furthermore, fungal sclerotia are only found in samples also containing modern seeds except for samples from TP77 (US3, US4, US5 and US6), a test pit which yielded hardly any archaeological plant remains. Fungal sclerotia, the dormant hard-bodied stage of fungus, are found in well-aerated and moist soil. Miksicek (1987) says that the presence of fungal sclerotia suggests open, well-drained areas with fluctuating moisture levels and Paz (2004) says that fungal sclerotia are known to occur in contexts full of vegetation debris and could therefore suggest changing vegetation cover in a stratigraphic sequence. Although both interpretations are correct, neither interpretation seems to be applicable in KSK where the presence of fungal sclerotia appears to be an index of bioturbation.

	Presence of fungal sclerotia	% of modern seeds / sample	Presence of roots	Interpretation
TP43 US4		0.79%	x	
TP52 Sample 1		15.15%	xxx	upper layer, high bioturbation
TP52 Sample 2		23.08%	xxx	upper layer, high bioturbation, this layer is not deep & lies close to the surface
TP52 Sample 3	Y	40.00%	xxx	high bioturbation, small sample size (n=5)
TP54 Sample 1		30.00%	xx	upper layer
TP54 Sample 2		62.50%	xx	upper layer, this layer is not deep & lies close to the surface
TP57 US6	Y	1.95%	x	
TP57 US12		15.09%	x	
TP62 Sample 1		45.36%	xxx	upper layer, high bioturbation
TP62 Sample 2		11.11%	xx	
TP66 US10		0.74%	xxx	
TP67 US2		40.43%	x	upper layer
TP67 US4		2.04%	x	
TP77 US2		7.41%	xxx	
S1 L.5	Y	0.44%	x	
S1 L.9	Y	28.57%	xxx	high bioturbation, small sample size (n=7)
TP105 US2	Y	27.45%	xx	upper layer
TP105 US3	Y	11.38%	xx	
TP105 US10		66.67%	xx	posthole infill, bioturbation, small sample size (n=3)
TP110 US2	Y	11.63%	xxx	
TP110 US3	Y	2.05%	xxx	
TP110 US4	Y	2.78%	xx	
TP116 US8		11.39%	xxx	
TP116 US10		4.39%	xxx	
TP117 US4	Y	25.89%	xxx	high bioturbation
TP117 US5		27.08%	xxx	high bioturbation
TP117 US7		71.43%	xxx	high bioturbation
TP117 US8		50.33%	xxx	high bioturbation
TP118 US13 terrace	Y	2.94%	xx	
TP119 US5	Y	39.05%	xxx	high bioturbation
TP125 US7		3.90%	x	
TP128 US7		2.51%	xxx	
TP128 US10		66.67%	xxx	high bioturbation, small sample size (n=3)
TP128 US12		2.50%	x	
TP130 US1		78.18%	xx	upper layer
TP130 US2	Y	13.33%	xx	
TP130 US3		3.80%	xx	
TP130 US4		1.00%	x	
TP130 US5	Y	0.17%	x	
TP130 US6		0.23%	x	
TP130 US7		0.23%	x	
TP130 US8		0.63%	x	
TP132 US1	Y	47.92%	xxx	upper layer, high bioturbation
TP132 US6		11.54%	xxx	
TP132 US7		1.09%	xx	
TP132 US8		0.61%	xxx	
TP132 US9		0.36%	xxx	
TP132 US13		3.70%	x	
TP132 US14		3.45%	x	
TP132 US16		2.86%	x	
TP132 US17	Y	2.00%	x	
TP132 US17b		0.60%	x	
TP135 US6		6.78%	x	
TP135 US8		4.13%	-	
TP135 US11		4.65%	x	
TP136 US13		25.00%	xxx	high bioturbation, small sample size (n=4)
Legend:	-	none		
	x	a few roots, 25% or less		
	xx	many roots, >25-60% of sample is made up of roots		
	xxx	mostly roots, >60% of sample is made up of roots		

Table 6.7: Representation of all modern seeds and fungal sclerotia found at KSK.

Figure 6.9: SEM of sclerotium of a fungus in TP110 US3 (Image by author).

6.5.3 The Economic Crops: cereals and pulses

The economic crops identified at KSK are the cereals *Oryza sativa* (rice), *Setaria italica* (foxtail millet), the pulses *Vigna radiata* (mungbean), *Macrotyloma uniflorum* (horsegram) and *Vigna* cf. *umbellata* (ricebean). These consist of whole seeds and seed fragments. In the case of *Oryza sativa*, spikelet bases dominate the assemblage. Whole seeds of the pulses cf. *Lablab* and *Cajanus* sp. and two fragments of cf. *Cajanus* were also identified. Table 6.8 shows the economic crops identified and a summary of the weeds that occur in the same context defined by their habitat. Samples where no cereals, pulses or weeds were found were omitted from the table. Rice is the most important cereal in present-day Thailand but it appears to also be the case in prehistoric times since it forms a significant part of the overall assemblage with a ubiquity index of 51%. Also, dryland weeds dominate the assemblage found in 68% of the samples at KSK.

	CEREALS		PULSES						WEEDS		
	Oryza	*Setaria italica*	*Cajanus* sp.	cf. *Cajanus*	cf. *Lablab*	*Macrotyloma uniflorum*	*Vigna radiata*	*Vigna* cf. *umbellata*	Dryland weeds	Wetland weeds	Dry & Wet weeds*
TP29 US10	x								x		
TP29 US12	x								x		
TP29 US13	x								x		
TP35 E. Profile	x								x		
TP43 US4	x								x		x
TP43 US5									x		
TP52 Sample 1											
TP52 Sample 2											
TP52 Sample 3											
TP54 Sample 1									x		
TP54 Sample 2											
TP57 US6	x								x		x
TP57 US12	x	x					x		x		
TP57 US16	x						x		x		
TP57 US31									x		
TP62 Sample 1											
TP62 Sample 2											
TP62 Sample 3											
TP66 US10	x								x		
TP66 US8									x	x	
TP67 US2									x		
TP67 US4	x								x		
TP69 US18											
TP69 US21							x				
TP69 US22	x						x				
TP77 US2									x		
TP77 US3											
TP77 US4											
TP77 US5											x
TP77 US6											
S1 L.4	x								x		
S1 L.5	x								x		x
S1 L.9									x		
TP105 US2									x		
TP105 US3			x	x					x		
TP105 US10											
TP110 US2									x	x	x
TP110 US3									x		x
TP110 US4									x		x
TP116 US8									x		
TP116 US9	x								x		
TP116 US10	x								x		x
TP117 US4	x								x		
TP117 US5	x								x		
TP117 US7									x		x
TP117 US8	x							x	x	x	x
TP118 US13 terrace											
TP119 US5	x								x		
TP125 US7										x	x
TP128 US7	x								x		
TP128 US10	x										
TP128 US11	x					x	x		x		
TP128 US12	x								x		
TP130 US1									x		x
TP130 US2											x
TP130 US3	x								x		
TP130 US4	x								x		
TP130 US5	x								x		
TP130 US6	x				x				x		x
TP130 US7	x	x							x		
TP130 US8	x								x		
TP132 US1									x		
TP132 US3						x					

	CEREALS		PULSES						WEEDS		
	Oryza	*Setaria italica*	*Cajanus* sp.	cf. *Cajanus*	cf. *Lablab*	*Macrotyloma uniflorum*	*Vigna radiata*	*Vigna* cf. *umbellata*	Dryland weeds	Wetland weeds	Dry & Wet weeds*
TP132 US4									x		
TP132 US6									x		
TP132 US7	x								x		x
TP132 US8	x								x		
TP132 US9	x								x		
TP132 US10	x								x		
TP132 US10 fireplace	x								x		
TP132 US11	x								x		
TP132 US12	x								x		
TP132 US13	x								x		
TP132 US14	x								x		
TP132 US16	x								x		
TP132 US17	x								x		
TP132 US17b	x								x		x
TP132 US17b cup	x										x
TP135 US6									x		
TP135 US8	x								x	x	x
TP135 US11									x		x
TP135 US15										x	
TP136 US7											
TP136 US8											
TP136 US13											
NISP	1599	2	1	2	1	2	18	1	4041	212	180
no. of samples	43	2	1	1	1	2	5	1	60	6	19
ubiquity (n=88)	49%	2%	1%	1%	1%	2%	6%	1%	68%	7%	22%

LEGEND:
* also includes weeds from unspecified ecologies
no. of samples - refers to no. of samples in the sampled population containing specified taxon
NISP - Number of Identified Specimens, NSP - not specified

Table 6.8: List of cereals and pulses and the weeds found in the same samples at KSK.

6.5.3.1 *Oryza sativa* (L.)

Common names: rice
Thai names: khao

Caryopses, spikelet bases, lemmas and husk of rice (ID nos. 1, 2, 3 and 78 respectively) were identified in forty-three samples from sixteen test pits, corresponding to a ubiquity rate of 49 % (Table 6.8). The breakdown of rice plant parts is found in Table 6.9.

	TOTAL	ubiquity
caryopsis	14	8
caryopsis fragment	314	23
spikelet base - domesticated	836	39
spikelet base - wild	115	22
spikelet base - immature	23	14
spikelet base - indeterminate	241	26
lemma	9	5
lemma apex - fractured	40	9
lemma apex - smooth	1	1
husk	6	2
Total rice plant parts	1599	

Table 6.9: Breakdown of rice plant parts at KSK.

Although the initial impression is that this high representation of rice in the samples means that rice was the most important economic crop or the staple at KSK, one must take into consideration that there are preservation biases which occur with charring events. It was to test such possible preservation biases that charring experiments were conducted. These are discussed in Chapters 5 and 8. The charring experiments demonstrate that husked rice has a higher preservation rate than some other crops such as the small millets, foxtail and broomcorn. Mungbean on the other hand, has a higher preservation rate than husked rice unless rice husk is included in the counts. Despite the experiments confirming a preservation bias in favour of rice against millets, it is the case that at KSK, the overwhelming presence of rice represents a real pattern in food use. This is demonstrated since rice is present as the sole cultivar in the majority of the samples that contain at least one economic crop (n=57) and if only cereals and pulses identified to species level (n=45; including *V. radiata, M. uniflorum, V. umbellata* and *S. italica*) are considered, 80% of the samples contain rice only.

If we were to use the ratios from the charring experiments found in Table 5.4 to extrapolate the amount of foxtail millet we might find charred in KSK given the amount of charred rice remains found and assuming that both were being used in equal proportions, we would expect to find between 23 to 302 millet seeds in the total assemblage (using the minimum *Oryza : Setaria* of 100:7 and the maximum 100:92 and a base from KSK of 328 rice grains). If the *Oryza : Setaria* ratio of 8:100 is used, then the amount of foxtail millet using the KSK base of 328 rice grains is 4,100 millet grains. Experiment 2 was intended to replicate Experiment 1 and yet there was great variability in the results. In Experiment 2A, no rice grains charred and this caused big discrepancies in the ratios. The actual amount of foxtail millet found in KSK is two seeds yielding a *Oryza : Setaria* ratio of 100:0.61. The foxtail millet grains were found in two distinct contexts with *Oryza : Setaria* ratios of 100:0.7 (TP130 US7) and 100:20 (TP57 US12). Rice also has a greater presence in KSK compared with mungbeans, even though experimental charring biases favour preservation of mungbeans. These ratios suggest that rice was definitely used more than any other crop including mungbeans. The charring experiment results are not conclusive and should not be taken as precise quantitative correction factors but rather illustrative of the tendencies of bias, i.e. favour mungbeans over rice and rice over *Setaria*.

The archaeobotanical remains at KSK show a real consumption pattern where the subsistence regime relied on the cereal rice. Also, the preserved rice parts at KSK show a real pattern of use, particularly crop processing from the later stages of the crop-processing sequence. Rice spikelet bases were the predominant waste product. The rice samples (n=43) were composed of 79.49% rice spikelet bases, lemmas and husk with the majority being rice spikelet bases (Figure 6.10).

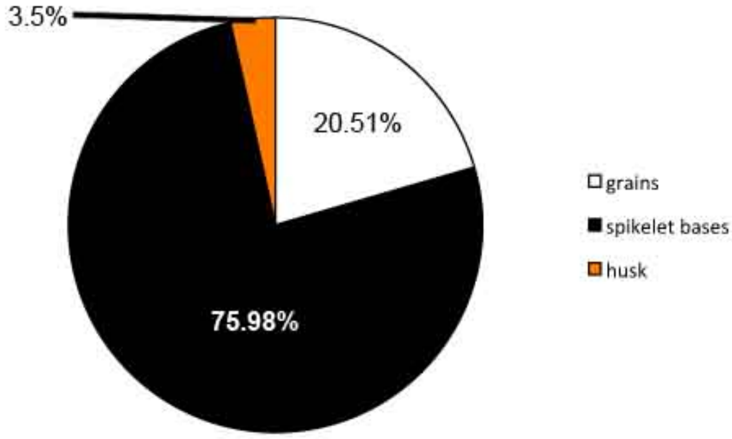


Figure 6.10: Rice plant parts found at KSK (n=1599).

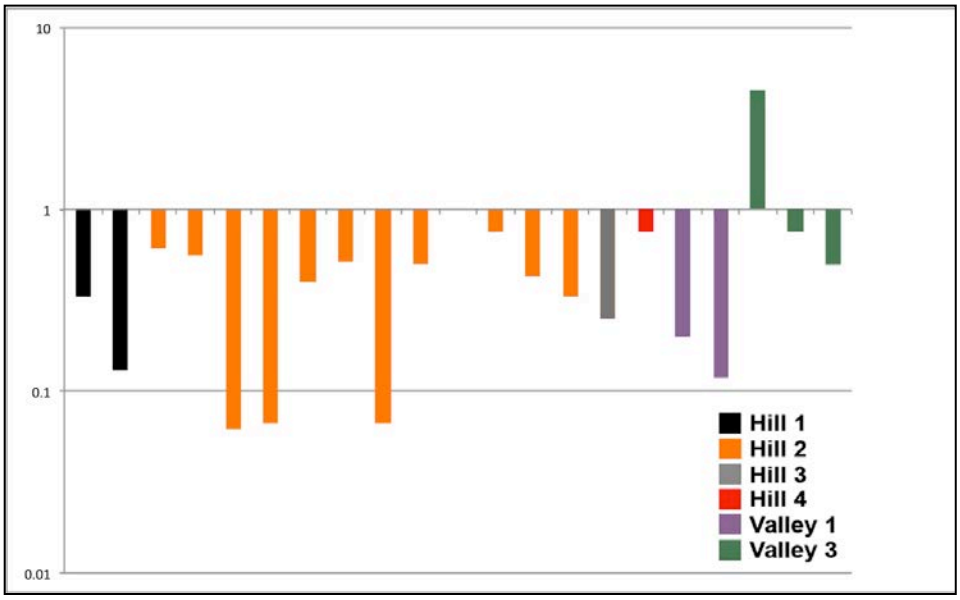


Figure 6.11: Graph of the ratios of *rice grain : rice chaff* converted to log scale. The grain rich samples are found above the main dividing line whilst the chaff rich samples fall below the line.

The archaeological evidence follows the trend suggested by the charring experiments discussed in Chapter 5. Those experiments show that rice spikelet bases preserved well. In seven out of the eight charring experiments, at least one spikelet base preserved indicating their robustness when charred (Table 5.7). On the other hand, the ratios from the charring experiments of *Oryza* caryopsis : *Oryza* sb (Table 5.4) shows that there is no preservation bias in favour of either two rice plant parts and one would expect both to be present in roughly similar amounts in the assemblage if the burning episodes involved whole rice spikelets. This is not the case in the total assemblage in KSK (*Oryza* caryopsis :*Oryza* sb is 27:100; Figure 6.10) or in each of the areas where rice was found. Figure 6.11 shows the ratio of rice grain and rice chaff found in each context but arranged by area (Hills 1 to 4, Valleys 1 and 3). All areas are chaff rich except for Valley 3, where at least one sample was grain rich. At KSK, there were more samples yielding rice spikelet bases than grains. This suggests that the rice parts found in KSK were charred after dehusking and not during cooking episodes. As a general rule, if there are rice grains present in a sample, rice spikelet bases are also present. However, the inverse does not hold true.

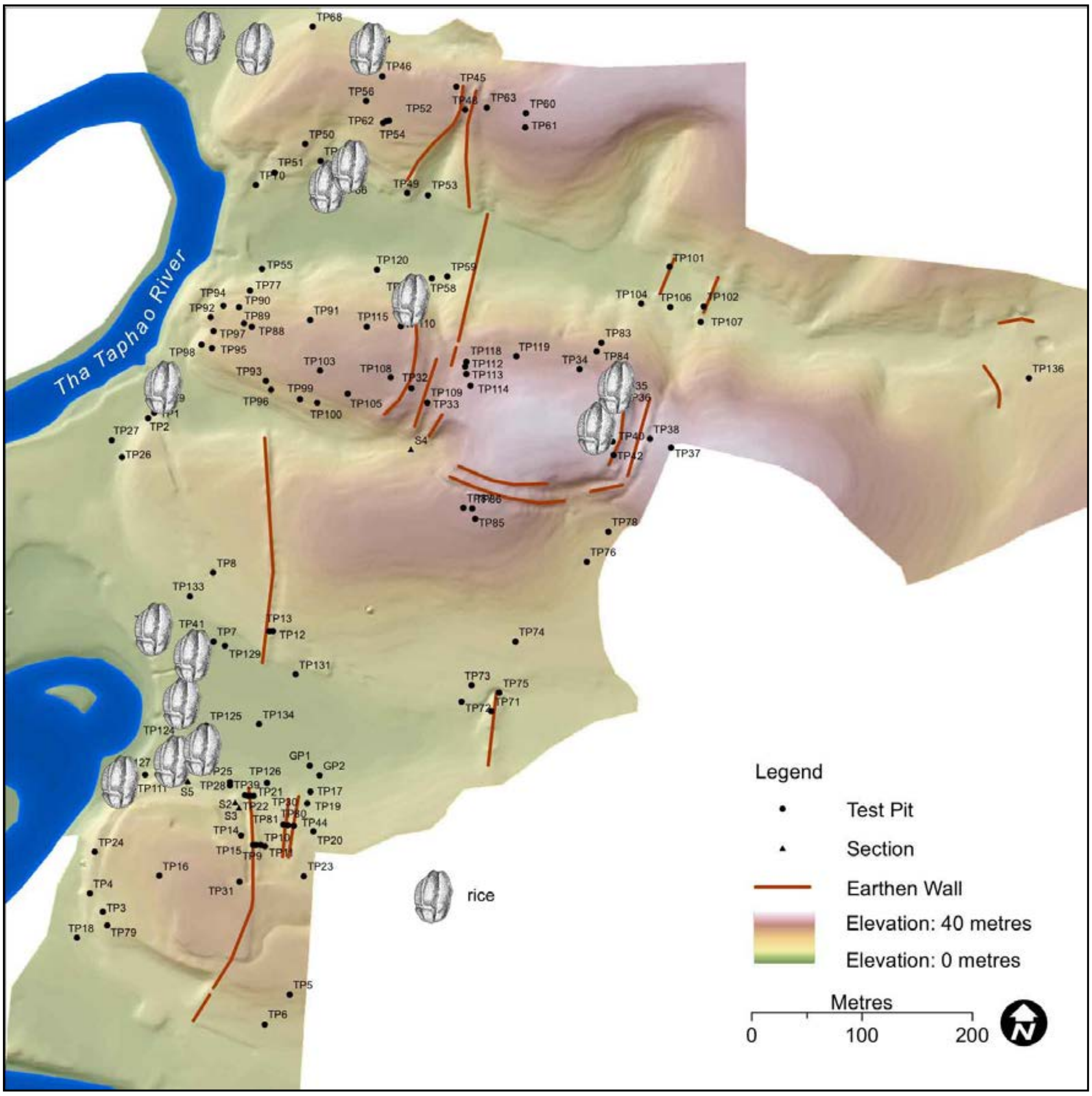


Figure 6.12: Map of KSK showing test pits that yielded rice remains.

The large number of spikelet bases found in all four hills of the site (Figure 6.11 and 6.12) indicates that rice was used all throughout the site regardless of what community was settled there. This means all populations, local and foreign, ate rice. The Indian population would have been familiar with rice since rice had already been domesticated in South Asia during the period of KSK. The evidence of spikelet bases also indicates that rice was being stored as spikelets. Rice stored as spikelets is more insect-resistant than hulled rice. It follows that rice was probably being dehusked as part of a daily routine on an ‘as needed’ basis. Furthermore, rice dehusked in households would have greater chances of preservation due to the proximity to a hearth which allows rice to become charred and therefore preserve (Thompson 1996; Harvey and Fuller 2005). But at KSK, the largest datasets of rice spikelet bases are found in close proximity to households or occupation areas (TP57, S1, TP128 and TP130) and not inside the house. Only one sample (TP132) is from within a house with a fireplace suggesting dehusking activities took place outside the household. Thompson (1996) notes in her ethnographic study that in the winnowing stage of rice processing, some of the waste fraction including husk and unfilled spikelets are burnt. These are used for kindling and fuel but also for pottery temper.

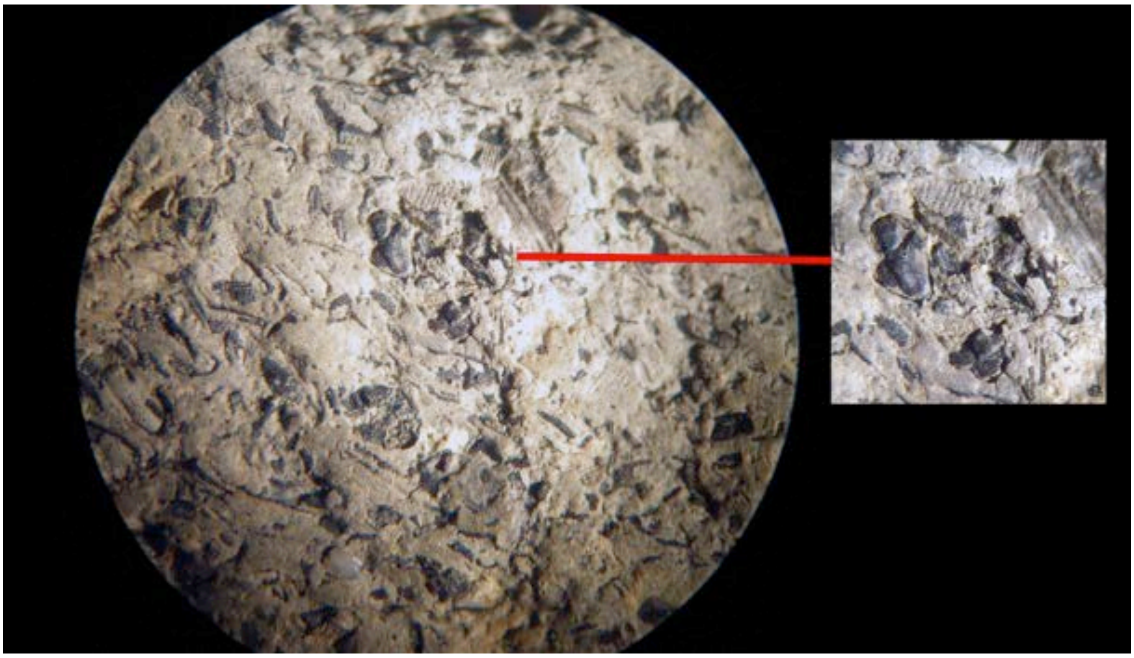


Figure 6.13: Image of a sherd from TP69US4 classified under group III by Bouvet showing rice husk and spikelet bases mixed in the temper (Image by author).

Use of rice at KSK is also seen in pottery where it is present as temper (Figure 6.13). But with no evidence of wasters or kilns, the existence of a pottery industry in KSK cannot be established. But lack of evidence does not necessarily mean that there was no local pottery industry. If however, there was a local pottery tradition at KSK and potters were using rice husk to temper clays as seen in Figure 6.13, then this means that rice waste products would have been widely available to the potters. This would provide further evidence of KSK as a producer site and not just a consumer site.

It should be noted that during the dehusking stage, rice grains and fragments are also present in the waste product (see Chapter 8). This could explain the existence in most samples of rice grains together with the spikelet bases. It should therefore be expected in archaeological assemblages to have a mixture of rice waste product (i.e. husk and spikelet bases) and grain, particularly fragmented grain as this would be a result of pounding and winnowing of lighter fraction. At KSK this holds true as the proportion of rice grain fragments is 95.7% of total rice grains. Compared to the charring experiments where whole rice spikelets were used in experiments 1 and 2, the ratio at KSK shows a skew towards fragmented grains (Table 6.10).

	Oryza caryopsis: Oryza frag
1A	100:40
1B	100:8
1C	50:100
2B	100:83
2C	63:100
2D	85:100
KSK	4.5:100

Table 6.10: Ratio of rice grains to rice grain fragments derived from the charring experiments and KSK.

Wild or domesticated?

The first task in the identification of rice involved demonstrating the domesticated, wild or immature status by carefully examining the spikelet base abscission scars, a method developed by Thompson (1996, 1997), and elaborated in Fuller et al. (2009) as discussed in Chapter 9. Proving domestication requires substantial assemblages of spikelet bases in order to quantify the data with a good level of statistical significance. KSK has yielded 1,215 rice spikelet bases in 40 test pits. After KSK, the largest dataset of rice spikelet bases from Mainland Southeast Asia is from Phu Khao Thong (n=638) followed by Ban Non Wat (n=69) [on-going research by author]. The first archaeobotanical study to report rice spikelet bases in Mainland Southeast Asia was Khok Phanom Di yielding a total of twenty-seven spikelet bases (Thompson 1996). The large dataset of spikelet bases from KSK shows that the rice was domesticated.

The reduction in seed shattering and therefore dispersal is the key trait attributed to domesticated rice and is brought about by the mutation of the *sh4* and *qSH1* genes (Fuller and Allaby 2009; Li et al. 2006). The domesticated phenotypes display tough rachides that require human involvement (e.g. threshing) to detach the seeds from the rachilla. The spikelet base scars found in domesticated rice *Oryza sativa* have rough edges and look gouged out, sometimes exhibiting a large central hole where the vascular bundles are situated. On the other hand, wild rice displays smooth circular scars and immature rice have protruding scars (Figure 6.14). The scars from the KSK samples were individually examined and the results are tabulated in Table 6.11 showing that the spikelet bases were morphologically predominantly domesticated (85.83%).

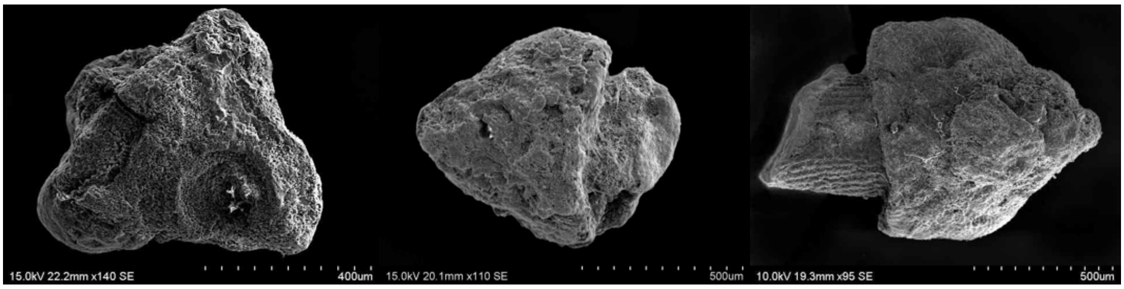


Figure 6.14: From L-R: Domesticated rice spikelet base (TP43 US4), Wild rice spikelet base (TP43 US4), and Immature rice spikelet base (S1 L5) [Images by author].

Status	Total	% of total
Domesticated	836	85.8%
Wild	115	11.8%
Immature	23	2.4%
Indeterminate	241	
Total spikelet bases	1215	

Table 6.11: *Oryza* spikelet bases found at KSK and their domestication status. Percentages exclude indeterminate spikelet bases.

There is a substantial minority (11.8 %; n=115) of wild spikelet bases at KSK. If wild rice were dominant, this would indicate that rice was being gathered wild or if cultivated, the process of domestication was not complete. These are clearly not the case in KSK and instead the presence of wild rice suggests that rice cultivation was infested with weedy rices. Wild rice in relatively low frequencies is expected in assemblages as a weed of cultivation. In modern rice fields, weedy rice or red rice is still considered one of the top twelve weeds (also known as 'the dirty dozen') of rice cultivation especially in dry-seeded/broadcasted rice (www.irri.org). In the third millennium BC at Liangzhu in the Lower Yangtze region of China, wild/weedy rice accounts for ~20% of the rice assemblage. One would expect to find wild rice frequencies to be lower at later periods because of better cultivation techniques (e.g. intensive cultivation) which would have developed over time. And indeed this seems to be the case when viewing the spikelet base types against the timeline (Figure 9.7). Also, archaeobotanical work in China indicates that the evolution of domesticated rice was gradual (Fuller et al. 2009a). This would show in the archaeological record as a decrease in wild rice frequency over time. Declining frequencies in wild rice should only be assessed when there is comparative material either from sites spanning long chronological sequences or data from several sites of different periods. A comparatively large proportion of wild rice can then be explored as a potential indicator of less-intensive forms of rice cultivation. Further work is needed particularly more examination of sites with spikelet base data, as well as studies to determine what levels of weedy rice might be expected in modern rice fields of different types of cultivation.

Japonica* or *indica?

The origins of rice have received the most attention in Southeast Asian archaeology (Thompson 1996; White 1995). The genetic evidence points to two centres of early cultivation, China for *japonica* and South Asia for ancestral *indica* (Fuller et al. 2010). Data indicate that rice domestication in China took place by 4500-4000 BC in the Lower Yangtze valley and spread to other regions soon after (Fuller and Qin 2009). On the other hand, *indica* was domesticated around 2000 BC in South Asia (Fuller 2011b). Mainland Southeast Asian literature provides evidence of the domesticated *Oryza sativa* as early as 2000-1500 BC (Neolithic period) at Khok Phanom Di (Thompson 1996) though it was not further identified as *japonica* or *indica*. Inferring the origins and movement of rice requires a pan-regional archaeobotanical study currently unavailable for Southeast Asia, but what data are available are reviewed in Chapter 9 (see also Castillo 2011; Fuller et al. 2010). By the time KSK became an entrepôt in the Late Prehistoric period, rice was domesticated as demonstrated above. However, links to both China and South Asia, as evidenced by the pottery, technologies and other material culture do not help unravel the question of how rice got to KSK. Domesticated rice probably would have existed in the region prior to the rise of KSK. Between the fourth and second century BC, groups of non-indigenous people who settled at KSK either temporarily or permanently may have brought varieties of rice with them from their regions of origin. Many such people may have come from elsewhere in Southeast Asia, but of interest is whether those from further afield, such as India, brought new crop species or subspecies. It can be asked whether rice was brought over by groups from South Asia, and if so, whether it would have been of the *indica* variety, and this would represent an introduction pathway for *indica* rice to Southeast Asia. However, it is believed that if rice was already available in the Southern Peninsula prior to the arrival of foreigners, these immigrant groups would have brought other species not locally available instead of rice, like mungbeans. In order to determine which subspecies of rice was present in KSK morphometrics and archaeogenetics were applied to the samples.

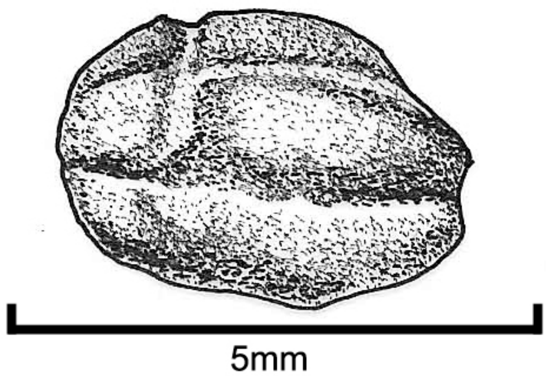


Figure 6.15: Drawing of a whole caryopsis from KSK (TP57 US16) showing the short and plump morphology normally associated with *Oryza sativa japonica* (Drawing by author).

Whole caryopses of rice at KSK were examined and morphologically are of the short plump type normally associated with *Oryza sativa japonica* (Figure 6.15). Figure 6.16 shows the data summarised in a paper by Fuller et al. 2007a of the different proportions of modern rice populations based on length-to-width ratios. These include modern wild rice and the domesticated rices, *japonica* and *indica*. The KSK rice samples were measured showing 92% (n=14) of the samples fell in the <2.3 group, indicating an affinity with the Chinese domesticate *Oryza sativa japonica*. Early rice cultivation in Burma, Japan and Korea indicates that *japonica* was cultivated as dry field crop (Fuller et al. 2010; Watabe et al. 1974). This seems to be the case also in the Thai-Malay Peninsula during the Metal Age and is discussed in the weed assemblage section where systems of cultivation are the focus. In present-day Southeast Asia, tropical *japonica* is cultivated in the uplands, usually rainfed, and *indica* in the lowlands (Fuller et al. 2010).

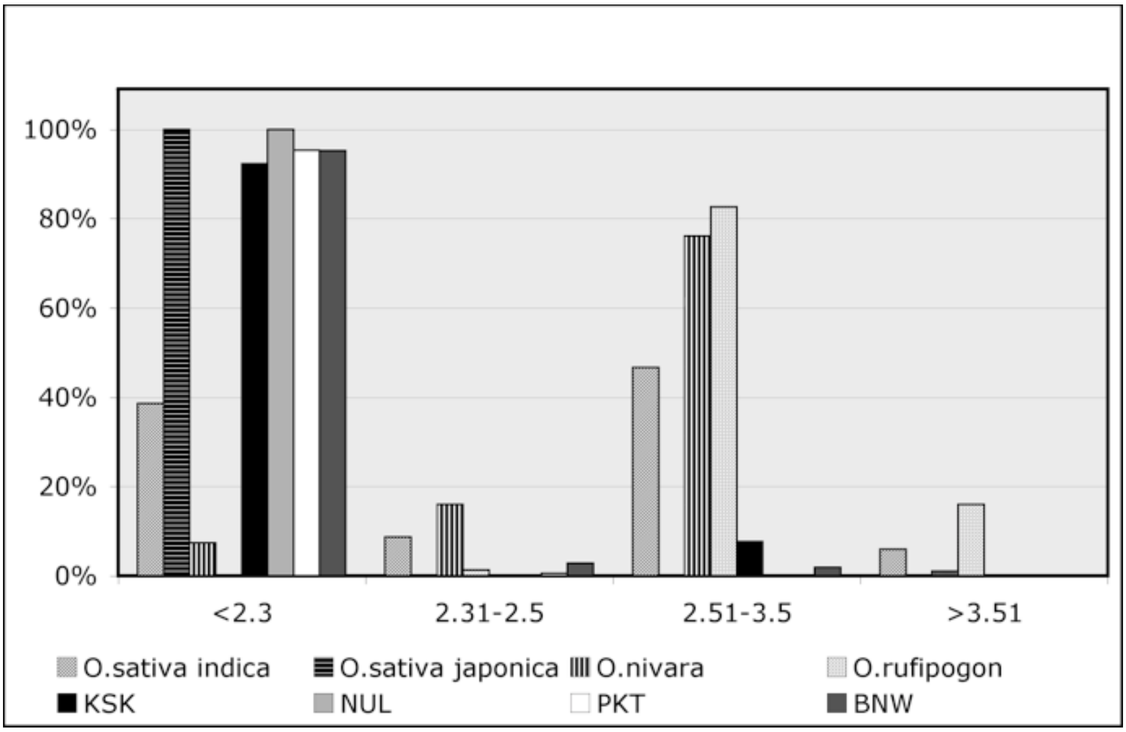


Figure 6.16: Proportions of modern rice populations (wild and domesticated in L/W ratios) and those from KSK in black (Adapted from Fuller et al. 2007a).

An aDNA study was conducted on some of the rice grain fragments (n=18) from KSK by Dr. Tanaka. More results are discussed in Chapter 9. Tanaka included modern rice measurements of *indica* and *japonica* subspecies (unpublished report). The L/W measurements of the KSK samples also fall neatly within the L/W range of modern *japonica* measurements by Tanaka (*indica:* 1.81-2.41; *japonica:* 1.54-2.5; average KSK: 1.7 and range of 1.52-1.88). Appendix 6.5 is the complete list of measurements of whole rice grains.

Country	Population name	tested sample	sample condition	Chloroplast genotype			Ch6 region genotype*			
				indica	*japonica*	N/A	-217	H	0	N/A
Thailand	ksk tp57 us16	18	broken	-	11	7	1	2	6	9

* Nucleotide sequencing in Ch6 region with "H" as heterozygous type and "-217" and "0" type in Ch6 region.
NA are non-amplification samples by PCR with specific primer.

Table 6.12: Genotype of KSK ancient rice grain population (Adapted from Tanaka unpublished report).

The aDNA study included chloroplast genotype determination based on four markers and nucleotide sequencing to determine specific genes including non-shattering (*qSh1* and *Sh4),* stickiness *(Waxy)* and white pericarp colour (*Rc).* The chloroplast genotype was successfully identified as *japonica* in eleven samples from KSK (Table 6.12, for individual samples see Appendix 6.6). Unfortunately, the nucleotide sequencing did not yield results.

Temperate or tropical *japonica?*

The archaeogenetics study did not assist in the differentiation of the rice in KSK as either from a temperate or tropical *japonica* group. As will be explained in Chapter 9, the presence of awns is a morphological trait normally associated with wild rice. However, the presence of awns does not necessarily confirm wild status because some domesticated rices, such as *javanica* (also known as *bulu)* belonging to the tropical *japonica* group are also awned. At KSK, 97.6% of the lemma apices had squared or angled fractures signifying that they were awned. So from the presence of lemma apices (n=41) in the assemblage it is proposed that the rice found in KSK was most likely tropical *japonica.*

6.5.3.2 *Setaria italica* (L.) Beauv. ssp. *italica*

Common names: foxtail millet
Thai names: khaao faang

Foxtail millet is also known as foxtail bristle grass, Italian millet or birdseed. It is an annual grass growing to *ca.* 2 m in height. It is a self-pollinating diploid (2n=18) that prefers dry conditions. The panicles are dense, erect and surrounded by bristles. The colours of foxtail millet grains are white, yellow, red, brown and black. Foxtail millet is eaten as a cereal, boiled or as gruel. It is also made into alcoholic and non-alcoholic beverages. As flour it is used to make bread, porridge and dumplings (Sakamoto 1987). It has been a cereal of economic importance since prehistoric times in Eurasia, particularly in north China. It was the staple food in many parts of Asia before rice replaced it as the more popular cereal (Lu et al. 2009a; Weber et al. 2010). Although of minor importance nowadays compared to rice it continues to be used in Europe and in Southeast Asia.

Besides rice, foxtail millet is another important crop originating from north China with a proposed date of domestication *ca.* 6000 BC. It preceded rice cultivation in China by at least 1500 years (Fuller et al. 2007a). Recent work using starch grain analysis from Nanzhuangtou and Donghulin has put back the date for foxtail millet exploitation by at least two millennia (Yang et al. 2012). A constraint in the study of foxtail millet is the paucity of evidence to reconstruct the process of domestication to show the stages between gathering, cultivation and full domestication (Fuller 2011a; Lu 2002). This is a task that has been achieved with rice and could be repeated with millet by more extensive sampling, especially from sites dating to earlier periods which could shed light on agricultural origins (Song 2011).

Just like rice, there are differing views on the origins of foxtail millet with single and multiple origins' proponents. Whether single (Cohen 1998; Sagart 2008; Vavilov 1926, 1992) or multiple origins (Bettinger et al. 2010; Fukunaga and Kato 2003; Fuller et al. 2008; Weber and Fuller 2008) are considered, the archaeological and genetic evidence indicates the general area of origin in north China (Song 2011).

Genetic evidence reveals the centre of diversity for foxtail millet lies in China so it is concluded where domestication took place (d'Ennequin et al. 2000). Other studies suggesting multiple centres of origin have proposed one in China and another in Europe (d'Ennequin et al. 2000; Li et al. 1995). It has also been proposed that foxtail millet originated in the region of Central Asia, Afghanistan, Pakistan and NW India (Sakamoto 1987). Indeed, genetics suggests differentiated geographical groups belonging to East Asia (China, Korea and Japan), the Nansei Islands of Japan-Taiwan-Philippines, India (including Afghanistan and Central Asia), and Europe (Eda et al. 2013). The genetic findings by Eda et al. (*ibid.)* strongly indicate long histories of use in specific geographic areas such as China and India with inter-regional crop movements, and a centre of diversity in East Asia. Eda et al. also find a localised domesticated line from Central Asia including Afghanistan and north Pakistan.

Archaeobotanical work shows that the discovery of the earliest foxtail millet is in the alluvial plains and loess plateaus of northern China (Liu et al. 2009) *ca.* 6000 BC and that it does not appear in European archaeological records until much later *ca.* second millennium BC (Zohary et al. 2012). It is therefore believed that domestication took place in the loess plateau region of northern China (Ho 1977; Liu et al. 2009) where the wild progenitor green foxtail (*Setaria italica* ssp. *viridis*) is also found. Green foxtail millet is an annual summer weed and although a distribution map is still forthcoming, it is found across temperate Eurasia (de Wet 1995a; Zohary et al. 2012) and rarely found in the tropics except at high altitudes (Defelice 2002). It is a weed that does well in disturbed habitats. Like rice, the main domestication trait of foxtail millet is the non-shattering rachilla whereas green foxtail naturally disperses its seed once mature. Archaeologically, the rachilla of foxtail millet is seldom preserved and so has not been used to determine the domestication status of foxtail millet in the same manner as rice. Instead the morphology of the grains is used to differentiate foxtail millet from its wild predecessor *S. viridis*. Green foxtail millet is smaller and more narrowly ovate than the domesticated type (Fuller and Zhang 2007 [Figure 6.17]). Although one should exercise caution as the smaller, narrower grains may instead represent immature foxtail millet. The identification of immature foxtail millets forms part of a study conducted by Song et al. (2013). Although one is able to differentiate immature from mature grains in an assemblage composed wholly of foxtail millet as demonstrated by Song et al., the authors do not provide a method of distinguishing immature foxtail millet from immature green foxtail millet.

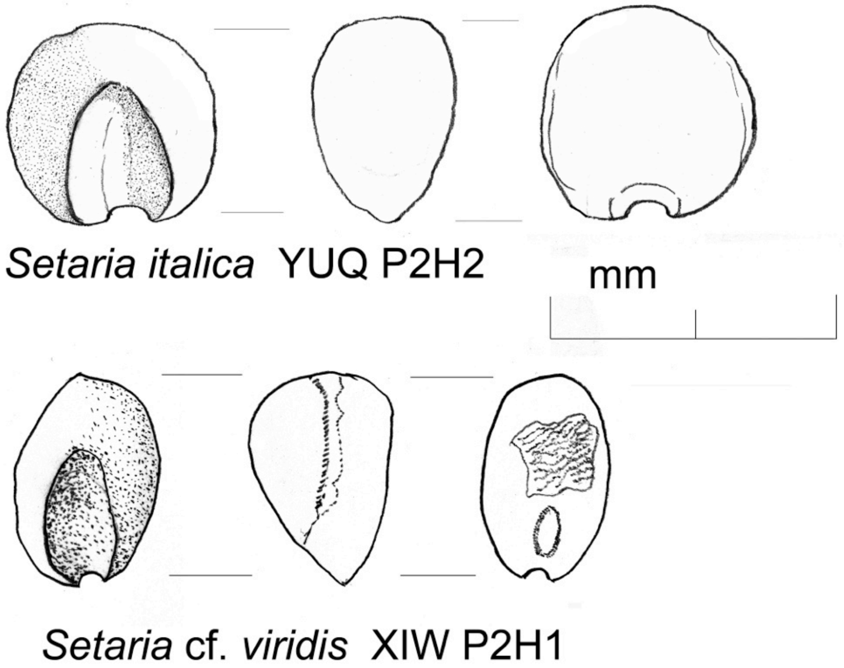


Figure 6.17: Drawings of foxtail millet and green foxtail millet (Source: Fuller and Zhang 2007).

Early finds of foxtail millet in northern China include charred grains dating to *ca.* 6000 BC at Xinglonggou, eastern Inner Mongolia and *ca.* 5800 BC in Yuezhuang in Jinan (Song 2011). However, the predominant millet found in both Xinglonggou and Yuezhuang is broomcorn millet (*Panicum miliaceum)* prompting discussions on whether broomcorn millet was domesticated prior to foxtail millet (Lee et al. 2007).

More sites situated in in the Yellow River basin dating from 5500-1300 cal. BC have evidence of foxtail millet (Lee et al. 2007; Liu et al. 2009). In all but one of twenty sites studied by Lee et al. (2007), foxtail millet is the more significant millet in the assemblage than broomcorn millet, which has a minor representation.

There is also evidence of the spread of foxtail millet alongside rice in sites dating to the early third millennium in Taiwan (Fuller et al. 2010). Rice and millets do not co-occur in archaeological sites in the Lower Yangtze suggesting that foxtail millet did not spread into Taiwan from the Lower Yangtze but instead from the Shandong coast or northern Jiangsu (Fuller et al. 2010; Sagart 2008; cf. Bellwood 2005). However, a route from northern China via the middle Yangtze has been proposed to explain the spread of foxtail millet southwards into mainland Southeast Asia (Fuller et al. 2010). Foxtail millet has been found with rice in the site of Chengtoushan located in the middle Yangtze *ca.*5800 cal. BP (Nasu et al. 2007) and in Gantouyan which is located at the border between southwestern China and Vietnam, dating to 4000 to 3000 BP (Lu 2009).

Evidence of millet in Mainland Southeast Asia is scarce and plotting the trajectory of millets southwards into Thailand is speculative. The only published reports of millets in Thailand, including *Setaria* and *Panicum,* are from central Thailand and the Southern Peninsula. Foxtail millet grains were found in the sites of Non Pa Wai, Non Mak La and Nil Kham Haeng in the Khao Wong Prachan Valley during the Neolithic in Non Pa Wai and during the Bronze Age period in all three sites (Pigott et al. 1997; Weber et al. 2010). A single *Setaria* seed from Non Pa Wai yielded an AMS date of 2470-2200 cal. BC (Weber et al. 2010). The other source of evidence is from KSK. The results from the Khao Wong Prachan Valley indicate that foxtail millet (*Setaria italica*) was being cultivated by the late third millennium BC whereas rice only appears in the first millenium BC (Weber et al. 2010). As rice use increased, the popularity of millets decreased. Pollen and phytoliths indicate a 'tropical savannah' environment existed in the period when millets were dominant in the Khao Wong Prachan Valley (Kealhofer 2002). A tropical savannah climate entails a more pronounced dry season and therefore, one possible explanation for the early use of millets instead of rice is the adaptability of millets to dry upland cultivation. Furthermore, foxtail millet can be found in infertile soils, high temperatures, low and erratic precipitation and acidic soils with poor water-holding capacity (Léder 2004). Cultivation in Southeast Asia is widespread today, though almost all production is by small-scale farmers mostly for fodder but also for household consumption and local trade (Burkill 1935; Léder 2004). Millets may also be associated with shifting cultivation which offers a less-taxable agricultural produce than the permanent rice fields that have normally been associated with the economies of cities and states in Southeast Asian history (Scott 2009).

At KSK, not enough evidence of foxtail millet has been found to suggest large-scale local cultivation. The results from the Khao Wong Prachan Valley show that millets can be found in the archaeological record using flotation and are just as visible in the archaeological record as rice. However, preliminary charring experiments suggest that there is a bias in favour of hulled rice compared to the hulled millets, *Setaria italica* and *Panicum miliaceum* (Chapter 5). When the three cereals were then charred naked, the results showed that rice did not preserve at all but foxtail and broomcorn millet occasionally did. The low quantity of foxtail millet in KSK may therefore be caused by a preservation bias against millets but it is more likely that the inhabitants at KSK were rice-centred and therefore, if there was millet cultivation, it would have been, as it is today, small-scale production. In the Thai-Malay Peninsula in the beginning of the twentieth century, *Setaria italica* 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 Southern Peninsula of Thailand prior to rice as is the case in the Khao Wong Prachan Valley. If so, rice cultivation in KSK would have been opportunistic farming as a result of a switch from one dryland cereal to another. The rice from KSK was most likely from dryland cultivation and this is demonstrated in the weed section.

Only two grains of *Setaria italica* (foxtail millet) were found at KSK, one seed each in TP130 (Hill 2) and TP57 (Valley 3). Compared to rice, this cereal is found in only 2% of the samples at KSK, though a few other weedy species *Setaria* sp. and *Panicum* spp. caryopses were also found. Weber and Fuller (2008) remark on the limited quantities of millet recovered from archaeological sites compared to the large cereals rice, wheat, barley and maize. Weber and Fuller proposed that the way millets are used and processed affect the formation processes and therefore preservation and recovery. Another issue are misidentifications encountered with millets in the archaeological record. Formation processes and misidentifications are exacerbated for very small millets such as foxtail millet where in the past recovery methods used sieves with large perforations (>1mm). Recent work has increased small millets recovery through extensive flotation (Weber et al. 2010) and smaller sieve perforations. Consequently, advances in millet identification have made this cereal more visible in the archaeological record (Fuller 1999). At KSK, the recovery of foxtail millet was possible because 250μm mesh was used in flotation.

	length (mm.)		width (mm.)		thickness (mm.)	
Setaria italica	mean	range	mean	range	mean	range
IoA reference collection (China)						
fresh (n=190)	2.20	1.9-2.5	1.70	1.4-1.9	1.40	1.1-1.7
carbonised (n=51)	1.84	1.51-2.52	1.64	1.32-2.14	1.46	1-1.9
IoA reference collection (China, dehusked)						
fresh (n=190)	1.70	1.4-1.9	1.50	1.1-1.8	1.20	0.7-1.5
carbonised (n=9)	1.74	1.08-2.2	1.59	1.26-1.83	1.26	0.92-1.52
IoA reference collection (India, dehusked)						
fresh (n=170)	2.50	2.2-2.8	1.60	1.2-1.7	1.30	1-1.15
carbonised (n=4)	1.53	1.4-1.72	1.59	1.45-1.92	1.21	0.93-1.36
modern from Xinzhou Shanxi/China (n=10)	3.34	3.24-3.48	3.41	3-3.6	2.36	1.8-2.64
modern from Yanshi, China (n=19)	2.87	2.64-3.24	3.23	3.12-3.48	2.63	2.04-3.36
modern from Karnataka, India (n=25)	3.37	1.7-4.08	2.64	1.4-3.24	1.93	1.1-2.4
modern from Gansu, China (n=20)	2.93	2.76-3.36	3.24	2.76-3.6	2.54	2.28-2.88
archaeological (n=10)						
[YFT P3H1 Ying valley, Late Longshan]	2.51	2.28-2.64	2.34	2.04-3.12	1.48	1.08-2.16
archaeological (n=10)						
[Paithan, Maharashtra Early Historic]	2.58	2.16-3.24	2.06	1.8-2.4	1.48	0.96-2.16
archaeological (n=20)						
[Luoyang, Henan Tand Dynasty]	2.41	2.16-2.76	2.11	1.8-2.28	1.69	1.44-1.92
archaeological (n=10)						
[XIW: PE(3) Ying valley, Late Longhsan]	2.47	2.28-2.64	2.14	2.04-2.4	1.76	1.44-2.16
archaeological (n=20)						
[YUQ :P2H2 Ying valley Yangshao]	2.42	2.04-2.64	2.29	2.04-2.76	1.81	0.84-2.4
Sources: Castillo unpub; Fuller & Kajale unpub; Fuller PhD measurements; Fuller & Zhang 2007; Song unpub.						

Table 6.13: Measurements of modern and archaeological foxtail millet.

The millet caryopsis identification criteria set out by Fuller (unpublished, 1999) and modern reference collections at the Institute of Archaeology, UCL (henceforth 'IoA') were used to identify *Setaria italica*. Some of the modern reference collections were charred in experiments described in Chapter 5. The identification criteria involved measuring the seed size and the embryo length as well as examining the adhering husk pattern. *Setaria italica* grains are small, plump and oval measuring *ca.* 2 mm in diameter (Fuller 2002). Measurements from the IoA reference collection are found in Table 6.13. The embryo spans 2/3 to 3/4 of the length of the grain and the lemma have finely rugose or beaded sculpturing (Fuller 2006b). Charred archaeological samples are expected to be smaller than fresh samples due to several factors including shrinkage, especially the length, caused by charring (Bowman 1966; Braadbaart 2008). The samples from KSK were compared to modern specimens and criteria defined above were met including the average embryo to length of grain ratio although the length and width of the KSK samples measured *ca.* 900x 900 μm (n=2) which is slightly smaller than modern and archaeological samples (Figure 6.18).

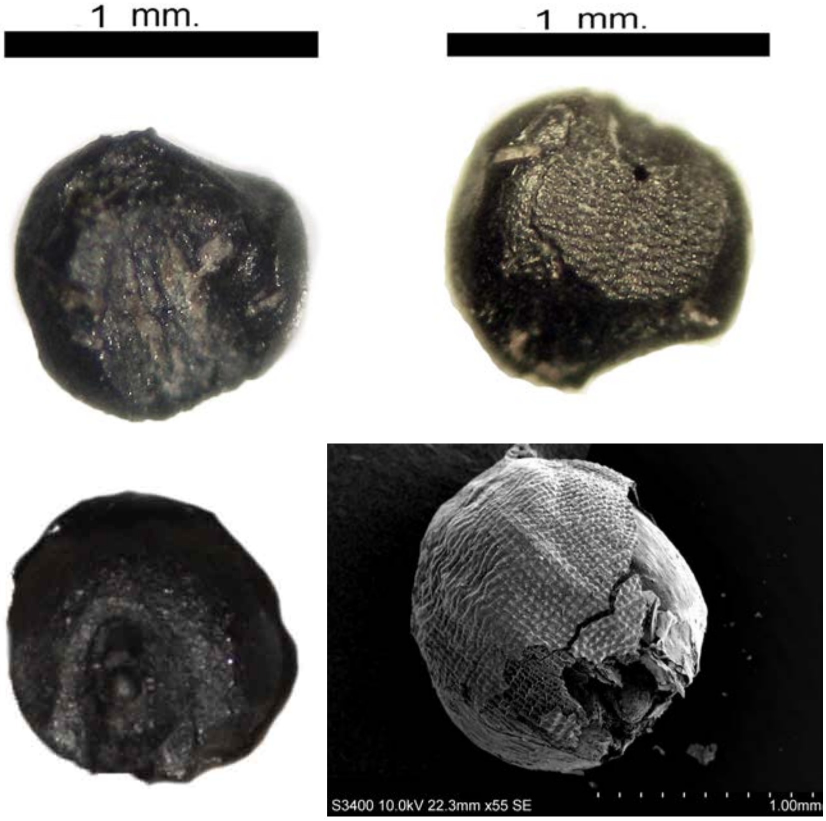


Figure 6.18: Above are two images of one of the archaeological foxtail millet grains from KSK TP57 US12 clearly showing the long embryo and the adhering husk with the beaded sculpturing. Below are images of modern charred foxtail millet grains from the IoA reference collection; (L) which show the length of embryo; (R) shows the adhering husk (Images by author).

The phytoliths of foxtail millet are also distinctive and these have been successfully differentiated from that of *Panicum miliaceum* (broomcorn or common millet). The most distinctive phytoliths of foxtail millet are characterised by cross shaped types, regularly arranged papillae and dendritic long cells with a Ω edge (Lu et al. 2009b). More difficult is distinguishing the phytoliths of foxtail millet from the wild progenitor green foxtail millet because the size of the phytoliths seems to be the only distinguishing factor (Zhang et al. 2011). Using phytolith analysis, noodles dating to the Late Neolithic in China made from foxtail millet have been identified (Lu et al. 2005).

6.5.3.3 *Paspalum* cf. *scrobiculatum*

Paspalum scrobiculatum L.
Common names: kodo millet, creeping paspalum
Thai names: yaa plong hin, ya-sakhorbik

Paspalum scrobiculatum is a small millet commonly referred to as 'kodo millet.' Kodo millet was domesticated in India (de Wet et al. 1983), specifically in the Ganges during the Chalcolithic period (Fuller in press). It is reported as the dominant crop in Paithan, western India in the third century BC where it occurs in 80% of the samples and 44% of all seeds identified (*ibid.*). One seed has been identified as *Paspalum* cf. *scrobiculatum* in KSK and could be either a weed of rice cultivation or another example of Indian crop diffusion. Wild kodo millet has been described as an *'aggressive colonizer in moist habitats across the tropics and the subtropics of the Old World* (de Wet 1995b)'. Furthermore, it is reportedly grown as a cereal only in India although it is gathered as a wild cereal in Africa (de Wet 1995b; Galinato et al. 1999). In Southeast Asia, it is reported as a common grass or a weed of upland rice fields in Indonesia and Thailand (Soerjani et al. 1987; Galinato et al. 1999). It may therefore be considered in KSK as a potential weed rather than a crop and is included under the heading weeds in section 6.5.6.

The identification criteria for kodo millet include the size and shape of the grain and hilum, the length of the embryo and the texture of the pericarp. The caryopsis is ellipsoid or subglobose from the dorsal view with a L:W≈1 and measures *ca.* 1.8-2.7 mm x 0.8-1.8 mm after a shrinkage value of -10% was applied (see Appendix 6.14 ID no. 42). I follow Fuller (2007b) in the application of a shrinkage factor to the measurements of modern cereals at -10% to take into account the effects of charring. In lateral view the naked grain has a flattened belly and is assymetric from the side view as it bulges out (Figure 6.19). The sculletum groove measures a third of the length of the grain and the pericarp has a reticulate surface with ridges forming irregular rounded patterns. If the husk is present, the whole seed is broadly elliptic with linearly arranged papillae over a smooth surface (Noda et al. 1985). The charred grain from KSK has a shape as described above, with a L:W ratio of approximately one, measures 1.07 x 0.934 x 0.79 mm, and has a sculletum length of *ca.* 42% the length of the grain. The hilum is covered with clay so it has not been studied, however, the SEM micrographs reveal a pericarp very similar to one taken from a modern reference collection (Figure 6.20).

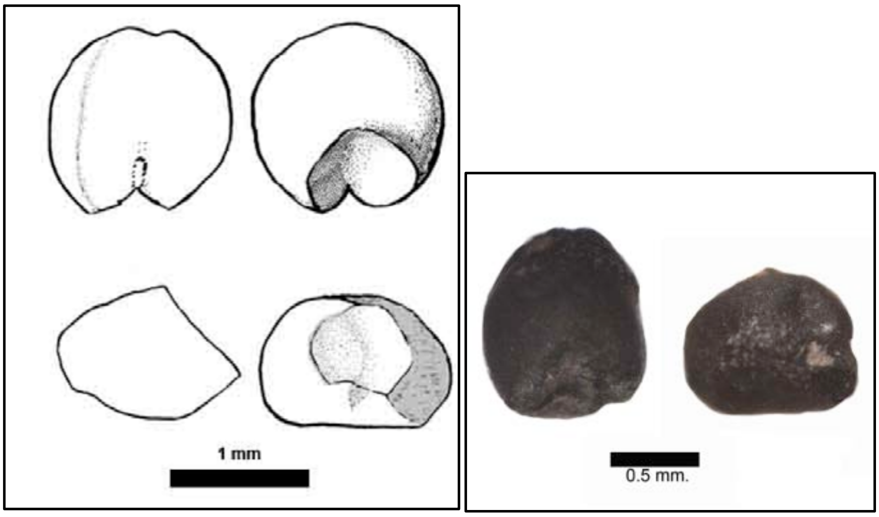


Figure 6.19: Left - Line drawing of archaeological kodo millet from Kurugodu; Right - Photograph of the grain from KSK TP132 US17b cup (Drawing in Fuller et al. 2004; Image by author).

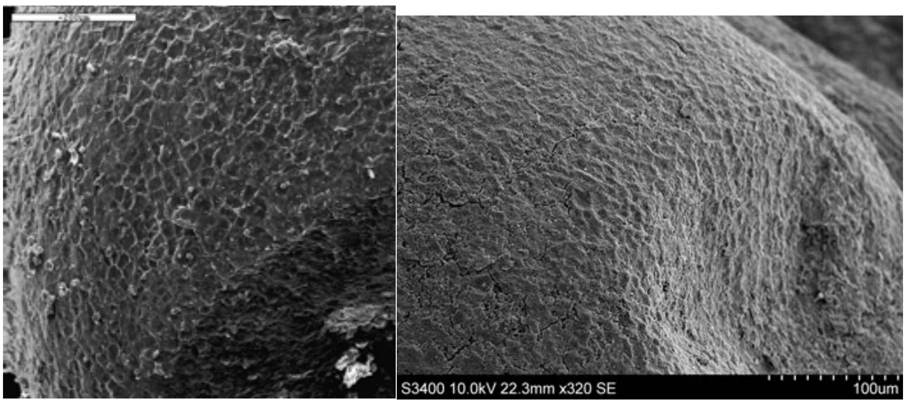


Figure 6.20: SEM micrographs of the pericarp of a modern sample (Left) and of the sample from KSK TP132 US17b cup (Right) [Images by Fuller (L) and author (R)].

6.5.3.4 *Vigna radiata* (L.) Wilczek var. *radiata*
Common names: mungbean, green gram, golden gram
Thai names: thua thong, thua kheaw

The wild progenitor of the mungbean is *Vigna radiata* var. *sublobata* (Roxb.) (Fuller and Harvey 2006; Tomooka et al. 2002). Wild mungbean is widespread across all of South Asia, Southeast Asia including Thailand, northern Australia and some parts of Africa (Figure 6.21). According to Zohary et al. (2012), determination of the geographical spread of modern wild progenitors indicates the possibility of several centres of domestication. However, studies based on morphology, existence of wild and weedy species as well as the existence of early archaeological remains from India narrows down the domestication of the mungbean to South Asia (Tomooka et al. 2002). Also, modern cultivated mungbeans have the greatest intra-specific genetic diversity in South Asia (Sangiri et al. 2007). A study by Tomooka et al. (1992) looked at the intraspecific protein variation found in mungbeans using seed protein electrophoresis (a technique used to separate protein molecules) and he proposed two dissemination paths from India after identifying proteins in mungbeans from the different regions. The southern path was from India to Southeast Asia then via Southeast Asia to China and Taiwan, and the northern path was via the Silk Road [Figure 6.22] (Tomooka et al. 2005). Interestingly, the centre of genetic diversity using seed protein electrophoresis lies in the area of Afghanistan, Iran and Iraq, and not India (Tomooka et al. 1992). This reinforces the observation that highest genetic diversity does not equate to the centre of origin (e.g. Hawkes 1983, 1990). Genetic diversity refers to the adaptation of populations to their environment seen as variations in heritable characters (Sangsiri 2009).

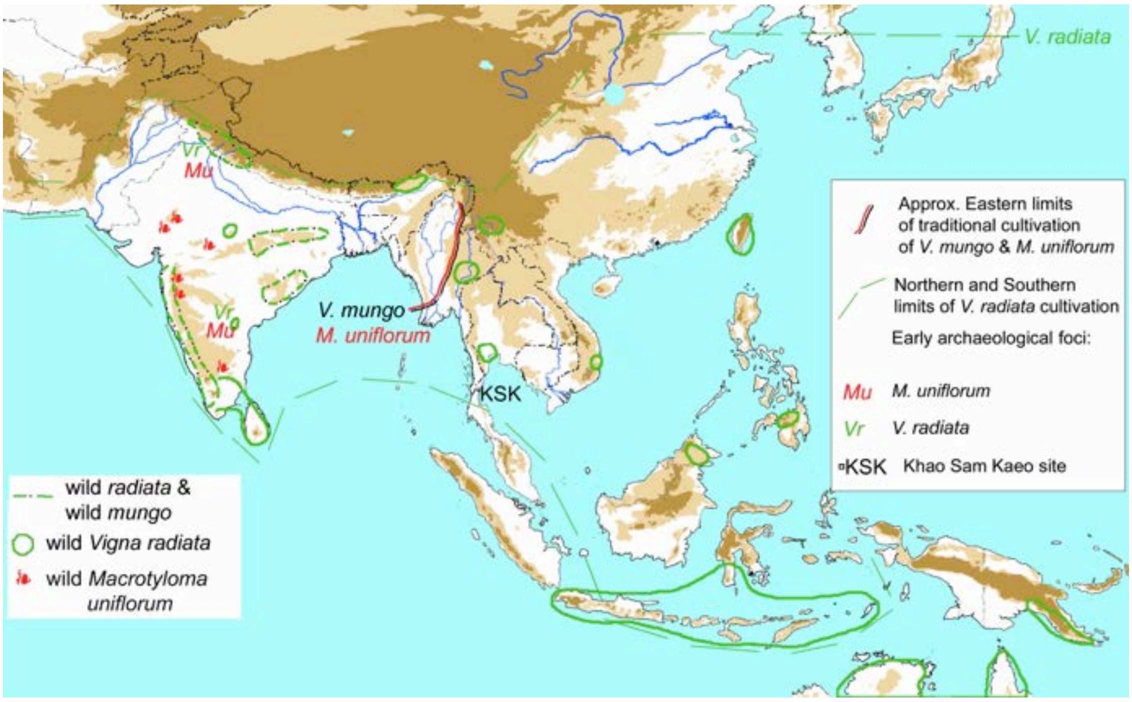


Figure 6.21: Map showing geographical distributions of wild *Vigna radiata* and *Macrotyloma uniflorum* and the early archaeological finds of *Vigna radiata* and *Macrotyloma uniflorum* in Khao Sam Kaeo [wild *Vign*a distribution based on Tomooka et al. 2002; wild *Macrotyloma* and early archaeological evidence from Fuller and Harvey 2006 (Map by Fuller adapted from Castillo and Fuller 2010)).

The implications of a wide geographic spread of wild mungbean which also includes Thailand is that the mungbean could have been domesticated by the local people where the wild mungbean occurred. However, this was clearly not the case in Thailand. Mungbean has not been found at any site other than KSK and PKT in Southeast Asia. KSK and PKT belong to the period when Indian artefacts and technologies are found in mainland Southeast Asia, generally regarded to happen after 500 BC (Bellwood 2005; Glover and Bellina 2011; Higham and Thosarat 2012). It is therefore believed that the introduction of this crop came through exchanges with South Asia (Castillo and Fuller 2010). The evidence from KSK corroborates Tomooka's hypothesised southern route from India to Southeast Asia and since KSK and PKT have the earliest mungbean finds, the proposed date of entry would be *ca.* 400-200 BC. It has been noted that the wild progenitor, subsp. *sublobata* is used as a pulse when food is scarce (Tomooka et al. 2002). However, in peninsular Thailand, it is likely that the wild form of mungbean was not gathered in prehistoric times since again there is no evidence in the archaeological record. This is further proof of the entry of the mungbean during the initial period of Indian contact. It is true that there has not been sufficient archaeobotanical research conducted in Thailand but mungbeans are rather large and just like rice, can be identified with the naked eye. The results in Chapters 5 and 8 also confirm that mungbean compared to the other crops used in the charring experiments has the greatest visibility and therefore they would, one imagines, have been found in archaeological sites if present.

A working hypothesis is that Indian crops had been brought to the mainland via the Southern Peninsula or maritime translocation from India across the Bay of Bengal. There is a distinct lack of mungbean evidence in prehistoric East Asian archaeobotany signalling a late adoption of this crop and therefore not a likely route of the mungbean to the Southern Peninsula of Thailand. It is the case in South India that early finds of mungbean co-occur with large quantities of horsegram and also in the Greater Indus Valley as early as *ca.* 2600-1900 BC (Fuller and Harvey 2006). A list of early finds in South Asia is found in Appendix 6.7. Fuller (2005) considers the 'basic Neolithic package' of south India to include the native mungbean, horsegram and the millets *Brachiaria ramosa* and *Setaria verticillata*. At KSK, two of these domesticates, mungbean and horsegram, are present and could also indicate that a package of crops from India, notably pulses of the Indian '*dhal,'* arrived in the Southern Peninsula via the Indian craftsmen that visited or settled in the site.

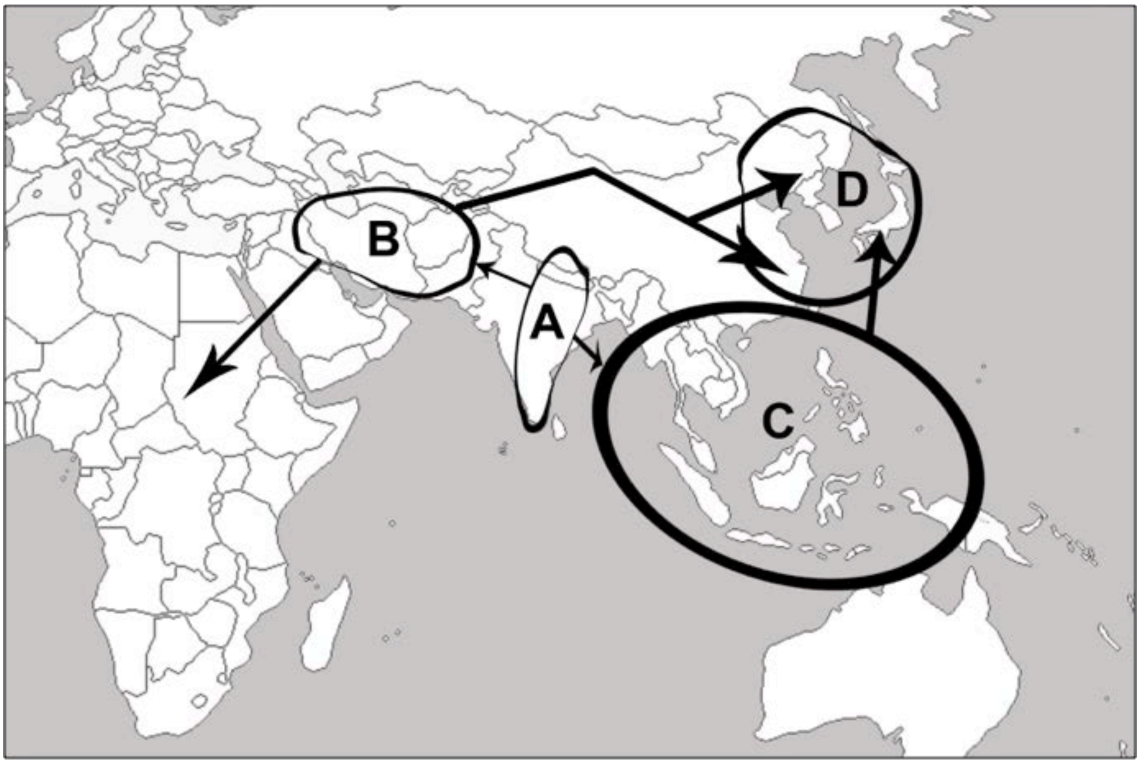


Figure 6.22: The origins and spread of mungbean deduced from the geographical distribution of habit and protein types. (A) Indian mungbean landraces have the most diverse protein and growth types. (B) In the Afghanistan-Iran-Iraq region, mungbean landraces are considered primitive. (C) In Southeast Asia, mungbean landrace is mainly characterised by large shiny green seeds, plants are tall with thick main stems, are late maturing and protein types are simple. (D) mungbean landraces include growth type diversity that is intermediate between Afghanistan-Iran-Iraq and Southeast Asian types. (Adapted from Tomooka et al. 2005; Map base from www.ngfl-cymru.org.uk).

Domestication of the mungbean in South Asia is likely to have occurred in south India, specifically the eastern Ghats, by late third millennium BC (Fuller and Harvey 2006) Although another centre may have been the eastern Harappan area where archaeological mungbeans date to the mid-third millennium BC (Appendix 6.7). Early finds of mungbean to the west of India is in Quseir al-Qadim, Egypt (van der Veen 2011). Two beans were found at Quseir al-Qadim dating to the Roman period (first to third century AD). The rarity of the finds suggest that this crop was not brought into the early port of Quseir al-Qadim as a trade item but instead was part of meals eaten on board the trading ships coming from India (*ibid.*). This interpretation is not only based on the rarity of finds but also the lack of mention in textual references. Around seventy desiccated whole mungbeans dating from the first to second centuries AD were also found in

Berenike. The interpretation of finds at Berenike contrasts with that of Quseir al-Qadim because they are considered to form part of the trade between the Roman Empire and India (Cappers 2006).

Economically, mungbean is the most important pulse grown in Thailand today even though it is considered a minor crop by the Thai government (Prasertsri 2011). PROSEA (Plant Resources of Southeast Asia 1993) classifies mungbeans under 'major secondary use vegetables' and in Thailand, as in Indonesia, it is reported as being frequently used in large quantities. Farmers are encouraged by the government to plant mungbeans as a second crop replacing off-season rice cultivation. Mungbean consumption in 2009 to 2011 continued to increase driven by local and domestic demand for vermicelli, which is made from this pulse and which accounts for more than half of mungbean use. Because of the high domestic demand for mungbean, Thailand has had to import from Myanmar. It is a pulse with a short maturity span (60-90 days) and it also helps to improve soil conditions (Tomooka et al. 1992). Given short growing periods it has the further advantage over other pulses, such as the cowpea, because it outyields them (FAOstat).

The mungbean grows best in seasonally dry tropical environments and is adapted to a range of well-drained soils despite being successfully grown in sandy soils with low fertility. Because of a wetter climate mungbean has not been successfully introduced in Malaysia even though it grew well on the eastern part of the peninsula (Burkill 1935). Until the first half of the twentieth century, mungbean was being grown as a second crop in rice fields in Malaysia. In the monsoon tropics, mungbean is grown on dryland cultivation regimes as a rainy season crop, and on wetlands as a dry-season crop (Siemonsma and Lampang 1989).

The mungbean plant is very versatile. The seeds can be dried and stored for use at a later date or they can be germinated and eaten as four days old seedlings (bean sprouts). The whole plant can also be used as fodder. In South Asia, split mungbeans are cooked with spices and made into *dhal*. In Southeast Asia, in addition to eating them as bean sprouts, they are used in the preparation of confectionary, or made into fine noodles (vermicelli). It has also been recorded by Burkill that in the Malay Peninsula mungbeans undergo a long process in the preparation of 'song than' or vegetable cheese which involves the husking, splitting, soaking and boiling of the beans, and finally making it into a thin paste which is shaped and dried.

Mungbean is a 'free-threshing' pulse. The pounding stage (equivalent to dehusking in rice) is not necessary and therefore, there is no resulting waste product or loss of seeds from this stage with the mungbean. Consequently, compared to other pulses that require 'pod-threshing,' such as the horsegram and pigeonpea, the mungbean will be less likely than its 'pod-threshing' counterparts to preserve archaeologically. Instead, the waste product and loss of seeds for mungbeans are often a result of winnowing and sieving. Charring which leads to preservation may result from parching or dry-roasting of mungbeans. Although as stated above, the mungbean does not require pounding, there are some instances where pounding is used to split the seeds, such as in the preparation of *dhals* or to make a dried bean paste like in the Malay Peninsula as reported by Burkill (see preceding paragraph). At KSK, all the mungbean finds are split cotyledons or fragments thereof. Perhaps, pounding was used to split the beans in a manner similar to modern-day preparation of *dhal* or bean paste. The preservation of mungbeans at KSK is more likely a result of processing rather than cooking.

The identification of the *Vigna* species is achieved through the examination of the size and shape of the cotyledons, the length and placement of the plumule and the surface pattern of the seed coat. Mungbeans from the IoA reference collection were measured so that modern samples could be compared with archaeological samples and these are found in Table 6.14 together with other published measurements. The mungbeans found at KSK are small relative to the modern measurement range of the IoA reference collection and those cited in publications. However, it should be noted that the mungbeans from KSK have no testa whereas the modern mungbeans were all measured with the testa making the modern samples relatively larger. Early Neolithic finds from India measuring *ca.* 1.7-2.7 mm length and 1.5-2.1 mm width are deemed to be cultivated even though close in size to the wild progenitor (Fuller et al. 2004). The KSK samples are slightly larger than the Indian Neolithic samples but not as large as the modern domesticates possibly indicating an increasing size after domestication. It is considered that the larger seed sizes occurred by the end of the first millennium AD (Fuller and Harvey 2006). Fuller and Harvey (2006) predict that archaeological wild mungbeans to measure less than 3 mm length and 2 mm width; these measurements include shrinkage adjustments caused by charring. KSK mungbeans may fall slightly below the domesticated values but there is no reason to suppose they are wild since as discussed here, they were most probably introduced as full domesticates from India.

	length (mm.)		width (mm.)		thickness (mm.)	
Vigna radiata	mean	range	mean	range	mean	range
fresh IoA reference collection w/ testa (n=198)	4.70	3.70-5.60	3.70	3.00-4.20	3.50	3.00-3.80
charred IoA reference collection no testa (n=9)	3.58	2.37-4.64	2.81	2.36-3.37	2.93	2.48-3.35
charred IoA reference collection with testa (n=99)	4.36	3.31-6.5	3.06	2.05-4.1	3.19	2.16-4
fresh Digital Atlas of Economic Plants w/ testa		4.00-6.00		3.00-4.00		
fresh Flora of China		2.50-4.00		2.50-3.00		
fresh PROTA: Cereals & Pulses (2006)		2.50-4.00		2.50-3.00		2.5-3.00
fresh Fuller & Harvey 2006 w/ testa (n=5 populations)	3.7748	2.99-4.71	3.1605	2.64-3.65	3.0981	2.31-3.70
population 1 (n=20)	3.8975	3.21-4.43	3.074	2.91-3.44	2.756	2.31-3.15
population 2 (n=20)	3.5145	3.2-4.14	3.0985	2.64-3.44	3.0225	2.64-3.27
population 3 (n=20)	3.566	2.99-4.06	3.0755	2.64-3.34	3.1795	2.8-3.42
population 4 (n=15)	3.9	3.16-4.71	3.2913	3-3.55	3.42	3.2-3.61
population 5 (n=20)	4.027	3.6-4.61	3.296	2.76-3.65	3.193	2.39-3.7
fresh Miyazaki 1982		3.5-6.2				
charred from archaeological site KSK no testa (n=6)	2.59	2.4-2.91	1.97	1.8-2.28		
charred from archaeological site PKT no testa (n=11)	3.03	2.60-3.9	2.23	1.75-2.80	2.45	2.12-2.80
w/ testa (n=5)	3.09	2.9-3.6	2.38	2.05-2.75	2.69	2.4-3.00
charred from archaeological site Kanmer (n=109) [early to Late Harappa*	4.14	3.78-4.5	3.73	2.97-4.5	3	2.5-3.5
charred from archaeological site Rojdi (n=5) [2000-1700 BC]	2.57		1.82			
charred from archaeological site Tokwa (n=69) [Neolithic]	3.52	3.3-3.75	2.62	2.25-3	2.5	2.0-3.0
charred from archaeological site Jhusi (n=76) [Neolithic]	3.65	3.3-4	2.75	2.5-3	2.75	2.5-3
charred from archaeological site Ojiyana (n>24) [Chalcolithic]		3-3.5		2-3		1.5-3
desiccated from archaeological site Berenike w/ testa (1st-2nd c. AD)		3.30-4.20				

* the actual identification is *Vigna* sp. although the Early Harappa samples are identified as *V. radiata* (Pokharia et al. 2011).

Sources: Cappers 2006; Fuller & Harvey 2006; Pokharia 2008a, 2008b; Pokharia et al. 2009; Pokharia et al. 2011; Weber 1991

Table 6.14: Modern and archaeological measurements of *Vigna radiata.*

Fuller et al. (2004) warn that many of the characteristics of *V. radiata* and *V. mungo* (black gram) are shared, such as the size and general shape making identification difficult. However, distinct characteristics of both are the hilum, plumule length and testa pattern. Black gram has a raised hilum encircled by a lip whereas the hilum in mungbeans is flat or flush with the seed coat. Unfortunately, the hilum hardly ever preserves in charred remains and therefore, the most reliable identification tool to distinguish amongst *Vigna* domesticates is the ratio of length of the plumule to the total length of a split cotyledon (Fuller et al. 2004). The plumule of the mungbean measures *ca.* 3/4 of the cotyledon whereas in black gram the plumule is half the length of the cotyledon. The plumule length can only be measured when the cotyledons are split and in KSK, all mungbean specimens were cotyledons or fragments thereof. The plumules in the KSK seeds measured *ca.* 3/4 of the cotyledon (Figure 6.23). Finally, the testa of the mungbean has a distinct pattern of wavy rows made up of long, thin rectangular cells (Fuller and Korisettar 2004). At KSK neither the hilum nor testa preserved.

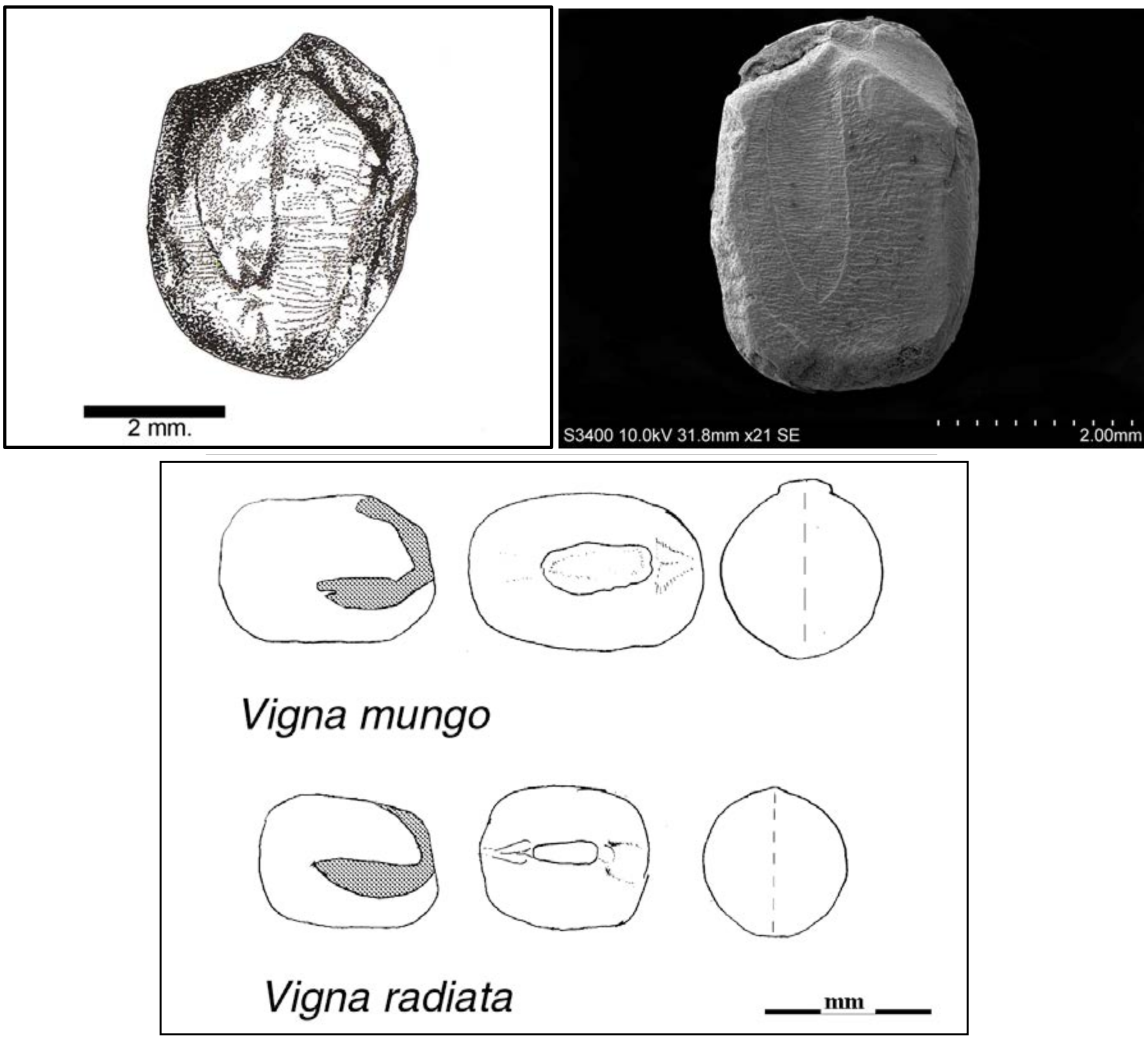


Figure 6.23: Top left: drawing of *Vigna radiata* cotyledon found at Khao Sam Kaeo TP57 US12 showing the size of the plumule. Top right: modern *Vigna radiata* cotyledon from IoA reference collection. Bottom: Identification key by Fuller showing the main difference between *Vigna radiata* (mungbean) and *Vigna mungo* (black gram). (Drawing in top left and image in top right by author; drawings at bottom by Fuller).

6.5.3.5 *Macrotyloma uniflorum* (Lamarck) Verdcourt
Common name: horsegram

Another important Neolithic pulse of South Asia (Fuller and Harvey 2006) is *Macrotyloma uniflorum* (horsegram). The earliest finds of horsegram are in the Greater Indus Valley *ca.* 2600-2000 BC and south India *ca.* 2300-1700 BC (Fuller and Harvey 2006). There is insufficient information regarding the origin of the wild progenitor of the horsegram but the probable centre of origin is in the savannahs and dry tropical evergreen areas of peninsular India where wild horsegram is reported (*ibid.*; Figure 6.21). To date horsegram has not been reported in any archaeological site in Southeast Asia.

Horsegram is grown as a dryland crop though it can be grown in areas with high rainfall during the dry season (Jansen 1989). It has the advantages to farmers of rapid growth, drought-resistance and tolerance to poor soil conditions. It is widely cultivated in the tropics mainly for its seeds which are used as a pulse although the whole plant is used for forage and green manure (Chen et al. 1994). The seeds may be eaten poached, boiled or fried, and are eaten whole, roughly grounded or pounded.

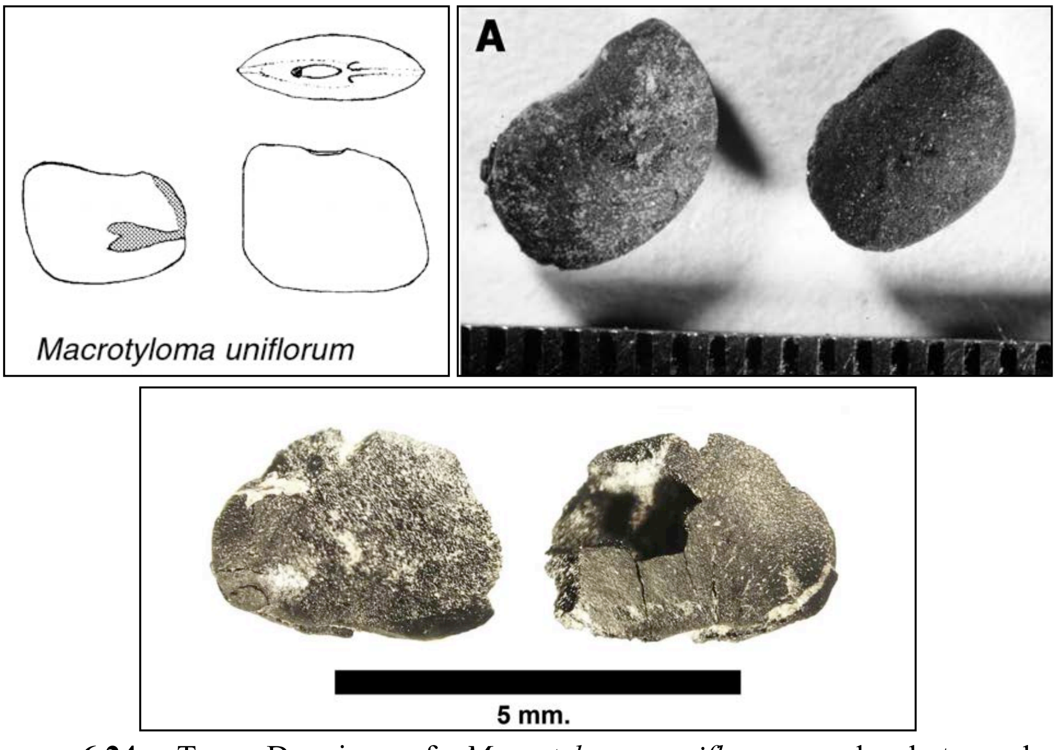


Figure 6.24: Top: Drawing of *Macrotyloma uniflorum* and photograph of archaeological horsegram from Sanganakallu, south India (SGK.98A.4). (Source: Fuller and Harvey 2006). Bottom: Image of horsegram from KSK TP128 US11 (Image by author).

From the lateral view, horsegram seeds are oblong, trapezoidal or orbicular-reniform, and are flat from the proximal view. Although in KSK the hilum was not preserved in either of the two seeds, these are usually small, thin and linear. The embryos measure a third of the length of the cotyledon. At KSK, both horsegram seeds were whole and still had some of the testa, although very brittle (Figure 6.24). A cracking testa seems to be another characteristic of archaeological samples from India as reported by Fuller and Harvey (2006).

	length (mm.)			width (mm.)			thickness (mm.)		
Macrotyloma uniflorum	mean	range	20% shrinkage	mean	range	20% shrinkage	mean	range	20% shrinkage
fresh Digital Atlas of Economic Plants w/ testa		5-6	4-4.8		2-4	1.6-3.2			
fresh Flora of China		3-4.2	2.4-3.36		2.8-3.5	2.24-2.8			
fresh Fuller & Harvey 2006 w/ testa (n=3 populations)		4.39-6.92	3.51-5.54		2.5-5.21	2-4.17		1.35-2.75	1.98-2.2
charred from archaeological site KSK w/ testa (n=2)	3.95	3.6-4.3		3.05	3-3.1		1.9		
charred from archaeological site PKT w/ testa (n=5)	3.514	2.65-3.92		2.526	2.05-2.98		1.61	1.4-1.8	
charred from archaeological site Kanmer (n=11) [Early to Late Harappa]	4.33	4.3-4.36		2.72	2.5-2.94		1.25	1-1.5	
charred from archaeological site Rojdi (n=9) [2000-1700 BC]	3.92			2.38					
charred from archaeological site Tekkalkota (1780-1540 BC)		4-6			3-4			2-2.5	
charred from archaeological site Jhusi (n=9) [Neolithic]	4.13	4-4.25		2.65	2.5-2.8		1.4	1.3-1.5	
charred from archaeological site Tekkalkota (330 BC)		4-6			3-4			2-2.5	
charred from archaeological site Ter (250 BC-250 AD)		4-9			4-5			2-3	
charred from archaeological site Ojiyana [Chalcolithic]		3.5-5.5			2.5-4			1-2	
charred from archaeological site Narhan I (n=9) [1400-800 BC]		4.25	3.5-5		2.8	2.2-3.4	1.75	1.5-2	
charred from archaeological site Sanghol (n=12) [100-300 AD]		4.125	3.25-5		2.75	2.5-3	1.5	1-2	

Sources: Fuller & Harvey 2006; Pokharia 2008b; Pokharia et al. 2009; Pokharia et al. 2011;Vishnu-Mittre 1974; Weber 1991

Table 6.15: Modern and archaeological measurements of horsegram including a shrinkage corrective factor.

Modern horsegram measurements with the testa are found in Table 6.15 together with some of the published measurements of archaeological samples. The modern material is not charred and a correction factor of -20% for shrinkage due to carbonisation is applied

(Fuller 2007b). More charring experiments are needed in order to distinguish the range of shrinkage for horsegram. However, the charring experiments for mungbean (Chapter 5) show a wide degree of variance in size between the pulses that retained their testa and those that did not (Table 5.8). The -20% shrinkage correction factor may therefore be large but it may also correct for the large grain size associated with modern cultivars, an increase that happens over time. Compared to the modern samples, the KSK seeds are smaller. Compared to the archaeological samples, the KSK horsegrams are larger than those from Rojdi, India but lie at the lower end of the range of archaeological samples from Terr and Tekkalkota.

Burkill (1935) reported that horsegram was introduced in the Malay Peninsula by the Europeans in the early 1900s, but it is conspicuously absent from modern agriculture in this area. Horsegram is another crop found at KSK which either suggests South Asian presence on site or that a package of crops travelled into Southeast Asia by networks of exchange with India. Horsegram found at KSK represents the earliest archaeological find of its kind although it seems it was either not adopted as a crop or dropped from the original package. The reasons for this are unknown and one can only speculate that it may not have been to the tastes of the Southeast Asian population as much as the mungbean or rice. Horsegram testa is relatively thick and cannot easily be converted into flour to make noodles (Kyi et al. 1997) and also, this pulse is not normally used as sprouts (only one entry was found referring to horsegram eaten as sprouts in rural areas of southern India - Kadam et al. 1985). These culinary limitations may be some of the reasons why horsegram does not cater to Southeast and East Asian tastes. The European introduction in the 1900s of horsegram was '*called the most successful of the cover crops tried*' and yet it was used for fodder and green manuring rather than food (Burkill 1935). Furthermore, horsegram is known as a poor man's pulse eaten in southern India (van Wyk 2005). Horsegram, like the mungbean, can be transported as a dry seed so it is possible that it was being brought in by the South Asian populations for their own consumption and planting was not attempted in KSK.

Horsegram is a 'pod-threshing' type of pulse requiring several stages of crop processing including cutting, threshing, pounding and several winnowing stages. This means that there are more chances of losing plant parts with 'pod-threshing' types than compared to 'free-threshing' types including the loss of seeds during the crop-processing stages. This leads to a higher likelihood of archaeological preservation, compared to the 'free-threshing' pulses, such as those belonging to the genus *Vigna*. In the South Asian Neolithic these characterisations may explain the larger amounts of horsegram compared to *Vigna* (Fuller and Harvey 2006). However, more *Vigna radiata* seeds were found at KSK compared to horsegram possibly because more mungbean was eaten. Perhaps the local population preferred mungbean to horsegram which is why it has higher representation in the site but also in modern Thailand.

Only two seeds of horsegram were recovered from KSK. One seed is associated with mungbean (TP128 US11) and the other is found with unidentified Fabaceae seeds. Fuller and Harvey (2006) compiled a list of archaeological sites in India where archaeobotany has been conducted and it showed that 75% south Indian sites have evidence of both pulses horsegram and mungbean in the assemblage suggesting that these pulses may have been a crop package (see Appendix 6.8). This seems to be the case in the Southern Peninsula of Thailand with both KSK and PKT having evidence of horsegram and mungbean. This co-occurence of Indian pulses is more visible in PKT and this will be discussed in Chapter 8.

6.5.3.6 *Vigna* cf. *umbellata*

Vigna umbellata **(Thunb.) Ohwi and Ohashi**
Common name: ricebean
Thai names: thua daeng, thua pae / thua ae, ma pae / ma pee

Ricebean is a traditional crop that is grown in South, Southeast and East Asia (Isemura et al. 2011). Although in the past it was suggested that ricebean was a native of South and Southeast Asia (van Oers 1989), it is now established through genomic studies that the original area of domestication for the ricebean is Southeast Asia where the wild progenitor *Vigna umbellata* var. *gracilis* is found and the greatest genetic diversity occurs (Isemura et al. 2011; Lawn 1995; Figure 6.25). Wild ricebean grows in a large area covering tropical monsoon forests of Nepal, Myanmar, Thailand, Malaysia, Laos, Indonesia and southeast China (Isemura et al. 2011; Tomooka et al. 2002). In Thailand, wild and weedy varieties are found mainly in the north and it is considered as a consequence of genetic studies that ricebean was domesticated in northern Thailand

(Seehalak et al. 2006). Furthermore, a close phylogenetic relationship has been established for the ricebean and the azuki bean (*Vigna angularis*) (Isemura et al. 2011).

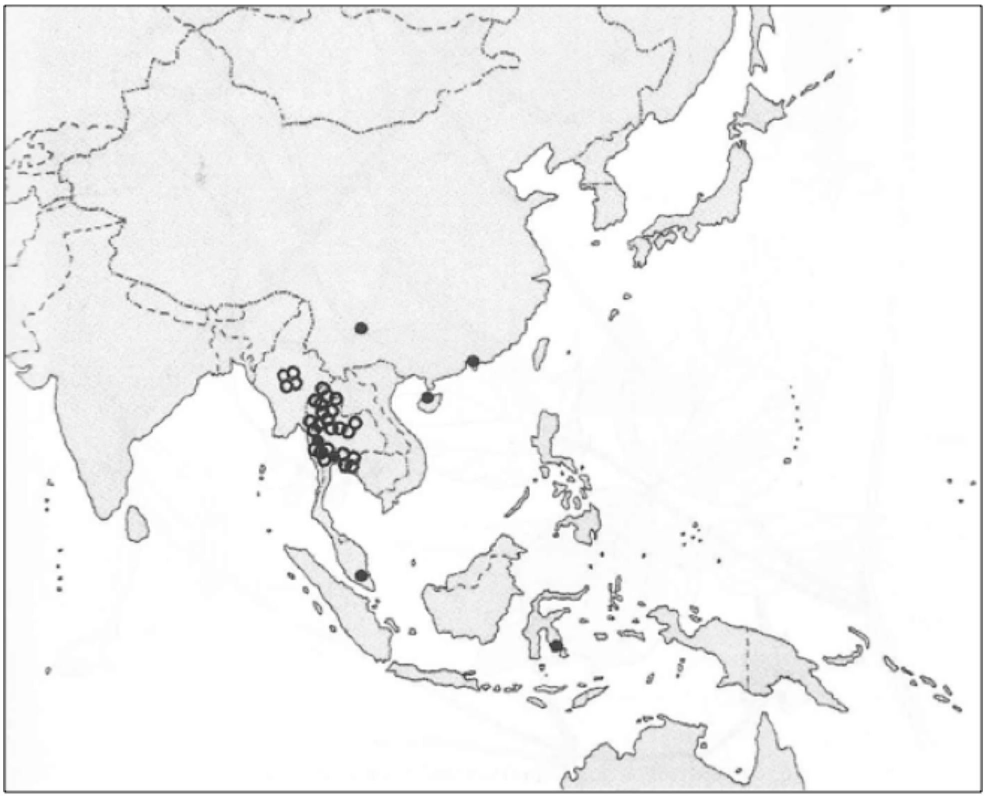


Figure 6.25: Distribution map of wild *Vigna umbellata* with 'o' symbolising Tomooka's direct collection and '•' symbolising herbarium specimens (Source: Tomooka et al. 2002).

Ricebean is still an important crop for both local consumption and trade by the hill tribes of northern Thailand (Anderson 1993). Some hill tribes in northern Thailand boil the immature pods with salt, this being considered a traditional preparation method (Tomooka et al. 2002). Boiled ricebean pods are sold in village markets in Thailand and in India (Arora et al. 1980; *ibid.*). Ricebean is also cultivated in association with rice by the hill tribes in north Thailand (Rerkasem et al. 1995). It is either used as intercrop or in rotation with the main cultivar, rice or maize. In northeastern and eastern India, it is cultivated in shifting cultivation fields. For example, the Adi from Arunachal Pradesh plant ricebean and other pulses, vegetables and cereals as part of the *jhum* system, which is shifting cultivation (Sarangi 2002). This diversity in crops allows them to maintain balanced nutrition, access to medicinal plants and conservation of their land and plant species. Ricebean has some advantage as an intercrop as the plants smother weeds, does not need much care and is fairly pest-free growing and even when stored (van Oers 1989; cf. Burkill 1935). Ricebean is normally broadcasted.

Ricebean is best suited to humid tropical lowlands and it can thrive at altitudes of up to 2,000 m. In the past, it was grown in the lowlands as a rotation crop of long-season rice varieties (Tomooka et al. 2002). It can grow in different types of soil though fertile loams are best. It is moderately drought resistant.

There are many ways of eating this legume. Ricebean is eaten as a dried pulse, as raw green pods and as a vegetable by cooking the immature pods, sprouts and young leaves (Ochse 1977; Tomooka et al. 2002; van Oers 1989*)*. The beans are sometimes also cooked with rice. Other uses include fodder, green manuring, cover crop and traditional medicine.

	length (mm.)			width (mm.)			thickness (mm.)		
Vigna umbellata	mean	range	20% shrinkage	mean	range	20% shrinkage	mean	range	20% shrinkage
IoA reference collection w/ testa (n=2) Myanmar	7.185	7.11-7.26	5.69-5.81	4.16	3.95-4.36	3.16-3.49	3.46	2.77-3.46	2.22-2.77
IoA reference collection w/ testa (n=2) Myanmar	5.01		4	2.76		2.21			
Digital Atlas of Economic Plants w/ testa		6-9	4.8-7.2		3-5	2.4-4			
cultivated Isemura et al. 2010	10.3	10.1-10.7	8.08-8.56	6	5.8-6.1	4.64-4.88	7	6.9-7.2	5.52-5.76
wild Isemura et al. 2010	4.3	4.3-4.4	3.44-3.52	2.2	2.1-2.2	1.68-1.76	2.5	2.4-2.5	1.92-2
Flora of China		4-9	3.2--7.2		3-3.5	2.4-2.8			
Tomooka et al. 2002 w/ testa	4.4		3.52	2.6		2.08	2.2		1.76
wild Tomooka et al. 2000 (n=31)	4.85	3.9-7.8	3.12-6.24	2.35	1.7-3.4	1.36-2.72	2.98	2.1-4.1	1.68-3.28
Fuller & Harvey 2006 w/ testa (n=2 populations)	5.89	5.04-6.46	4.71	3.63	2.6-3.94	2.90	2.85	2.45-3.15	1.96-2.52
Prosea 1989		5-10	4-8		2-5	1.6-4			
charred from archaeological site KSK no testa (n=1)	4.29			2.81			2.26		
charred from archaeological site PKT no testa (n=1)	4.08			2.39			2.55		
Source: Fuller & Harvey 2006; Isemura et al. 2010; Tomooka et al. 2002, 2000									

Table 6.16: Modern domesticated and wild, and archaeological measurements of ricebean including a shrinkage corrective factor**.**

The overall shape and size of seeds are the main identification criteria (Figure 6.26). The seeds and hilum of the ricebean are elliptic. The hilum is protruding and measures *ca.* 2.5 x 1 mm (Tomooka et al. 2002). The hilum has burned away or fallen off from the KSK sample but the scar clearly shows its location and is 2.1 mm long. Measurements of modern ricebean are found in Table 6.16 although these contain the testa whereas the KSK sample has no preserved testa. Likewise, because there was no charred comparative material, the -20% shrinkage factor was applied. The KSK seed is still smaller than the general range of measurements of modern seeds even when the shrinkage factor was applied. Modern wild ricebean from the IoA reference collection measured 5.01 mm x 2.76 mm (and with shrinkage correction: 4 mm x 2.21 mm), and those from Isemura et al. (2010) and Tomooka et al. (2000) are even smaller. The KSK seed is plumper than the wild ricebean. Charring normally causes a decrease in length but a relative increase in width and thickness (Chapter 5).

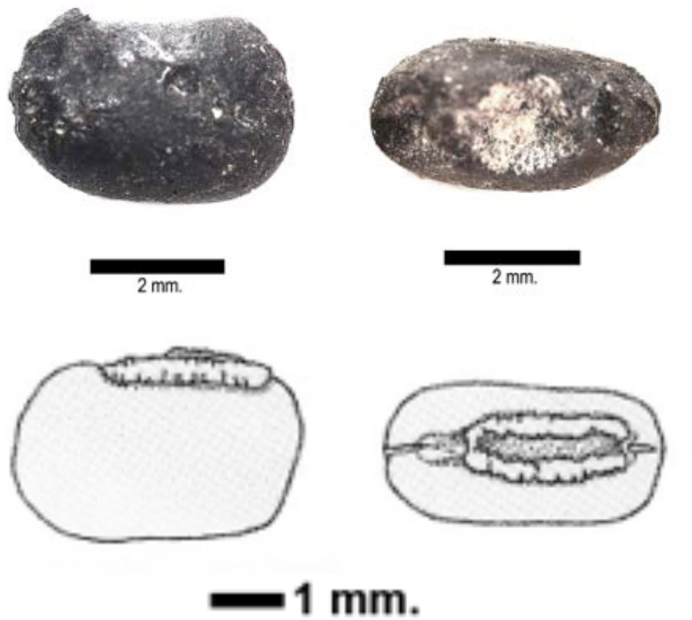


Figure 6.26: *Vigna umbellata.* Top: archaeological seed from TP117 US8 (Image by author). Bottom: line drawing by Tomooka et al. 2002.

Figure 6.27 shows the archaeological ricebean next to modern domesticated and wild forms from the IoA reference collection. The photographs found in Figure 6.27 have been adjusted for a shrinkage factor of -20%.

The evidence for this crop at KSK is limited as only one complete seed was found. However, it is of importance as it is one of the few Southeast Asian cultivars in the archaeobotanical assemblage. KSK and PKT are the first sites from which archaeological ricebean in Southeast Asia has been reported. Using the identification criteria spelt out above, the ricebean found in KSK does not fall neatly into the domesticated category but is also not of the wild type. Perhaps it was in the early stages of domestication where an increase in grain size is only beginning. The question arises as to why in the Late Prehistoric period the local population in the peninsula of Thailand consumed this pulse but not mungbean, not even wild mungbean when it would have been available. If the ricebean was being cultivated and probably domesticated by the Late Prehistoric period, why has it not been found in earlier archaeological sites? It may be due to the lack of archaeobotanical studies of the region even though as mentioned in the mungbean section, pulses are relatively large and should be visible with the naked eye. It may also be a function of the sites that have been excavated so far. Most archaeology has concentrated on burial sites (Chapter 3) and unless beans were buried alongside human remains (e.g. rice burials from Noen U Loke and Non Muang Kao) or left in burial goods, they would only be found in sites with habitation.

Figure 6.27: Left - size comparison of archaeological ricebean from KSK (centre) flanked by a domesticated ricebean from Myanmar (left) and a wild ricebean from Thailand (right). Right - size comparison of the archaeological ricebean with the reference material after applying a -20% shrinkage factor (Images by author).

6.5.3.7 *Cajanus* sp. / cf. *Cajanus*

Cajanus cajan (L.) Millsp.
Common names: pigeonpea, congo pea, red gram
Thai names: thua rae / tūa rê, thua maetaai, ma hae

Several domestication centres for *Cajanus cajan* have been suggested including Malaya, Africa (Purseglove 1968; Thothathri and Jain 1980) and South Asia. Although this pulse is widely cultivated in the dry tropics, it is now established that the pigeonpea is of South Asian origin, which is also the centre of diversity (Fuller and Harvey 2006). The wild progenitor is *Cajanus cajanifolia* which occurs in the eastern part of the Indian Peninsula (Fuller and Harvey 2006; van der Maesen 1989). India's *Cajanus* production is estimated at *ca.* 85-90% of the total world production (van der Maesen 1989, 1995).

Together with the mungbean, ricebean and cowpea, the pigeon pea is an important crop cultivated by the hill tribes in Thailand (Anderson 1993). In Malaysia, they are planted in paddyfield dikelets and in gardens up to 2,000 m above sea level (Ochse 1977). It thrives on fertile soils and can withstand moisture or drier areas. It is used as an intercrop with millets, cotton or groundnut. In Laos, upland farmers from many ethnic groups cultivate both pigeonpea and mungbean alongside rice (Roder et al. 1996).

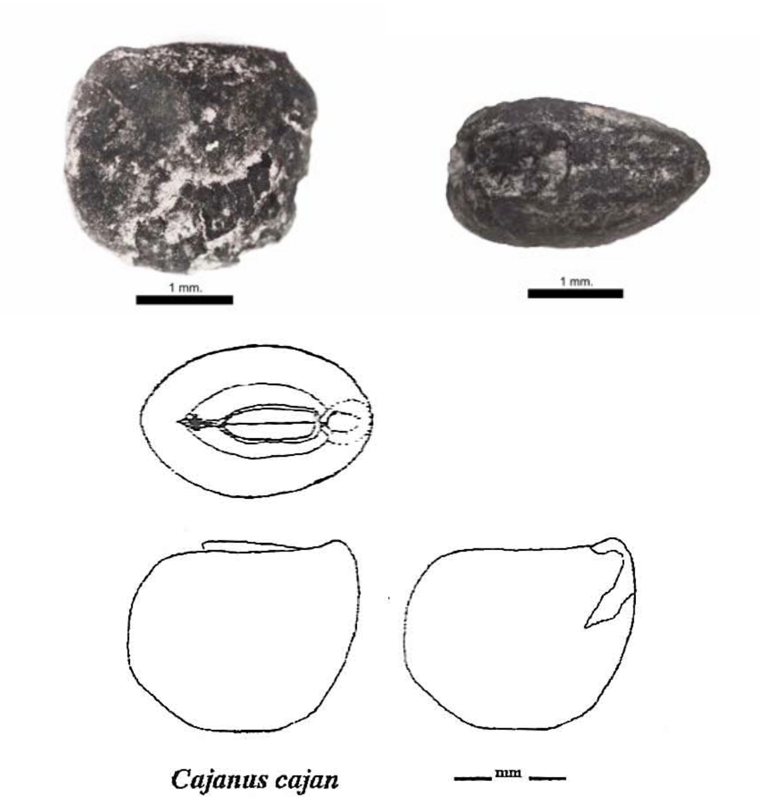


Figure 6.28: Images of *Cajanus* sp. from TP105 US3 and line drawings of modern reference material from India (Images by author; line drawings in Fuller et al. 2004).

It is sometimes suggested that the movement of this crop from India to Africa happened *ca.* 2200 BC (van der Maesen 1989). The earliest evidence of pigeonpea in Africa is from the early 1884 report by Schweinfurth of a single seed found in Dra Abu el-Nga, Egypt dating *ca.* 2400-2200 BC (Cappers 2006; van der Maesen 1989). However, this early date should be viewed with caution as the evidence of domesticated pigeonpea from India dates to the middle of the second millennium BC (Fuller and Harvey 2006). There are very few sites from India with evidence of pigeonpea (Appendix 6.7). The introduction of pigeonpea to Southeast Asia, as was suggested by Burkill in 1953 based on linguistics, dates to the last centuries BC. Burkill proposes that the pigeonpea came with Indian traders that travelled across the Bay of Bengal on trading voyages to *Subarnabhumi* (De 1974). The evidence from KSK and PKT accords with this Burkill early hypothesis. So far, the KSK and PKT *Cajanus*-type seeds are the earliest found in Southeast Asia.

Pigeonpea is eaten as a pulse or vegetable but it has other uses such as animal feed (seed coats and crushed seeds), fodder (green leaves), fuel wood (dry stems) and medicine (leaves used in an infusion or decoction) (Burkill 1935). The seeds, both ripe and immature, leaves, young pods and sprouts are eaten (van Wyk 2005). Like the mungbean, the pigeon pea is used to prepare *dhal* in India; the seeds are dried, the testa removed and the cotyledons split. In Southeast Asia, the preference is for fresh seeds and pods eaten as vegetables though roasted seeds are also eaten (van der Maesen 1989).

	length (mm.)			width (mm.)			thickness (mm.)	
Cajanus cajan	mean	range	20% shrinkage	mean	range	20% shrinkage	mean	range
Digital Atlas of Economic Plants w/ testa		6-9	4.8-7.2		4-7	3.2-5.6		
Flora of China w/ testa	5		4					
Fuller & Harvey 2006 w/ testa (n=6 populations)		4.59-7	3.67-5.6		4.21-6.41	3.37-5.13		3.22-5.65
population 1 (n=20)	5.2865	5-5.72		5.0495	4.6-5.41		3.983	3.57-4.22
population 2 (n=15)	5.9713	5.08-7		4.7626	4.21-5.05		3.9867	3.22-4.49
population 3 (n=20)	5.1295	4.59-5.67		5.06	4.45-5.77		3.9285	3.44-5.65
population 4 (n=20)	6.146	5.78-6.44		5.201	4.72-5.55		4.214	3.95-4.64
population 5 (n=20)	6.144	5.21-6.81		5.728	4.98-6.41		4.4485	3.39-5.08
population 6 (n=20)	5.9175	4.66-6.76		4.973	4.34-5.46		4.3225	3.7-4.89
charred *Cajanus* sp. from archaeological site Gopalpur (n=2)	3			2.75	2.7-2.8		1.19	1.18-1.2
charred *Cajanus* sp. from archaeological site Sanganakallu		4.1-4.7			3.6-4.4			1.4-2
charred *Cajanus* sp. from archaeological site KSK no testa (n=1)	3.33			3.07			2.07	
charred cf. *Cajanus* from archaeological site KSK no testa (n=1)	3.95			3.39				
charred *Cajanus* sp. from archaeological site PKT no testa (n=1)	2.3			2			1.6	
Source: Fuller et al. 2004; Fuller & Harvey 2006, unpublished								

Table 6.17: Modern and archaeological measurements of pigeonpea including a shrinkage corrective factor.

Problems with identification have affected archaeological citing for the pigeonpea. The description of pigeonpea as a neutral pea-shape is misleading and causes misidentifications. For example, the Abyssinian pea (*Pisum abyssinicum)* from Berenike dating to the early centuries AD was identified originally as pigeonpea (Cappers 2006). Another problem with identification is the difficulty in distinguishing between the wild and domesticated variety. Domesticated pigeonpea seeds are flat in the proximal view and are not uniformly shaped in the lateral view. They can be either kidney-shaped, round or squarish (Fuller and Harvey 2006). Wild pigeonpea are flatter than the domesticated variety and also possess a hilum with a ring-like structure. However, the hilum does not always preserve archaeologically. The best identification criterion if the cotyledons are split is the shape of the plumule which is diagonal like an apostrophe (*ibid.*). The whole seeds from KSK have not been split open so the plumule shape has not been studied. However, the general shape of the seeds from KSK is comparable to modern reference collections (Figure 6.28). The pigeonpea seeds from KSK are slightly smaller than modern collections even after factoring in shrinkage (Table 6.17).

6.5.3.8 cf. *Lablab*

Lablab purpureus L. (Sweet)
Common names: hyacinth bean, bonavist bean, dolichoris semen (pharmaceutical)
Thai names: thua paep

The hyacinth bean is a native of tropical east Africa although India and Southeast Asia have often been proposed as alternative areas of origin (Shivashankar and Kulkarni 1989). There may be scant evidence for early archaeobotanical remains in Africa but genetic studies confirm the hyacinth bean to have been domesticated in Africa (Fuller and Harvey 2006). Although there is a high diversity of the crop in India, the wild progenitor *Lablab purpureus* subsp. *uncinatus* occurs in Africa but not in India (for wild species in tropical Africa see Verdcourt 1970). It therefore follows that a very early introduction of this crop from Africa to India would account for such diversification (Fuller 2002). In fact, finds in India date to as early as the second millennium BC (Appendix 6.7; Fuller 2011b; Fuller et al. 2007c).

The immature pods of the hyacinth bean are a popular vegetable in Southeast Asia. Other parts that are eaten as vegetables are the leaves, young shoots and inflorescences (Shivashankar and Kulkarni 1989). In South Asia, it is normally used as a pulse such as made into *dhal* although immature seeds are also boiled or roasted. Other uses are for fodder, green manure, erosion control, as a cover crop and traditional medicine.

The hyacinth bean grows well in hot climates between 18-30°C and is drought tolerant but can grow in areas where rainfall is 200-2,500 mm per year (Shivashankar and Kulkarni 1989). Although it is a plant that prefers the lowlands, it is also grown as a dryland crop in altitudes up to 2,000 m. Given these conditions, it is a crop that could be grown in Chumphon province where KSK is located.

The seeds are variable in shape ranging from oblong to reniform with a long linear hilum. Compared to horsegram, the lateral ends are more smoothly curved (Fuller and Harvey 2006). The best distinguishing mark is the hilum which extends to almost half of the circumference of the seed laterally and is covered by a keeled strophiole (*ibid.*). Measurements of modern populations of the hyacinth bean range from 7.5-13.22 mm long, 5.32-9.95 mm wide and 3.07-6.6 mm thick (*ibid.*).

There is only a large fragment of a cotyledon at KSK and therefore cannot be identified with certainty (Figure 6.29). However, it would be possible for the hyacinth bean to have been part of the Indian package of crops brought across the Bay of Bengal in this early period.

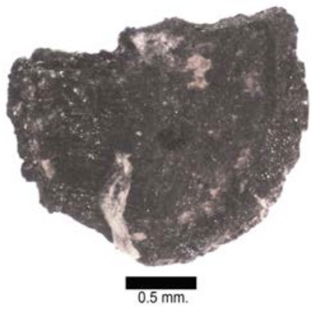


Figure 6.29: Cotyledon fragment identified as cf. *Lablab* from KSK TP130 US6 (Images by author).

6.5.3.9 A few notes on pulses (Fabaceae)

There is some archaeobotanical evidence for pulses in Southeast Asia other than these studies at KSK and PKT. These sites are listed in Appendix 6.9. Most of the identifications have been done to genus level and the few that have been narrowed down to species level are rejected on the basis of misidentification. The earliest finds are in cave sites in the northwest of Thailand, namely Spirit Cave, Banyan Valley Cave and Tham Pa Chan (Steep Cliff Cave). These caves are hunter-gatherer sites and show early gathering of pulses. All investigations at the sites where pulses have been found used flotation or dry-sieving to retrieve plant remains. The discovery of plant remains using these methods indicates yet again the value of archaeobotanical methods in fieldwork.

At KSK, seeds from the genus *Vigna* (namely mungbean, ricebean and *Vigna* sp. and *Vigna* spp.) are the pulses that occur most frequency. *Vignas* are annual legumes that thrive in warm weather (Lawn 1995). Most of the *Vignas* have high nutritional values as pulses, such as *V. radiata* and *V. umbellata* but as discussed in the preceding sections, they also have other uses such as for eating as vegetables, fodder, green manuring and cover crops. Many of them are also adapted to dry and tropical habitats. These qualities would have made the Asian *Vignas* attractive cultivars.

The charring experiments provided some interesting results regarding shrinkage in pulses. It has been observed that when the seed coat in pulses is destroyed, shrinkage greatly increases. These results were observed in the charring experiments conducted by the author and by Fuller and Harvey (2006). Table 6.18 shows the percentage of shrinkage found in mungbeans and soybeans. Both pulses were placed in the fire with seed coats. Soybeans generally retained their seed coats. Although in the charring experiment, the shrinkage percentage for mungbeans without testa veered from the -20% shrinkage adjustment used in this study, it shows that there definitely is a need to adjust measurements of modern seeds to incorporate these changes.

	length % shrinkage / increase	width % shrinkage / increase	thickness % shrinkage / increase
Vigna radiata			
fresh (n=198)			
charred no testa (n=9)	-23.47%	-15.76%	4.30%
charred w/ testa (n=99)	-6.80%	-16.84%	-7.58%
Glycine max			
fresh (n=135)			
carbonised w/ testa (n=66)	-3.77%	-16.09%	-38.91%

Table 6.18: Results from the charring experiments showing the percentage of shrinkage or increase for mungbean and soybean.

6.5.4 The Cash Crops: evidence of exchange networks

A central theme in the archaeology of KSK is the existence of long-distance networks and the presence of an urban site that acted as an entrepôt in Late Prehistory. In the archaeobotanical record, the evidence most indicative of exchange are cash crops, including field crops used in craft production (e.g. fibres), and perennial fruits. At KSK, there is evidence to suggest a marketplace for items such as long pepper, tree cotton and fruits as seen in Table 6.19. It is proposed that both long pepper and tree cotton were brought to KSK whereas fruits, specifically *Citrus*, were probably cultivated in KSK or nearby.

Sample	*Piper longum*	cf. *Gossypium*	rind	cf. *Citrus* rind	*Citrus* sp. rind	fruit pedicel	fruit rind & septum	TP context	US context
TP52 Sample 1	x							platforms	
TP52 Sample 2	x		x					platforms	
TP54 Sample 1	x							platforms	
TP57 US6			x					burial	nearby occupation
TP62 Sample 1				x				platforms	
TP67 US2	x							nearby occupation	erosion
TP67 US4					x			nearby occupation	erosion
TP105 US3	x							possible habitation	posthole dug into bedrock, contains a lot of charcoal
TP110 US2	x							house, settlement	house, contains a lot of charcoal
TP110 US3	x		x			x		house, settlement	house
TP110 US4	x							house, settlement	house
TP117 US4			x					platforms, burial	second platform
TP117 US8	x		x	x			x	platforms, burial	posthole
TP119 US5	x		x					possible habitation	
TP130 US1			x					nearby occupation	
TP130 US3	x							nearby occupation	after KSK period
TP130 US5	x							nearby occupation	third cultural deposit
TP130 US6		x		x				nearby occupation	third cultural deposit
TP130 US7					x			nearby occupation	second cultural deposit
TP130 US8	x							nearby occupation	1st cultural deposit
TP132 US1	x							house, fireplace, terraces, glass working area, cremation area	possible Ayutthaya period agricultural area?
TP132 US7				x				house, fireplace, terraces, glass working area, cremation area	second occupation layer, rebuilt terrace
TP136 US8	x							uplands, hinterland	
no. of samples	15	1	7	4	2	1	1		
ubiquity (n=85)	18%	1%	8%	5%	2%	1%	1%		
NISP	177	1	29	9	7	1	1		

LEGEND:
no. of samples - refers to no. of samples in the sampled population containing specified taxon
NISP - Number of Identified Specimens

Table 6.19: Cash crops found at KSK and their context.

6.5.4.1 cf. *Citrus* / *Citrus* sp.

Cultivars from the genus *Citrus* are distributed throughout the world, especially the tropics and subtropics but are domesticates of South, East and Southeast Asia, specifically of eastern India, Burma and southern China (Burkill 1935; Roose et al. 1995; Zohary et al. 2012). Trees of some wild species are still found in Borneo, Malaysia and Indonesia, and Yunnan province in China has high genetic diversity (Roose et al. 1995). Tanaka (1954) posited northeastern India and northern Burma as the primary centre of origin of *Citrus,* with China as a secondary centre of distribution. However, some authors have argued that a rich diversity of wild and cultivated *Citrus* is found in Yunnan and should therefore form part of the primary centre of origin alongside NE India and N Burma (Gmitter and Hu 1990). Most botanists agree there are only four true species of *Citrus,* namely *C. medica* (citron)*, C. reticulata* (mandarin)*, C. maxima* (pomelo) and *C. halimii.* All other cultivated species of *Citrus* are deemed to be hybrids from the first three true species (Mabberley 1997). For example, lemons and limes are all post-domestication derivatives of citron (*C. medica*). Only citron was grown in the Mediterranean Basin by the end of the fourth century BC (Lippi 2012; Zohary et al. 2012). Lemons and Seville oranges were differentiated during the Roman period (Mabberley 1997). A recent study by Kumar et al. (2012) has included three more species as true species, namely *C. indica* (Indian wild orange), *C. latipes* (Khasi papeda) and *C. hystrix* (Melanesian papeda). Figure 6.30 shows the distribution of four wild *Citrus* species including *C. maxima* discussed below. 'Tanaka's line' represents the division where development and spread of *Citrus* probably took place south of the line whereas north of the line is where the closely related genus *Fortunella* (kumquat genus) is found.

Citrus trees grow best in mild warm areas with moisture. It can therefore be cultivated in three distinct climate zones; subtropical, semi-tropical and tropical. The genus *Citrus* is economically important mainly as a fresh fruit although other parts of the fruit (e.g. the rind), the flowers and leaves are used for the extraction of essential oils and medicine. Other uses are as spices and cattle feed (Verheij and Stone 1991).

It has been noted in archaeobotany that the seeds and rind of the genus *Citrus* are difficult to narrow to species level based on morphological criteria (van der Veen 2011).

This is largely due to hybridisation but also the difficulty in distinguishing between wild and naturalised cultigens. At KSK, only carbonised rind fragments have been found across the entire site and these have been identified as either cf. *Citrus* or *Citrus* sp. The rind of *Citrus* fruits is leathery and the exocarp is densely glandular. The genus *Citrus* is readily identified by oil glands spread throughout the entire plant including the rind. These oil glands may be pellucid if found in leaves, or forming pits and oily dots when they are located in a thick part of the plant such as the rind. The gland dots are responsible for the fragrant oils found in the genus *Citrus*.

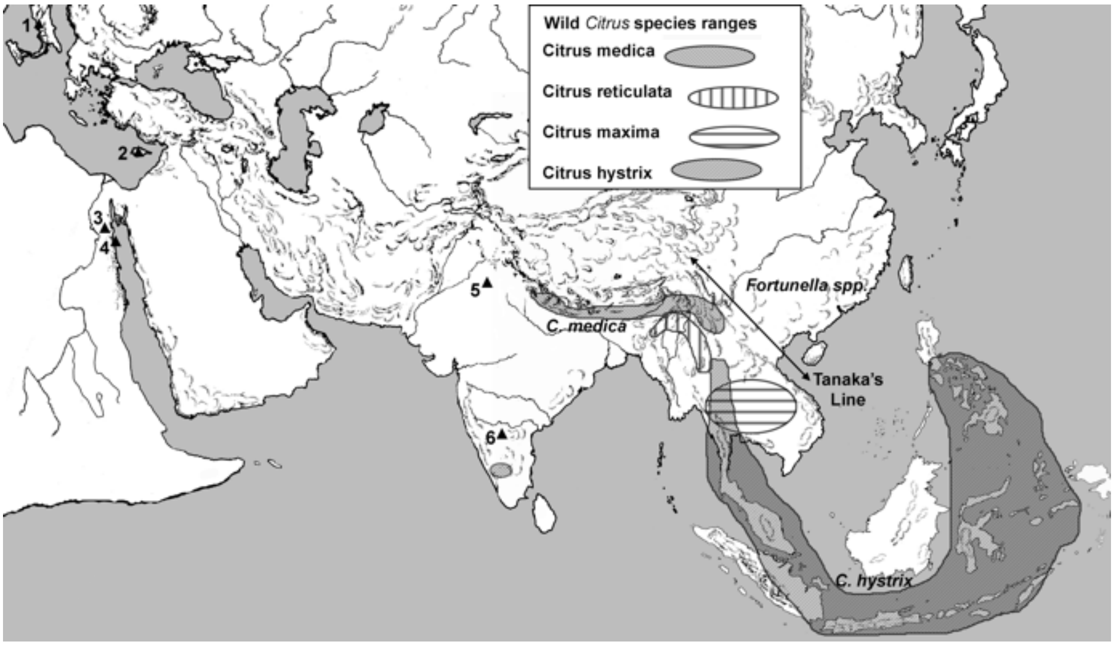


Figure 6.30: Distribution of wild *Citrus* (courtesy of Fuller).

Citrus maxima (Burm.) Merr.
Common names: pummelo, shaddock, pomelo
Thai names: som-o, ma-o

A potential match with the KSK rind fragments is the cultivar of Southeast Asian origin *Citrus maxima* (pomelo). The remains from KSK have been compared to modern rind specimens of citruses bought at markets and shops, and a match with the genus *Citrus* has been established. Figure 6.31 shows a close-up of the fragments from KSK compared to modern rind of *Citrus maxima.* Appendix 6.10 shows six cultivars from the genus *Citrus* before and after charring. The closest match is with the *Citrus maxima* dried rind. The similarities in the glandular structure can be seen although more work involving charring and close-up imagery of cultivars and wild *Citrus* fruit rind is essential in order to establish the species. Furthermore, more charring experiments should be done in anoxic conditions as this might curtail the oil glands from expanding too much and becoming deformed, also different heating lengths at varying temperatures are needed.

The definite origins of pomelo are still unknown but Thailand has been proposed as a possibility. This is based on environmental niches and the best match of cultivars (Niyomdham 1991). Pomelo is a fruit that is grown in gardens as well as small orchards. It is a tree that thrives in average monthly temperatures of 25-30°C, in climates with some cool and dry months and an annual rainfall between 1,500-1,800mm. The best pomelo orchards in modern Thailand are found on riverbanks or former riverbanks (Niyomdham 1991). KSK fits all the criteria for optimal growing conditions of pomelo and today, a commercial pomelo orchard is located in Valley 2 at KSK.

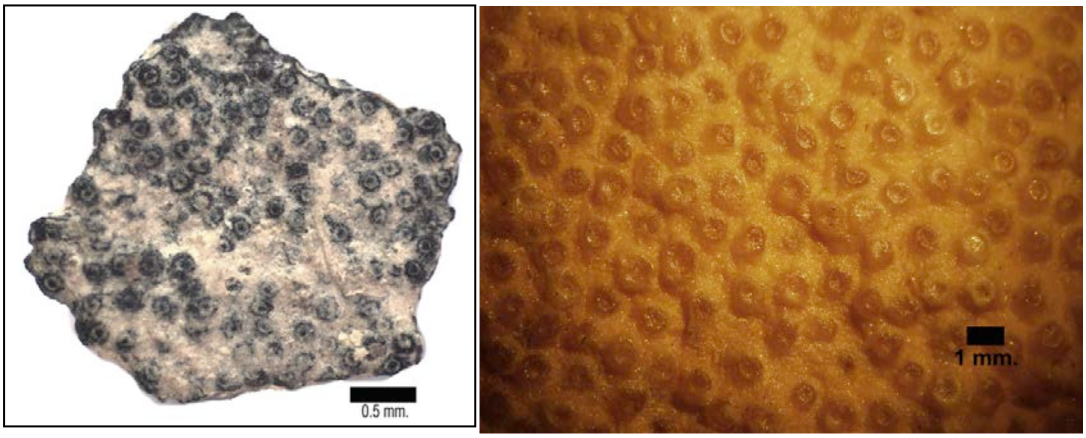


Figure 6.31: Left: *Citrus* sp. rind fragment from TP102 US10; Right: Rind of fresh pomelo (Images by author).

6.5.4.2 cf. *Gossypium*

Gossypium arboreum L.
Common name: tree cotton

There are four types of cultivated cotton; two are native to the Old World and two are from the New World. *Gossypium herbaceum,* L. originates from Africa whereas *G. arboreum L.* is native to South Asia where it is reported to have the widest crop diversity (Zohary et al. 2012). Although some evidence of weedy forms of *G. arboreum* has been reported in southern Sindh and the central Deccan (Fuller 2008b), the wild progenitor of *G. arboreum* is unknown and therefore the route towards domestication is poorly understood (Wendel 1995). The other two cotton crops, *G. hirsutum* L. and *G. barbadense* L., are New World species (Wendel 1995; Zohary et al. 2012).

The earliest evidence of cotton dates to *ca*. 5000BC from Mehrgarh in the Indian subcontinent (Fuller 2008b; Moulherat et al. 2002; Zohary et al. 2012). It has been argued that the Mehrgarh sample is the earliest evidence of cotton use although the cotton was probably wild (Zohary et al. 2012). It is presently impossible to distinguish cotton archaeological remains between the different cultivated types of cotton and wild cotton (Fuller 2008b). More evidence of cotton use in the form of textile fragments is found in Harappan sites from South Asia dating *ca.* 2600-2000 BC (Fuller 2008b; Zohary et al. 2012). Cotton fibre fragments dating to *ca.* 4400 BC from Jordan, northern Arabia have also been reported and together with the samples from Mehrgarh which suggest cotton cultivation was in place in the fifth millenium BC (Fuller 2008b). Because there is no evidence for textile production in prehistoric Africa until the Roman period but there is early cotton use evidence in the Indian subcontinent, the Arabian archaeological cotton remains have been interpreted as the Indian type rather than the African type (Fuller 2008b; Moulherat et al. 2002). Based on misidentification and dating issues, cotton found in goat coprolites in Nubia and dating to *ca.* 4500 BP have been considered problematic by several authors (Fuller 2008b; Moulherat et al. 2002; Zohary et al. 2012).

The cotton found in Thailand in the early prehistoric period is probably also the native Indian species. This conclusion is based on geographical grounds, the archaeological evidence of cotton in India and the close association with South Asia with respect to material culture in both sites where cotton has been reported, KSK and Ban Don Ta Phet.

Cotton grows widely in tropical and subtropical areas and although there is some cotton production in the north and northeast of Thailand, it is not considered a favourable area to grow cotton even if Thailand is a tropical country (Nuttonson 1963). Although cotton requires an abundance of water at the beginning of the season, it is sensitive to heavy rains and requires dry conditions when the fruit and seed develop (Fuller 2008b; www.ecocrop.fao.org). The difficulties of growing cotton in Thailand arise from the unpredictability of rainfall and the lack of cold weather that reduces the impact of pests

(Nuttonson 1963). In the early part of the twentieth century, the Europeans made several attempts to introduce various cotton species from both the New World and Old World to Southeast Asia including the Malay Peninsula with no success (Burkill 1935). Failure was attributed to high humidity. It therefore follows that if cultivated in Late Prehistory, the farmers at KSK would have encountered the same problems as in modern times and therefore KSK was not engaged in cotton production.

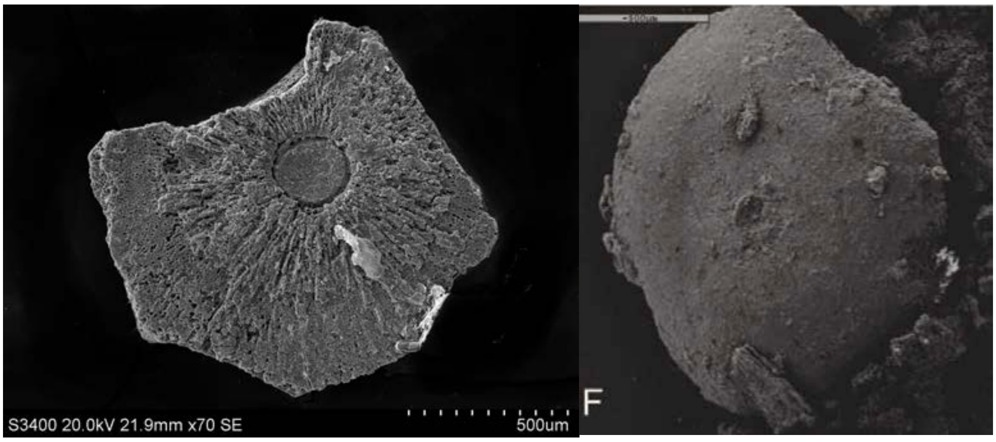


Figure 6.32: Images of archaeological cotton funicular caps: Left -from KSK in TP130 US6; Right - from Garhwal, India (Images: Left by author; Right by Fuller 2008b).

The identification of tree cotton at KSK can be compared with another site dating to the same period as KSK, Ban Don Ta Phet, which is located in central Thailand. Ban Don Ta Phet provides ample evidence of links with South Asia, China and other Southeast Asian groups in its material culture as well as in its archaeobotanical remains (Cameron 2010; Glover 1990; Glover and Bellina 2011). A single thread found at Ban Don Ta Phet was identified as *Gossypium arboreum,* the cotton domesticate from South Asia and dated to *ca.* 390-360 BC (Cameron 2010). This is the earliest evidence of cotton from South Asia in Thailand and outside its native India (Cameron 2010; Glover 1990). KSK is the second site that illustrates the availability of cotton in Thailand during the Late Prehistoric period. However, the sample from KSK is not thread but a funicular cap (Figure 6.32). Although no textile fragments or fibres have been found in KSK, one possible hypothesis for the presence of a cotton seed fragment in KSK is that there was on-site processing of the fibre into thread. However, if there was any large scale processing in any of the excavation area we would expect many more cotton pieces. It is possible that the raw cotton bolls were imported unprocessed from somewhere else such as a drier zone in central Thailand although direct exchange of cotton bolls from India to KSK is most probable since KSK was an entrepôt. It has been noted that centres of commercial textile production were situated along ancient trade routes in South Asia (Cameron 2010).

The contexts where both these samples of *Gossypium* were found are significant. In Ban Don Ta Phet, the thread adhered to a bone fragment in a burial context, whereas at KSK it was in a cultural deposit. It is believed that exotic goods were buried with elites in the Bronze Age and thereafter in Thailand (Higham and Thosarat 1998) and perhaps cotton textile was one such good at Ban Don Ta Phet. A seed fragment in a cultural deposit suggests processing of the raw material rather than trade in finished products (i.e. textile).

6.5.4.3 *Piper* cf. *longum*

Piper longum L.
Common name: long pepper
Thai name: phrik-hang; dipli and dipli-chuak (peninsular) refer to *Piper retrofractum*

The spice trade was an important impetus for the European long-distance exploration and voyages from the fifteenth century. But spices were traded commodities long before European presence in Southeast Asia. In Southeast Asia, markets were abundant in cloves, nutmeg, mace and pepper. Interestingly, black pepper was a major traded commodity but not a major consumable amongst Southeast Asians in the eighteenth century (Reid 1988). The Greeks and Romans were familiar with long pepper (Atal and Ojha 1964). Pepper was known as early as the fourth century BC in Rome (Burkill 1935). The Greek travel and trade journal '*The Periplus of the Erythraean Sea*' written in the first centuries AD documents some of the traded items, many of them coming from the Indian Ocean to the Red Sea ports:

> '*49. There are imported into this market-town, wine, Italian preferred, also Laodicean and Arabian; copper, tin, and lead; coral and topaz; thin clothing and inferior sorts of all kinds; bright-colored girdles a cubit wide; storax, sweet clover, flint glass, realgar, antimony, gold and silver coin, on which there is a profit when exchanged for the money of the country; and ointment, but not very costly and not much. And for the King there are brought into those places very costly vessels of silver, singing boys, beautiful maidens for the harem, fine wines, thin clothing of the finest weaves, and the choicest ointments. There are exported from these places spikenard, costus, bdellium, ivory, agate and carnelian, lycium, cotton cloth of all kinds, silk cloth, mallow cloth, yarn,* ***long pepper*** *and such other things as are brought here from the various market-towns. Those bound for this market-town from Egypt make the voyage favorably about the month of July, that is Epiphi*' (Schoff 1974).

Although both long pepper and black pepper were traded, long pepper commanded a higher price in Rome in the first century AD according to Pliny (Dalby 2002; Pliny n.d.; Wendrich et al. 2003). Long pepper is used principally for seasoning and as medicine. The treatise on Indian medicine *Susruta Samhita* dating to *ca.* first century BC- first century AD records the use of long pepper as a drug (Atal and Ohja 1964). Medicinal uses for long pepper have been recorded throughout historical times in South Asia such as in *Shri Bhav Prakasha* and *Shankar Nighantu* dating to the fourteenth century AD (*ibid.*), as well as in the West: the eleventh century AD Herbal *de Viribus Herbarium* by Macer (accessed on-line), and the nineteenth century AD *Pharmacographia* (Fluckiger and Hanbury 1879). However, the term long pepper has been used loosely to denote a whole range of fruits belonging to the genus *Piper*.

Piper is a large genus composed of 1,000-2,000 species and mainly found in the tropics (Heywood et al. 2007; Suwanphakdee and Simpson 2012; Tseng et al. 1999). Several species are economically important including the familiar *Piper nigrum* (black pepper), *Piper betle* (betel leaf), *Piper longum* (Indian long pepper), *Piper retrofractum* (Javanese long pepper), and *Piper cubeba* (cubebs) [see Appendix 6.12]. The origin for all these species is Asia: western Ghats for *P. nigrum*, Southeast Asia including insular SEA for *P. betle,* and Assam, northeast Himalayas and the Indo-Burmese hills extending westward to the middle Himalayas (Kumoan) for *Piper longum* (Burkill 1935; Cappers 2006; Dalby 2002; GRIN; Jaramillo and Manos 2001; Morrison 2002). The Southeast Asian long pepper, *P. retrofractum* (Javanese long pepper), is native to Indonesia but also cultivated in Thailand and exported to India and China from Southeast Asia and *P. cubeba* is native to Java, Indonesia (Dalby 2002). The exact dates of the introduction of *P. longum* and *P. nigrum* into the Thai-Malay Peninsula and Insular Southeast Asia are uncertain. De Waard (1989) proposed that black pepper was introduced to Southeast Asia *ca*. 100 BC although archaeobotanical evidence is still needed to confirm this date. To the west of South Asia, *P. nigrum* has been reported in Berenike and in Quseir al-Qadim dating to the first century AD, Shenshef dating to the fifth – sixth century AD, Mons Claudianus and Qasr Ibrim (Cappers 2006; Tomber 2008; van der Veen 2011). In South Asia, there is evidence for black pepper in Sanghol, Punjab from the Kushana period, Pattanam, Kerala and Mantai dating to the sixth to seventh century AD (Fuller pers. comm.; Saraswat and Pokharia 1998). However, the earliest archaeobotanical evidence of black pepper is the peppercorn fragments found in the abdominal cavity as part of the mixture used to embalm the mummy of Ramses II (Balout 1985). The long pepper from KSK is the first reported find in any archaeological site from any period.

Eleven test pits contained *Piper longum.* Fifteen samples altogether contained *Piper longum* in varying quantities and state of preservation. The drupes in many cases were found to be intact and although the infructescences were fragmented, they contained enough structure to allow identification (Figure 6.33).

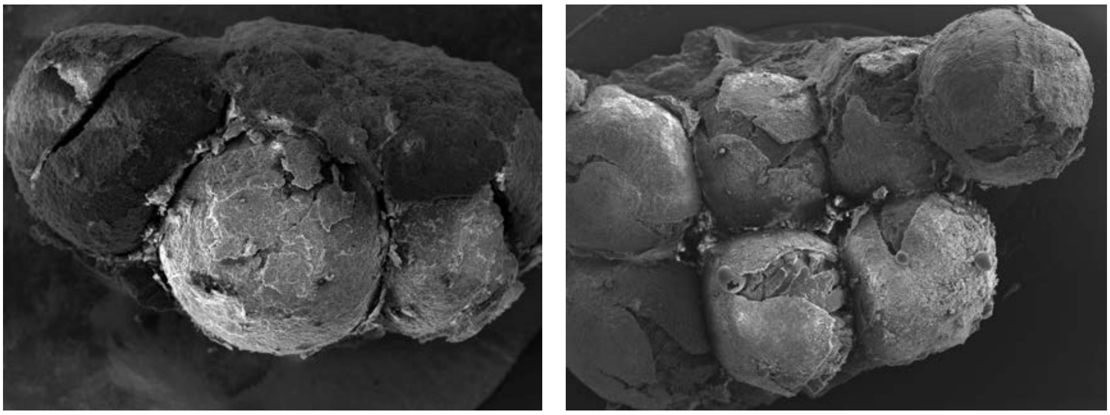


Figure 6.33: SEM micrographs: Left - *Piper* cf. *longum* drupes from KSK (TP110 US2) at x42 magnification; Right - charred modern *Piper longum* drupes at x21 magnification (Images by author).

Long pepper samples were bought in the markets of Thailand and Drummond Street (UK) but these were immature and their identification to species level was uncertain. It took two trips to Kew Gardens to locate several specimens of long pepper properly described and identified with certainty by botanists. Samples from Kew Gardens were then charred at 250°C in anaerobic conditions for four hours. These were mounted and images were taken with the SEM. Appendix 6.11 is the list of modern samples from the Kew Economic Botany Collection with images before and after charring. The KSK samples matched those of *Piper longum*, but none of the other *Piper* spp. examined. Good comparative material of *Piper retrofactum* was hard to obtain but finally this species was ruled out after acquiring some from the herbarium in Thailand collected by the Piperaceae expert Dr. Suwanphakdee.

The identification of long pepper was fraught with difficulties due to the lack of modern reference material. The comparative study is focused on economic *Piper* species rather than the full range of wild *Piper* spp. that exist in the flora of Thailand, which consists of approximately forty-six to fifty species (Suwanphakdee 2012; Suwanphakdee and Simpson 2012; Suwanphakdee et al. 2012). Appendix 6.12 lists some of the species found in Thailand including their uses. Many of the modern species charred as comparative material were also from other regions such as the Americas as these were part of the collection at Kew's Economic Botany Collection.

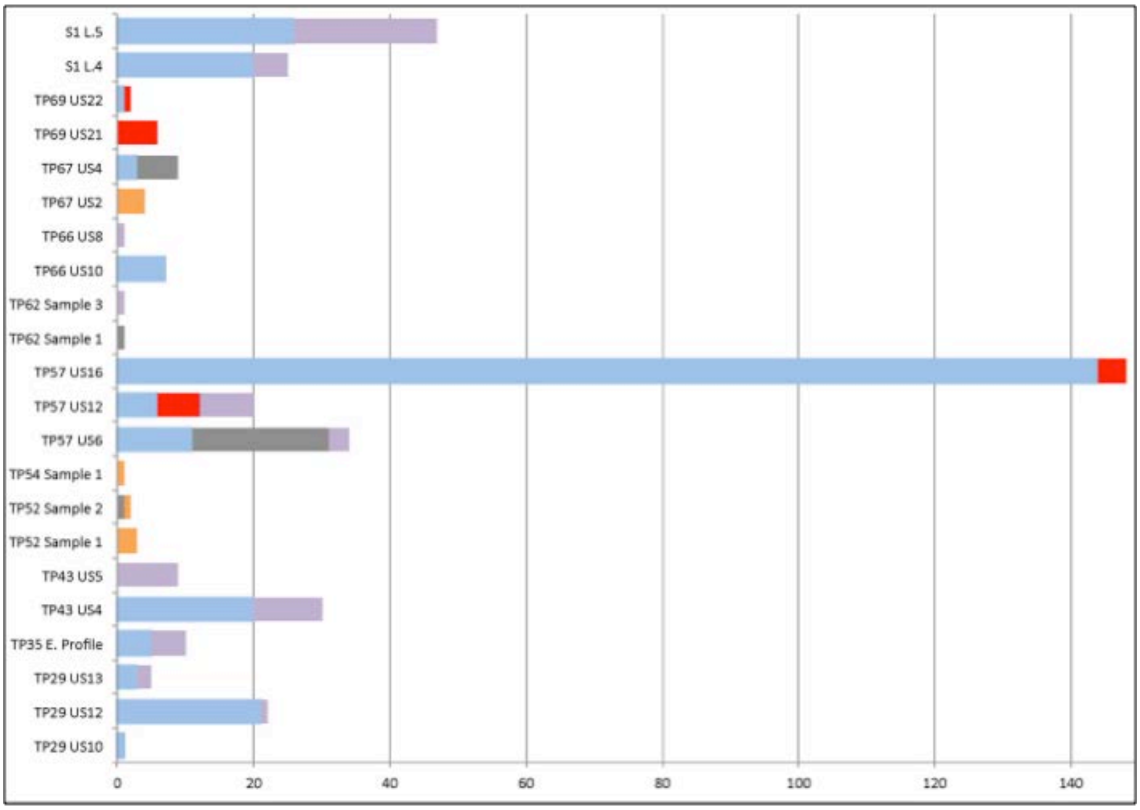
The identification of *Piper longum* in this study is significant. The existence of long pepper at KSK makes this the earliest documented site to have evidence of long pepper and since this crop originated in the greater Assam region, possibly the earliest evidence of the spice trade in Southeast Asia. Further questions arise such as: Was KSK an intermediary in the spice trade? What was the network of links and who was supplying this spice to whom? Were the locals also consuming long pepper? And finally, was the local population engaged in the cultivation of long pepper in this early period?

In 2011, an interview was conducted with residents of a household in KSK regarding agricultural practices. One of the questions concerned the use of long pepper by the household. The interviewee was a man named E Kachai (38 years old) who said they had in the past used long pepper in the preparation of curries. His parents planted long pepper in their garden and it was used not only for cooking but also for traditional Thai medicine. Since the introduction of European medicine his family no longer uses traditional Thai medicine. Some people still use long pepper when cooking old recipes but they now buy it and it comes from the northeast of Thailand. If they cannot obtain long pepper for these old recipes, they use chilli because it is easier to grow and it is also spicier. E Kachai's family does not cook and even if they did they consider the recipes are too complicated to make anyway, so never buy long pepper.

However, it is also necessary to state that the AMS date derived from one of the samples (TP130 US5) sent to the University of Oxford Radiocarbon Accelerator Unit came back with a modern date. Furthermore, seven of the fifteen samples are considered potentially unsatisfactory because of high contamination levels in them. These seven samples had levels of modern intrusions greater that 15%, a high proportion of roots signifying bioturbation and several samples also contained fungal sclerotia. This means that an alternative interpretation should be considered for the samples with long pepper. Perhaps these are modern and some samples have made their way to lower stratigraphic layers because of bioturbation. If this is the case, then other wild/weedy *Piper* species native to the Southern Peninsula of Thailand should be considered and these are found in Appendix 6.12 (marked with an 'x' in the Peninsula column). Since the hills at KSK have been taken over by jungle, it is a possibility that wild *Piper* would form part of the understory or found as climbers on trees. The problem with this alternative interpretation is that the KSK long pepper remains are charred and modern intrusions are normally not charred.

6.5.5 Overall analysis of economic crops, pulses and cash crops

General trends in the archaeobotanical assemblage from the entire site are discussed in this section. Figures 6.33 show the total frequencies of crops in the site per sample. The crops were divided into the following group headings: cereals - includes *Oryza* sp. and *Setaria* spp.; pulses - includes all *Vigna* species, *Macrotyloma uniflorum, Cajanus* spp. and cf. *Lablab*; fruits - includes *Citrus* spp., fruit pedicel, rinds and septum; cash crops - includes cf. *Gossypium* and *Piper* cf. *longum;* and parenchyma which may represent roots, tubers, rhizomes and fruits. Another archaeobotanical study needs to be conducted involving the identification of parenchymatous tissue although the samples from KSK are fragments probably too small to be identified (measuring < 1cm).



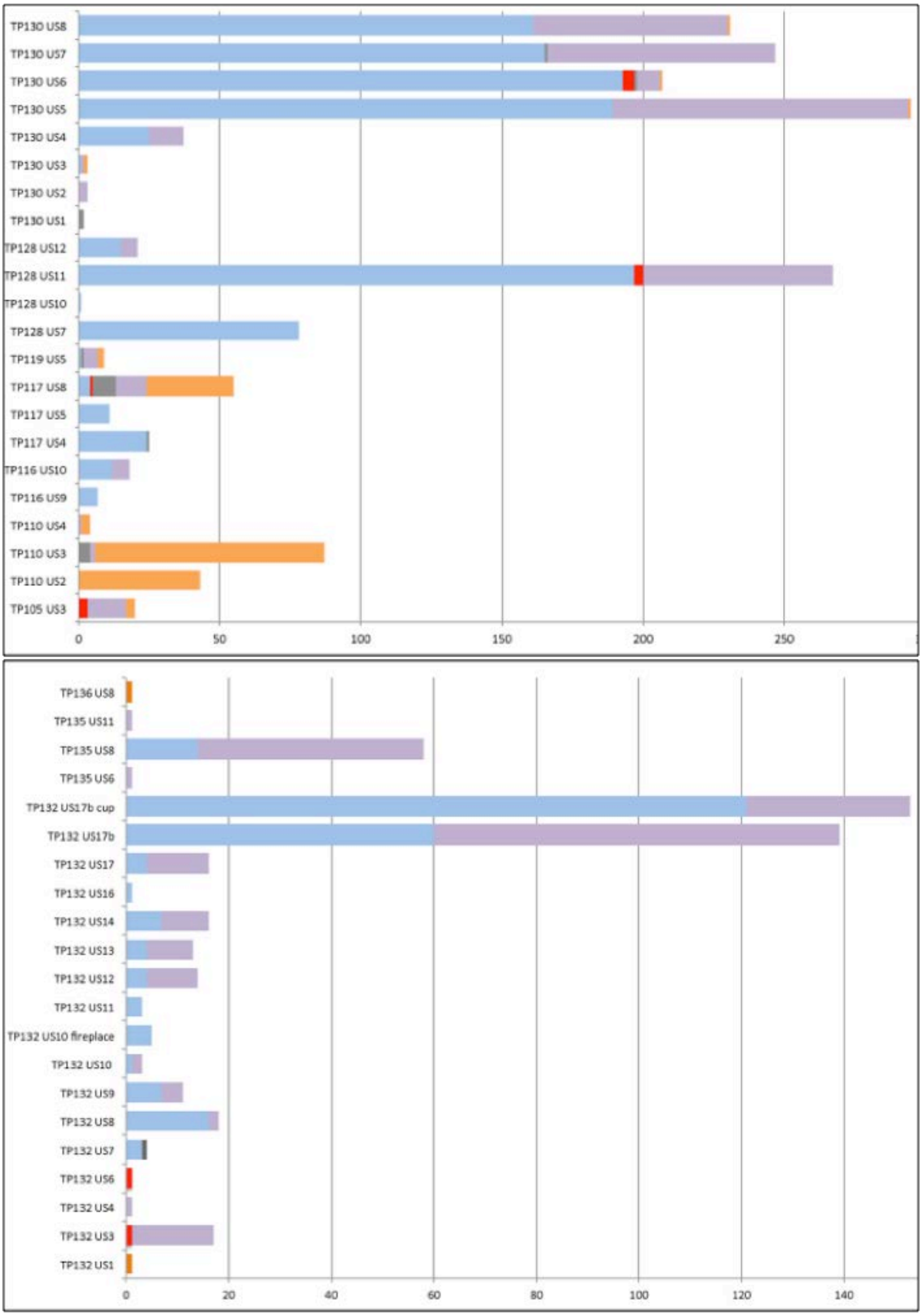


Figure 6.34: Frequencies of cereals, pulses, fruits, cash crops and parenchyma in each sample across the entire site excluding sterile samples.

Legend: cereals, pulses, fruits, parenchyma, cash crops

The bar graphs in Figure 6.34 show that in many of the samples, both cereals and parenchyma occur together. The Pearson Correlation Coefficient is 0.76 for the two variables (Table 6.20), which means that there is a high degree of positive correlation between the two. There may be several ways to interpret these results. The first is that the parenchyma fragments represent the use of tubers and roots on-site and is part of waste occurring during food preparation. As has been discussed in section 6.5.3.1, most of the rice evidence found in KSK is routine rice processing waste. Therefore, an alternative explanation is that the parenchyma are rice grain fragments that were charred together with rice spikelet bases and husk and formed part of rice processing waste. Discussions on rice crop processing can be found in Chapter 8 which show that in several stages of crop processing including the winnowing stage, rice fragments form part of the waste product. The husk most probably turns to ash and do not preserve, the robust spikelet bases remain recognisable and the rice fragments become distorted and unrecognisable. The small parenchymatous fragments from KSK are similar to those from the charring experiments (Chapter 5). The parenchyma fragments from the charring experiments could not be identified and were not counted although it must be a possibility that they were very distorted rice fragments.

Correlation Coefficients Matrix			
Sample size	43	*Critical value (5%)*	2.02
cash crops vs. cereals	-0.13		
parenchyma vs. cereals	0.76		

Table 6.20: Pearson Correlation Coefficient results.

When the variables, cash crops and cereals, were analysed for correlation, a low degree of negative correlation was found (Table 6.20). Generally, the bar graph shows that cash crops occur mostly in samples where there are no cereals to be found. There appears to be a difference in location between where rice processing is taking place and where cash crops are found. One would expect rice crop processing would take place outside the household whereas cash crops would probably be found in market areas in communal spaces where they are traded. However, this interpretation cannot be verified with the available data.

Presence of the five crop groups across the entire site was plotted according to location (Valley 1 and hinterlands, Hill 2, Hill 3 and Hill 4) and these are found in Figure 6.35. Although cereals were found in more samples from Valley 1 and the hinterlands and

Hill 2 than in Hills 3 and 4, the graph shows all crop types are found across the entire site. More samples from Hill 2 were analysed than from any other location and none of the samples were sterile. On the other hand, Hill 3 had the highest number of sterile samples (Table 6.21). However, this sampling bias should not affect the overall results because both sampling and analysis of data were done randomly and should therefore be representative of each hill. Cereals, basically rice, have the highest ubiquity across the whole site excluding parenchyma and Hill 3. Therefore, this signifies that because there was widespread use of rice across the site, it was the most important crop.

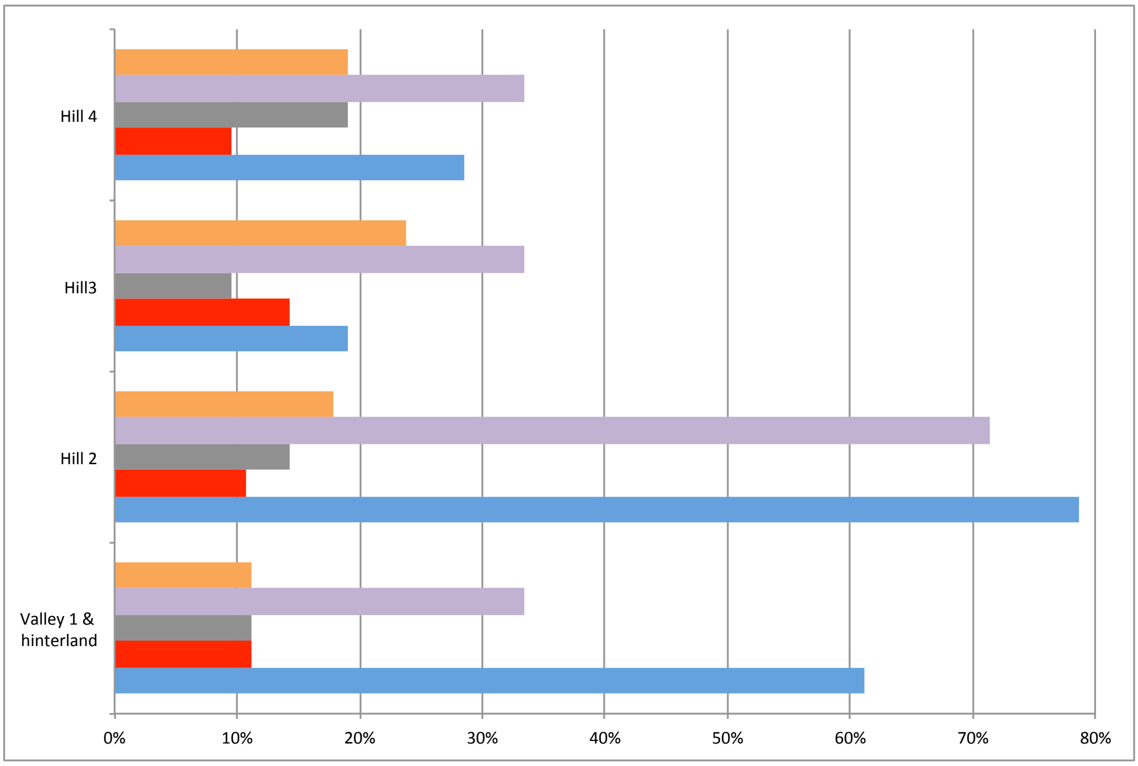
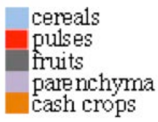


Figure 6.35: Presence of each crop group in samples from KSK, including samples where no economic or cash crops where found.

Legend:



Cash crops have a higher representation in Hill 3. It was hoped that the graph would show crop type presence with a distinct geographical distribution in order to determine if Hills 3 and 4 contained only crops originating from India. This has not been demonstrated in this graph. However, correspondence analysis was run to see the observed association between the location and the crop groups (Figure 6.36). The distance between the groups is a measure of how closely related they are. It was found that the cash crop group was more closely associated to Hill 3, cereals and parenchyma were closely associated with each other and also Valley 1 and the hinterlands and Hill 2.

Location	No. of samples analysed	No. of sterile samples
Valley 1 & hinterlands	18	6
Hill 2	28	0
Hill 3	21	11
Hill 4	21	6

Table 6.21: Tally of the number of samples analysed per location and the number of samples that did not yield macroremains.

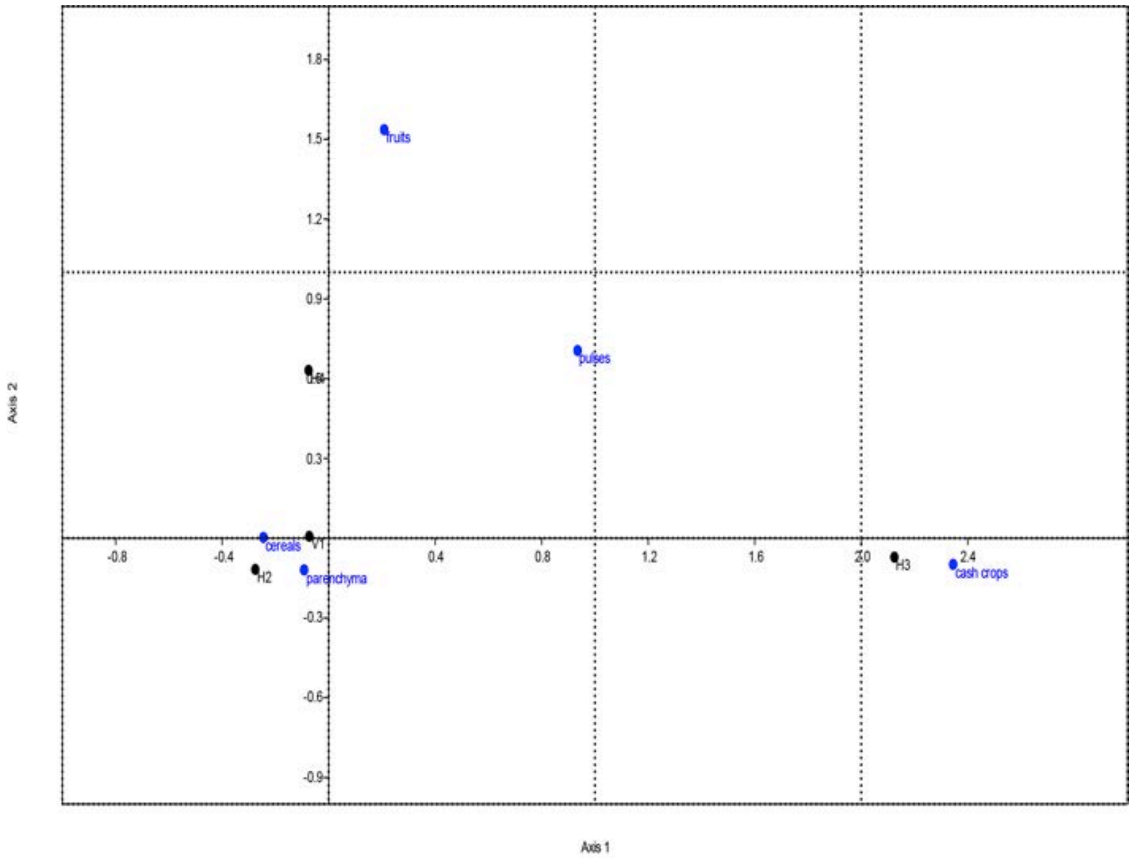


Figure 6.36: Correspondence analysis results using location and crop groups.

Mungbeans make up1.12% of the total KSK archaeobotanical assemblage. They are represented in 6% of the samples and are the second most common economic crop in KSK (Table 6.22). The concentration of finds is located in Hills 3 and 4 with the exception of a fragment found in TP128 US11 (Figure 6.37). The location may be a reflection of the north-south division of the site with the group made up of South Asians and other foreigners coming from Southeast and East Asia located in the northern area. This is given further credence by the evidence of *Cajanus* (probably *Cajanus cajan* -

pigeonpea), another South Asian domesticate with samples only found in Hill 3. However, the foreign cultivars *Macrotyloma uniflorum* (horsegram) and *Lablab* [if *Lablab purpureus* (hyacinth pea)] are only found in the southern part of the site. Overall, the north-south division of the site (as hypothesised by Bellina) with respect to foreign vs. local cultivars does not strictly follow the material culture evidence. However, although a north-south division seems to exist for the material culture, one still finds Indian ceramics and ornaments in the southern part of the site. It is also hypothesised that South Asian craftsmen worked in the southern part as was discussed in section 6.1. In the plant remains analysis, the concentration of Indian cultivars is not unique to the northern part of the site although mungbeans were much more frequent there.

	Location	*Vigna radiata*	*Macrotyloma uniflorum*	*Vigna* sp.	cf. *Lablab*	*Vigna* spp.	*Vigna* cf. *umbellata*	*Cajanus* sp.	cf. *Cajanus*	Fabaceae type A	Fabaceae type B
TP54 Sample 1	Hill 4										x
TP57 US12	Hill 4	x								x	
TP57 US16	Hill 4	x									
TP69 US21	Hill 3	x									
TP69 US22	Hill 3	x									
TP105 US3	Hill 3							x	x		
TP117 US8	Valley 1						x				
TP128 US11	Valley 1	x	x			x					
TP130 US6	Hill 2			x	x	x					
TP132 US3	Hill 2		x							x	
TP132 US6	Hill 2					x					
NISP		**18**	**2**	**2**	**1**	**3**	**1**	**1**	**2**	**2**	**1**
ubiquity		**5.68%**	**2.27%**	**1.14%**	**1.14%**	**3.41%**	**1.14%**	**1.14%**	**1.14%**	**2.27%**	**1.14%**

Table 6.22: Presence/absence table of pulses found in KSK.

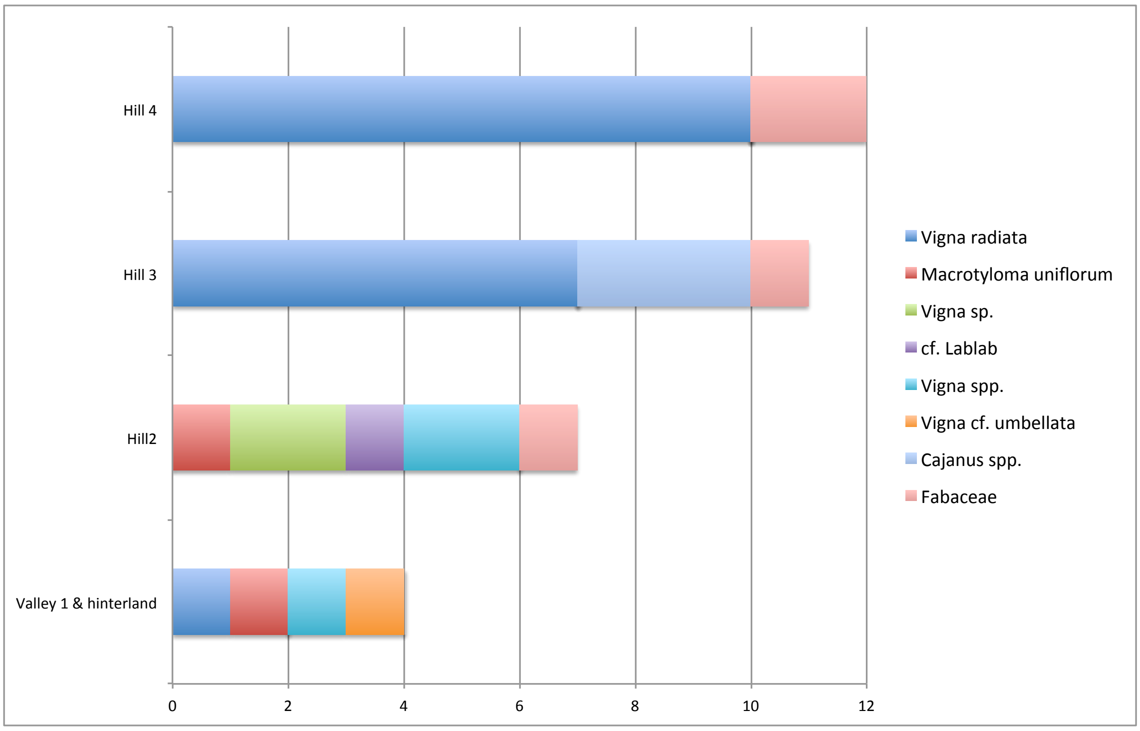


Figure 6.37: Frequencies of pulses by location in KSK.

6.5.6 Weeds

Although the identification of economic and cash crops in the archaeobotanical assemblage is an advance towards understanding the subsistence regime in KSK, it is the weed flora that allows the archaeobotanist to define systems of land use and cultivation practices. The chapter on rice (Chapter 9) discusses how the identification of weeds associated with economic crops can prove useful in archaeobotanical studies since weed species occur in particular ecological zones; move from their original habitat together with certain crop packages; and illustrate different crop processing stages (Bogaard et al. 1999; Colledge 1994; Colledge at al. 2005; Fuller and Qin 2009; Jones 1981, 2002; Jones et al. 2010; Kealhofer and Piperno 1994). At KSK the weeds identified have been used to define the system of cultivation in place, whether wetland or dryland. Not all of the seeds were identified to species level and discussions in this section are limited to those identified to genus. The general result from the study of weeds shows that rice cultivation at KSK was based on a dryland system.

	Family	Species	weed ubiquity*	co-occurrence w/ *Oryza*** (n=43)	co-occurrence w/ *V. radiata* (n=5)	co-occurrence w/ pulses (n=10)
DRYLAND						
	Asteraceae	*Acmella paniculata*	62.50%	93.02%	60.00%	70.00%
	Asteraceae	*Mikania* cf. *cordata*	12.50%	4.65%	-	20.00%
	Asteraceae	cf. *Eupatorium*	1.14%	2.33%	-	-
	Commelinaceae	cf. *Cyanotis*	1.14%	-	-	-
	Oxalidaceae	*Oxalis* sp.	1.14%	2.33%	-	10.00%
	Phyllanthaceae	*Phyllanthus urinaria*	1.14%	2.33%	-	-
	Poaceae	*Brachiaria mutica*	1.14%	2.33%	-	-
	Poaceae	*Eleusine indica*	2.27%	2.33%	-	10.00%
	Poaceae	*Eleusine* sp.	1.14%	2.33%	20.00%	10.00%
WETLAND						
	Cyperaceae	*Cyperus* cf. *pulcherrimus*	1.14%	-	-	-
	Cyperaceae	*Cyperus* cf. *pygmaeus*	2.27%	2.33%	-	10.00%
	Cyperaceae	*Rhynchospora corymbosa*	1.14%	-	-	-
	Cyperaceae	*Scirpus* sp.	1.14%	-	-	-
	Hydrocharitaceae	*Blyxa aubertii*	1.14%	2.33%	-	-
	Hydrocharitaceae	*Ottelia* cf. *alismoides*	1.14%	2.33%	-	-
	Najadaceae	*Najas graminea*	1.14%	-	-	-
	Pontederiaceae	*Monochoria* cf. *hastata*	1.14%	-	-	-
BOTH WET & DRY						
	Amaranthaceae	*Alternanthera* cf. *sessilis*	3.41%	4.65%	-	-
	Cleomaceae	*Cleome viscosa*	2.27%	4.65%	-	20.00%
	Convolvulaceae	cf. *Ipomoea*	2.27%	-	-	-
	Convolvulaceae	*Ipomoea* sp.	1.14%	-	-	-
	Poaceae	cf. *Panicum*	1.14%	2.33%	-	-
	Poaceae	*Paspalum* cf. *scrobiculatum*	1.14%	2.33%	-	-
	Polygonaceae	cf. *Rumex*	9.09%	6.98%	-	80.00%
UNSPECIFIED						
	Portulacaceae	*Portulaca* cf. *quadrifida*	2.27%	4.65%	-	10.00%

* ubiquity rate all samples (n=88)
** same results for total cereals (n=43)

Table 6.23: Breakdown of weed flora according to habitat and ubiquity rate at KSK, as well as co-occurrence of each weed with rice, mungbeans and total pulses.

Table 6.23 shows the weed flora classified into dryland or wetland habitats with some of the weeds occurring in both habitats and one which remains unspecified. Table 6.23 also includes the ubiquity index of the weeds at KSK and their level of co-occurrence with some of the economic crops (also Table 6.24). In KSK, 62.5% of all the samples contained the dryland weed *Acmella paniculata,* followed by 12.5% of samples containing at least one seed of *Mikania* cf. *cordata,* another dryland weed from the Asteraceae family. Another weed found in 9.09% of the samples is cf. *Rumex,* a genus found in both dryland and wetland systems of cultivation.

Appendix 6.14 contains the information of individual plant identifications from KSK. The information includes the common names in English and Thai (when applicable), measurements, archaeological descriptions, habitats, area of origin, and images of both archaeological and modern specimens. This Appendix gives identification details for each weed species.

	Species	Oryza	*Vigna radiata*	*Vigna umbellata*	*Macrotyloma uniflorum*	*Cajanus* spp.	*Lablab* sp.
DRY	*Acmella paniculata*	x	x	x	x	x	x
	Mikania cf. *cordata*	x		x		x	
	cf. *Eupatorium*	x					
	cf. *Cyanotis*						
	Oxalis sp.	x		x			
	Phyllanthus urinaria	x					
	Brachiaria mutica	x					
	Eleusine indica	x					
	Eleusine sp.	x	x		x		
WET	*Cyperus* cf. *pulcherrimus*						
	Cyperus cf. *pygmaeus*	x		x			
	Rhynchospora corymbosa						
	Scirpus sp.						
	Blyxa aubertii	x					
	Ottelia cf. *alismoides*	x					
	Najas graminea						
	Monochoria cf. *hastata*						
WET & DRY	*Alternanthera* cf. *sessilis*	x					
	Cleome viscosa	x		x			x
	cf. *Ipomoea*						
	Ipomoea sp.						
	cf. *Panicum*	x					
	Paspalum cf. *scrobiculatum*	x					
	cf. *Rumex*	x		x			
NSP	*Portulaca* cf. *quadrifida*	x		x			

Table 6.24: Weeds that are found in samples containing some of the economic crops at KSK.

Table 6.24 lists the co-occurrence of weeds and some of the economic crops which may have been cultivated in KSK. The four weeds that co-occur most commonly with economic crops are *Acmella paniculata, Mikania* cf. *cordata, Eleusine* sp. and *Cleome viscosa.* All of these four weeds are dryland weeds although *C. viscosa* can occur in both wet and dry habitats.

Figure 6.38: Top left - *Rhynchosphora corymbosa*; Top right - *Cyperus* cf. *pulcherrimus,* Bottom left -*Najas graminea,* Bottom right - *Scirpus* sp. (Images by author).

As seen in both tables, the majority of weeds represented at KSK are from dryland habitats. The weeds normally associated with wetland habitats are found mainly in TP125 and TP130. The highest frequency of wetland weeds at KSK is found in 'TP125 US7.' The archaeobotanical assemblage from this sample is made up predominantly of three species of weed flora, *Rhynchosphora corymbosa*, *Cyperus* cf. *pulcherrimus* and *Najas graminea* (Figure 6.38). The location of this test pit is in a lowland area prone to flooding. The plant remains were waterlogged in clay and belong to the post-occupation period of KSK signifying the samples are wild flora. TP125 US7 shows a lack of economic and cash crop evidence and the weed species cannot therefore be interpreted as weeds of cultivation. Instead, these weeds would have occurred as part of the natural habitat that surrounds riverbanks and swampy areas. TP135 also lies in a low-lying area next to the Tha Tapao River and the layer where *Scirpus* sp. is found does not contain any economic crops and probably belongs to the pre-occupation period of KSK. This area was probably flooded frequently because of its close proximity to the Tha Tapao River. The presence of these wetland weeds demonstrates their usefulness in interpreting habitats. The test pits where they came from had been analysed through geomorphology and were interpreted as having been formed by fluvial deposits or flooding. Both the archaeobotanical and geomorphological studies arrive at similar interpretations independently.

Of particular interest in this study are the cultivation systems for rice agriculture that existed in prehistoric Thailand. Moody (1989) reports that there are more than 1,800 weed species in South and Southeast Asia that grow in association with rice. The weeds grow in the same ecological zones as rice, and rice grows in diverse geographical areas ranging from sea level to high altitudes of 3,000 m, dry and hot climates to humid areas with up to 4,000 mm annual rainfall (Moody 1989). It is not possible at the moment to differentiate between these different cultivation systems just by examining archaeological rice plant parts. Therefore, archaeobotanists use the weed flora to try and understand the different ecological zones where they occur, to determine whether they are weeds associated with economic crops, and if they are associated with crops to then reconstruct the agricultural regime. At KSK, there is sufficient weed flora associated with the rice plant parts to reconstruct the cultivation system that might have been in place.

It has already been established above in what habitats the weed flora are found. It has also been shown in Tables 6.23 and 6.24 that many of these weeds do co-occur in the samples with economic crops that may have been potentially cultivated at KSK. It will now be demonstrated that some of these weeds are weeds of cultivation, in particular rice cultivation. The predominant weed and the taxon with the highest number of counts in the entire site belong to the Asteraceae family. It has been identified as *Acmella paniculata* (Figure 6.39). Of major significance is the high level of co-occurrence of this weed with rice at KSK (Appendix 6.13). 93% of the samples with rice contained *A. paniculata* (n=40).Only two samples that contained rice did not contain the weed *A. paniculata*. The sample from 'TP69 US22'is a rice fragment from a habitation layer and may therefore represent part of a meal, but sample 'TP132 US17b cup' was a dark soil deposit collected from within and around a cup. Interestingly, the only other archaeobotanical remains present in sample 'TP132 US17b cup' besides the large number of rice parts (mostly spikelet bases) consists of one unidentified seed, a substantial amount of small fragments of parenchymatous tissue, one seed of *Paspalum*cf. *scrobiculatum*, one Malvaceae seed and another undetermined Poaceae seed. The contents of the cup represent a deliberate act by a person at KSK more than 2000 years ago to place starchy food plant remains, including rice and edible starchy wild (or weedy) grain parts in a cup. The purpose of placing cereal grains and fragments in a cup is unknown although comparison can be made with the unhusked rice grains and husks found in a bronze bowl in Iron Age Ban Don Ta Phet (Glover 1990). The Ban Don Ta Phet bowl and its contents were found in a burial context and are clearly part of an assemblage of grave goods.

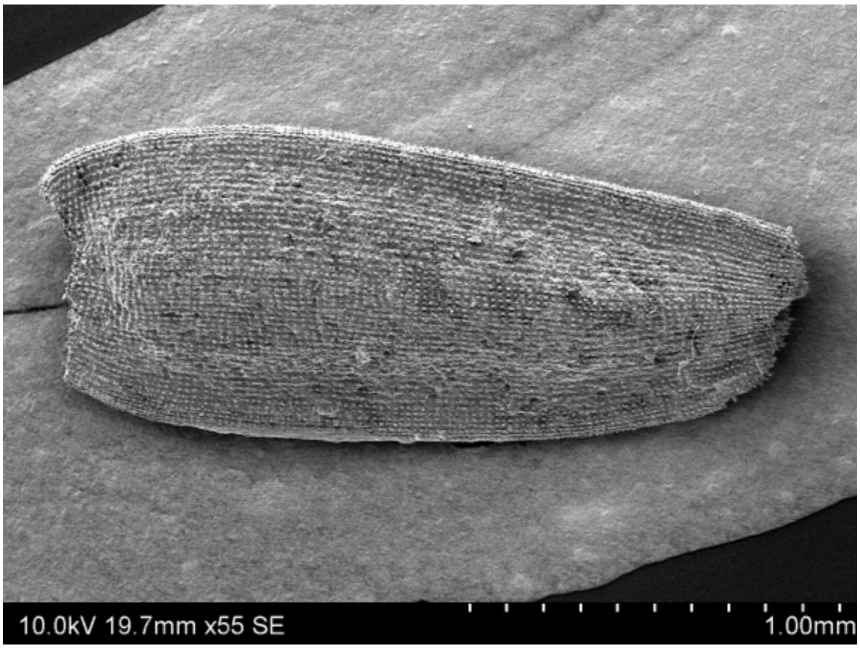


Figure 6.39: SEM micrograph of *Acmella paniculata* from KSK TP57 US6 (Image by author).

The Pearson Correlation Coefficient yielded a high positive correlation of 0.84 for *A. paniculata* vs. *Oryza.* The same test was run for all pulses and *A. paniculata* and the Pearson Correlation Coefficient showed a low positive correlation of 0.12 between *A. paniculata* and total pulses. Furthermore, four out of the five samples with mungbean co-occurred with rice and also the weed *A. paniculata*, but the only mungbean sample without rice, did not co-occur with the weed *A. paniculata* either. Sixty percent of the samples with pulses co-occur with rice and *A. paniculata* but out of the remaining 40% of samples with pulses that did not co-occur with rice, half also did not co-occur with *A. paniculata.* The high level of co-occurrence and correlation with rice suggests that *A. paniculata* is a weed of rice but not necessarily of the pulses.

A. paniculata has been classified as a weed of rice cultivation and is an indicator of dryland or upland cultivation although it has also been reported in transplanted fields (Moody 1989; Soerjani et al. 1987). It is reported as a weed of rice in South and Southeast Asia including Thailand (Moody 1989). Smitinand (1986) reports it as a weed in shifting cultivation systems in Thailand. In 2011, Dr. Weisskopf and I examined modern weeds found in different rice cultivation systems in Chiang Mai and Mae Hong Son. *A. paniculata* was a dominant weed with high densities in shifting rice cultivation fields. However, it was only found on the bunds of some of the wetland rice fields examined and never in the rice field itself. Furthermore, a dissertation on plant succession shows that a shifting cultivation field left fallow for a year has *A. paniculata* as the dominant species (Paisalwattana 1982). All of these observations confirm *A. paniculata* to be a weed of dry rice cultivation, and potentially an indicator of shifting cultivation.

Table 6.25 is the complete list of weeds identified at KSK together with the type of cultivation system with which they are commonly associated. One of the identifications, *Calendula arvensis,* is native to Africa or Europe. The one silicified seed of *Calendula arvensis* may be a modern intrusion in TP110 US2 and is excluded from the discussions on cultivation systems. Several sources were used in the analysis of the weed flora. However, the majority of the information available on weeds in Thailand is from published material dedicated to rice cultivation and to a lesser extent, crop rotation. This may bias interpretations towards discussions of rice cultivation but the results so far show that many of the weeds found in KSK were indeed weeds associated with rice and to a lesser extent with the pulses. Most of the weeds found at KSK are defined by several sources as upland cultivation weeds. The definition of upland is confused in the literature, although one of the world's leading authorities in rice and its cultivation is IRRI and their definition is '*rice grown on both flat and sloping fields that are not bunded, that were prepared and seeded under dry conditions, and that depend on rainfall for moisture'* (De Datta 1975). This approach is followed in this dissertation.

Family	Species	reported as weed of rice in Thailand	dry-seeded	upland	wet-seeded	transplanted	deepwater	rainfed	wetland	remarks
Amaranthaceae	*Alternanthera* cf. *sessilis*	✔		✔			✔		✔	weedy on marshy ground, tidal rice
Asteraceae	*Acmella paniculata*	✔		✔				✔		*Spilanthes paniculata* are synonyms; weed also reported in shifting cultivation
Asteraceae	*Mikania* cf. *cordata*	✔		✔						thickets and forests
Asteraceae	*Calendula arvensis*									native to Africa & Europe
Asteraceae	cf. *Eupatorium*			✔						most *Eupatorium* that occur in Asia are in hill slopes; very similar morphology to *E. odoratum* which a native of Americas, species that occurs in Thailand & native to Asia is *E. lindleyanum*
Cleomaceae	*Cleome viscosa*	✔	✔	✔				✔	✔	weed also reported in shifting cultivation
Commelinaceae	cf. *Cyanotis*	✔		✔				✔		*Cyanotis axillaris* and *C. cristata* are weeds of rice, in rainfed upland (gogo rancah) and rainfed upland fallow rice fields respectively
Convolvulaceae	cf. *Ipomoea*									several *Ipomea* species found in Thailand, including *I. aquatica*
Convolvulaceae	*Ipomoea* sp.									several *Ipomea* species found in Thailand, including *I. aquatica*
Cyperaceae	*Cyperus* cf. *pulcherrimus*	✔	✔				✔		✔	lowland-irrigated
Cyperaceae	*Cyperus* cf. *pygmaeus*							✔	✔	desiccated pools & ditches, riverbanks, open wet places in cultivated ground; synonym of *Cyperus michelianus* subsp. *pygmaeus*
Cyperaceae	*Rhynchospora corymbosa*	✔	✔						✔	dry-seeded, tidal, swamps, muddy river banks
Cyperaceae	*Scirpus* sp.					✔				most *Scirpus* spp. found in Thailand are in transplanted or wetland rice cultivation systems (*S. articulatus, S. ciliaris, S. grossus, S. juncoides, S. lateriflorus, S. maritimus, S. supinus*)
Hydrocharitaceae	*Blyxa aubertii*	✔			✔	✔				lowland, marshy
Hydrocharitaceae	*Ottelia* cf. *alismoides*	✔			✔	✔	✔		✔	prefer aquatic conditions, found in canals & paddy fields, lowland-irrigated
Najadaceae	*Najas graminea*	✔				✔			✔	prefer stagnant water conditions
Oxalidaceae	*Oxalis* sp.			✔						*O. corniculata* & *O. corymbosa* both upland
Phyllanthaceae	*Phyllanthus urinaria*	✔		✔						
Poaceae	*Brachiaria mutica*	✔	✔	✔	✔	✔		✔		prefer poorly drained soil, found along paddy and water courses
Poaceae	cf. *Panicum* & *Panicum* sp.									*Panicum paludosum* & *P. repens* are found in Thailand; *P. repens* found in rainfed, upland fields
Poaceae	*Eleusine indica*	✔	✔	✔						prefer low moistured soils, found in wastelands, roadside & crop lands; weed also reported in shifting cultivation
Poaceae	*Eleusine* sp.									
Poaceae	*Paspalum* cf. *scrobiculatum*	✔	✔	✔		✔	✔			weed also reported in shifting cultivation
Polygonaceae	cf. *Rumex*			✔					✔	dry/wet; *Rumex crispus* found in Thailand reported in shifting cultivation and wetland cultivation systems
Pontederiaceae	*Monochoria* cf. *hastata*	✔				✔	✔		✔	distributed in canals, ponds & ditches
Portulacaceae	*Portulaca* cf. *quadrifida*									pantropical weed except in Australia; *P. oleracea* is a weed of upland rice

Sources: Flora of Thailand; GRIN; Galinato et al. 199; Maxwell et al. 1987; Moody 1989; Noda et al. 1985; Smitinand 1986; Soerjani et al. 1987; Suwanketnikom 1980; Zhang & Hirota 2000.

Table 6.25: List of weeds found in KSK, the type of cultivation system they are most likely to be found and some observations regarding the habitat they prefer.

A. paniculata, together with *Mikania* cf. *cordata* and cf. *Eupatorium,* belongs to the Asteraceae family. Although Asteraceae is a large family, it generally forms part of the drier vegetation types (Heywood et al. 2007). Sixty-five samples from KSK contained at least one weed seed and forty-one samples contained both weeds and rice. When their presence was examined with that of rice, it was noted that those that co-occur with rice (except for one sample) are known to be dryland weeds. Ten out of these forty-one samples containing rice had weeds found in both wetland and dryland habitats; and two of the samples also had wetland weeds. Out of the seventeen weeds identified to species level, fifteen are known to be weeds of rice and fourteen are known to occur as weeds of rice in Thailand (Moody 1989; Soerjani et at. 1987). So it may be concluded that the rice found at KSK was probably cultivated in a dryland / upland cultivation regime.

6.5.7 Agricultural Practices in Khao Sam Kaeo

A dry and upland cultivation regime is confirmed by the geomorphological analysis conducted in KSK by Allen and Silapanth (unpublished report) and Allen (2009) who situate probable cultivation on gently sloping plateau land and hill slopes. Three test pits (TP106, TP130 andTP136) located in hill slopes were identified as having soils formerly cultivable. The three test pits show the presence of humic soils suggesting that the soils were formed during stable periods, most likely a result of human management (Allen in preparation). The analysis further shows that the soil stability in all of the three test pits ceases at a certain point and is taken over by erosion and redeposition. Overuse of hilltop slopes in order to increase food production entails shorter fallow periods which lead to depletion of vegetation and nutrients in the soil and so eventually accelerating erosion. Allen believes that the soil stability in these three test pits ceased due to overuse of the hilltop slopes as a result of dryland agriculture.

All three test pits studied by Allen were sampled for macroremains and phytoliths. The macroremains samples from three stratigraphic layers in TP136 did not yield any meaningful results and TP106 was not analysed. The phytolith analysis will probably prove to be a more useful methodology in identifying whether cultivation took place in these two areas. The premise for phytolith analysis being that rice plant parts associated with harvesting and threshing, such as leaves and husk from rice grains left in the field, will be preserved in the soil. In cultivated fields, the limitations of the macroremains analysis is that the plant remains would have needed to come into contact with fire in order to char and preserve. This does not necessarily happen in a cultivated field unless the fields and plots are burnt after harvest such as with stubble burning or before harvest with 'slash and burn.' Nevertheless, charred leaves and husk generally do not preserve and usually turn to ash (see Chapters 5 and 8 for issues on preservation). The macroremains from TP130 were analysed and the sample was rich in plant remains including high frequencies of rice and parenchyma. TP130 also contained foxtail millet, long pepper and cotton. Although the geomorphology suggests cultivable land, it is more probable that this test pit was dug in an area where crop processing took place or where domestic waste, including crop-processing by-product, was secondarily dumped from activities carried on adjacent settlement hills. The rice plant parts include rice grain fragments, spikelet bases and husk alongside the weed associated with rice cultivation, *A. paniculata.* The archaeological assemblage resembles either the pounded remains found in the mortar after the first winnowing is done to get rid of immature and unfilled spikelets (see Chapter 8 Figure 8.8b) or the second winnowing waste product (Figure 8.10). In these two stages, one will most likely find rice grain fragments, spikelet bases, husk and weeds similar in size to the rice grains. Secondary dumping would best explain how cotton processing waste and foxtail millet became preserved with rice dehusking by-product.

Geomorphological studies elucidate issues of land use and cultivation practices. For example, Allen suggests that in the first millennium AD, communities located in the Thai-Malay peninsula, specifically in Kedah in modern-day Malaysia, practiced dryland cereal cultivation (1991). Her evidence shows that present-day floodplains in Kedah only arose as a result of coastal progradation and only then did a switch to wetland rice agriculture occur. This hypothesis that cereal cultivation is originally dryland also seems to apply to KSK. Similarly, other sites that initially had dryland agriculture are those from the Khao Wong Prachan Valley [KWPV] (the sites being Non Pa Wai, Nil Kham Haeng, Non Mak La). These sites have evidence for foxtail millet cultivation at least by the second millennium BC, in Non Pa Wai as early as the mid-third millennium BC, and the weed flora is made up of dryland cultivation weeds (Weber et al. 2010). When rice became the dominant cereal cultivated in the KWPV 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 also known as 'opportunistic farming.' An example of 'opportunistic farming' is found in Xipo, China during the Middle Yangshao Period when rice was cultivated alongside millets and probably followed the dryland cultivation system used for millets (Weisskopf 2010).

Although, upland rice was still being practiced in the 1970s in southern Thailand, today most upland rice cultivated in Thailand is undertaken by the hill tribes and done mostly with shifting cultivation. A study conducted in the 1970s shows that rice was grown under rubber trees and also in newly opened fields that were cleared with fire (De Datta 1975). Rice was planted alongside other crops, such as the crops from the New World - corn and cassava. A similar system was probably used during the Late Prehistoric period in KSK and its hinterlands. Another indication of dryland cultivation in KSK is the presence of economic crops (discussed in section 6.5.3) which are drought resistant and mainly found in upland cultivation systems. For example, the mungbean has a short lifespan and can be grown during the dry season, as part of a double-cropping regime or in between rice cultivation cycles (Fukui and Hattori 1974). At KSK, rice could have been cultivated alongside other dryland crops using double-cropping or crop rotation. It is also possible that rice was grown under orchard trees. Double-cropping could have included pulses, and tubers such as taro. Arboriculture would not have been limited to *Citrus* trees although the best evidence of fruit trees in KSK belongs to this genus. Double-cropping is usually part of upland cultivation systems whereas in lowland paddy fields, dryland crops are planted before or after rice is harvested (De Datta 1979).

Bellina and Bernard (in preparation) have studied the morphology of KSK in order to understand, amongst other things, the interaction between the landscape and settlement. The excavations discovered manmade earthworks in the form of walls and ditches, some of which have been interpreted as erosion control mechanisms and drainage systems. A system of drains was found at KSK next to platforms and occupation floors associated with habitation. Hills normally provide a natural drainage system for excess water. However, water draining directly down a slope causes erosion and needs to be controlled. Building drains along the hill contours or within the hills along the walls, building catch pits or planting cover crops helps control erosion (Bellina pers. comm.; Grist 1950). Drainage would have been an important aspect of urban planning at KSK because of the torrential rains the site would have been subjected to just like today. Clearly, drainage had a role in the settlement to control natural flooding but it may also have been associated to agriculture. Stagnant water and flooding would have affected dryland cultivation on the hill slopes.

6.6 KHAO SAM KAEO and the EVOLUTION OF AGRICULTURE IN MAINLAND SOUTHEAST ASIA.

Because rice is the largest dataset compared to the other taxa at KSK, discussions above have revolved around rice. Rice is also the crop that has received the most attention from Southeast Asian scholars and helps situate KSK in discussions of the evolution of agriculture in mainland Southeast Asia. A detailed review of rice in prehistoric Thailand is found in Chapter 9.

Due to the dearth of archaeobotanical studies, it is difficult to establish how agriculture evolved in Thailand from the Neolithic Period to the Late Prehistoric period. More archaeobotanical studies are needed from sites across Thailand and with longer chronologies in order to gauge changes in diets and agricultural practices. White (1995) proposes that in Southeast Asia both upland and wetland systems were derived from inundated rice cultivation dependent on rainfall, systems which were extensive rather than intensive and therefore, less labour demanding. Sites with archaeobotanical studies although limited in number appear to substantiate this view. Khok Phanom Di during the Neolithic period was probably dependent on natural flooding. Dryland cultivation dependent on rainfall was practiced in the KWPV sites during the Neolithic and Bronze Ages before rice was cultivated and in the Late Prehistoric sites KSK and PKT (PKT is discussed in Chapter 7). This was also the case in Kedah located further south in the Thai-Malay Peninsula during the proto-historic period where dryland systems of cultivation preceded irrigated rice agriculture.

The evidence so far available suggests that wetland systems of agriculture were used in the Lower Yangtze *ca.* 4000 BC when it spread outwards. However, wetland cultivation was probably not adopted in Southeast Asia when rice was first introduced. When rice was initially introduced to Southeast Asia remains unknown. In contrast to Southeast Asia, the rice evidence in Korea and Japan indicate that paddy field agriculture was established by at least the later Mumun period (*ca.* 550-300 BC) and the Yayoi period (*ca.* 300 BC-300 AD) respectively (Fuller et al. 2010). The introduction of paddy field agriculture to Korea and Japan spread from China, either from the Lower Yangtze or Shandong (*ibid.)*. But there also appears to be an earlier introduction of dryland rice from Shandong to Korea and Japan which shows that the diffusion of crops and technologies happened in several stages and came from different areas. Fuller et al.

(2010) propose that rice cultivation in Southeast Asia first spread along the coasts and lower mountain slope zones from the middle Yangtze via Guangdong. Further evidence for this hypothesis is needed from archaeobotanical studies. Perhaps archaeobotanists should start looking at the dispersal routes for foxtail millet into Southeast Asia as well. It is likely that before the arrival of rice in Thailand, there had been a previous dispersal of foxtail millet. Foxtail millet had reached the middle Yangtze by the sixth millennium BP (Nasu et al. 2007) and in Guangxi bordering Vietnam by the fifth to fourth millennium BP (Lu 2009). However, there is not enough evidence to reconstruct a more precise dispersal route into Thailand. Higham had originally hypothesised rice dispersed down major rivers into Southeast Asia (1995, 2002b, 2004, 2005). Furthermore, Higham proposed a dispersal route for rice from Yunnan (2005; also Higham et al. 2011) and more recently, from both Yunnan and Guanxi (2013). The archaeological record provides 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). On the other hand, Guanxi has been described as a 'spread zone' to Southeast Asia during the Neolithic with evidence of comparable decorative motifs in pottery (Rispoli 2007).

The sites from the KWPV show that millets preceded rice in central Thailand. The earliest dated millet is from a single grain found in Non Pa Wai with an AMS date of 2470-2200 cal. BC (Weber et al. 2010). The millet evidence predates the earliest evidence for domesticated rice in Thailand found at Khok Phanom Di *ca.* 2000-1500 BC. It is proposed here that millets came from the middle Yangtze to Thailand prior to rice; and that rice arrived at a later period, which could have been via the Guangdong and Guangxi route. Another possibility is that the crop package of rice and millets breaks apart before their arrival into Thailand and only millets are adopted in the KWPV, and rice elsewhere, such as in Khok Phanom Di. The millet dispersal route could have been via Yunnan although evidence to support this is still needed including material culture, but there is evidence for broomcorn and foxtail millet cultivation in Sichuan province in southwestern China dating to *ca.* 4000-2500 BC and combined rice and millet farming *ca.* 2700 BC (Guedes 2011). In Yunnan province, there is a dearth of archaeobotanical evidence and reports for the earliest rice evidence date to *ca.* 2500-2000 BC with no corresponding millet evidence (*ibid.*). The lack of millet evidence in Yunnan could be due to the lack of systematic archaeobotanical research.

The earliest rice cultivation systems practiced in the interior of Thailand would have been dryland along with the adoption of millet cultivation, and in the coastal areas, it would most likely have been décrue cultivation of rice in lowlying wetlands and floodplain margins. Décrue is defined as a cultivation system that depends on the natural flooding of the area used for cultivation, after the seeds are sown directly into the field by broadcasting (Harlan and Pasquereau 1969). The dryland farming mode of cultivation may have been extended to rice farming once rice was introduced to the KWPV at a later period (Castillo 2011).

In KSK there is not enough chronological depth to see changes in cultivation systems but the weeds of cultivation show that dryland farming took place. The other crops found at KSK such as the pulses are also dryland crops. It is hard to establish that all pulses were cultivated at KSK during this period, but it certainly seems likely that mungbeans were locally cultivated since mungbeans are well represented in the archaeobotanical assemblage at KSK and in present-day Thailand they are the major pulse cultivated and consumed. As discussed in sections 6.5.3.4 and 6.5.3.5 which takes into account preservation issues for mungbean as a result of crop processing, one would expect to find more horsegram than mungbean in the assemblage if they were both consumed in equal quantities. However, this is clearly not the case and it can therefore be interpreted that mungbean was an important comestible at KSK that could have been easily cultivated as part of a double-cropping regime with rice.

Rice in KSK has also been studied using morphology and archeogenetics and it is identified as *Oryza sativa japonica* and most likely tropical *japonica,* which is cultivated in the uplands. The rice in present-day Thailand is the Indian origin variety *Oryza sativa indica,* largely grown in lowland irrigated fields. This variety of rice was probably introduced in the Thai-Malay peninsula alongside wetland farming systems as a result of sustained contact and exchanges with India (Castillo 2011). Evidence for this contact with India and exchange of crops such as the Indian pulses but also cotton and long pepper is abundant at KSK. These links between India and KSK probably represent the earliest contact period. This evidence implies that the transfer of lowland rice cultivation by more labour intensive methods was not amongst the very first agricultural transfers from India to Thailand, but rather it was companion crops or condiments that spread first. It would not have been until the early centuries AD that *indica* rice reached the peninsula. Again, this indicates the need for more archaeobotanical work including sites dating to the early part of the first millennium AD to understand the switch from *japonica* to *indica* and from dryland to wetland systems.

6.7 CONCLUSION

KSK is the earliest urban site that has been studied in Southeast Asia with an exchange network and specialised labour. It has been demonstrated that there existed an agricultural base consisting mainly of the cereal rice that must have allowed part of the local population to engage in crafts specialisation but also supported foreign craftsmen and transient merchants. The existence of a population of merchants and craftsmen, local and foreign, settled and transient, would necessarily entail a continuous food supply and this would have meant nearby cultivation. The agricultural area at KSK has not been located exactly but the archaeobotanical and geomorphological studies provide sufficient evidence for local cultivation taking place in the hill slopes of KSK and the hinterlands. Interestingly, the geomorphology suggests that eventually the cultivable areas in KSK became overused and stressed making the soils unstable. This possibly contributed to the decline of KSK as a population centre.

The foreign populations at KSK would have brought with them their preferred dietary staples and if these foreign populations stayed for prolonged periods of time, they would have tried to cultivate these crops. Or perhaps the local populations would have tried to cultivate the crops themselves, initially to supply the demand of foreign enclaves but eventually adopting some for local subsistence. Examples of crops brought in from South Asia at KSK are the mungbean and horsegram, which provide a contrast in terms of long-term adoption processes. Although several Indian domesticates were exchanged in this initial period of contact, it seems that some crops were adopted by the local populations such as the mungbean, whereas others, like the horsegram, were not. Horsegram has not been traditionally important in Southeast Asia. Technological issues may be one of the reasons for adopting or rejecting crop cultivation, but in KSK, it seems dietary preferences along with social representations attached to some crops (as discussed in Chapter 7) played a role as well.

There is no information on the development of KSK as an entrepôt or whether rice agriculture was being cultivated in the hinterlands prior to the establishment of KSK. However, the archaeobotanical evidence suggests that dryland farming techniques and rice cultivation were in place from the inception of KSK and all throughout the period of exchange and craft activity. Samples belonging to the earliest occupation periods at KSK (the lowest US levels with anthropogenic deposits) have rice plant parts and weeds of cultivation that confirm rice cultivation being practiced from the start.

This site shows that the organisation of its labour may have been linked to its advantageous position along trade routes. The role of KSK as an entrepôt would have meant a port of entry and exchange for local, regional and foreign products. Cash crops would have been some of these exchanged products and it is hypothesised that KSK shows one of the earliest representations of the spice trade in Southeast Asia. Long pepper has been known as an important spice since the early centuries AD and yet it has not been reported from any archaeological site until now. The evidence for long pepper and cotton shows that there was a network of exchange from India to Thailand that existed in the second half of the first millennium BC. The only foodstuff found at KSK which could potentially represent local produce is the existence of ricebean and fruit rind, specifically *Citrus,* and possibly pomelo (*Citrus maxima*) which is native to mainland Southeast Asia.

The poor state of preservation and the low amounts of charred archaeobotanical remains are still the biggest limitations faced by archaeobotanists working in tropical environments. However, this study proves that archaeobotanical studies can be conducted in areas considered difficult and still yield results. It has also been demonstrated that many of the issues discussed in archaeology regarding agriculture, its origins and the movements of crops, are best discussed using the hard evidence of the plant remains themselves. Finally, food provides clues to identities and in the case of KSK, we know there were local, regional and foreign settlers. This is evident from the material culture (e.g. pottery classified as 'domestic' ware, Indian-type ware; Bouvet 2012) although the archaeobotany provides further insights on crops that were brought in, adopted or even dropped.

CHAPTER 7
Phu Khao Thong

7.1 SITE DESCRIPTION

The site of Phu Khao Thong (henceforth PKT) is a small hill situated in Suksamran district, Ranong province (Figure 7.1). The site lies in the west coast of the Thai-Malay Peninsula along the Andaman Coast, only 2.8 km from the sea and 152 km from Khao Sam Kaeo (KSK) as the crow flies. In Thai the name Phu Khao Thong translates to 'gold hill' referring to the many gold artefacts that were found there.

Figure 7.1: Photograph of Phu Khao Thong (Image by Bellina).

Phu Khao Thong is also the name used to designate a group of archaeological sites including PKT, Ban Kluai Nok, Khao Kluai (also Bang Kluk 1) and Rai Nai (also Bang Kluk 2) [Figure 7.2] (Chaisuwan 2011). These sites are grouped together because of their geographic location on the Andaman coast and their comparable relative dating using associated artefacts. This complex of sites yielded imported artefacts and have evidence for glass and semi-precious ornament production (Bellina et al. in preparation). Phu Khao Thong is a small site and is hypothesised to be an entrepôt with the possible settlement area in the nearby site Ban Kluay Nok. However, as discussed below there is some evidence of postholes in Phu Khao Thong signifying there was some habitation; terraces had also been cut into the rock to make flat areas (*ibid.*). The finds in PKT are rich in both quantity and quality (Chaisuwan 2011). Out of these four sites, archaeobotanical samples from only PKT were retrieved. This chapter discusses the results from PKT only.

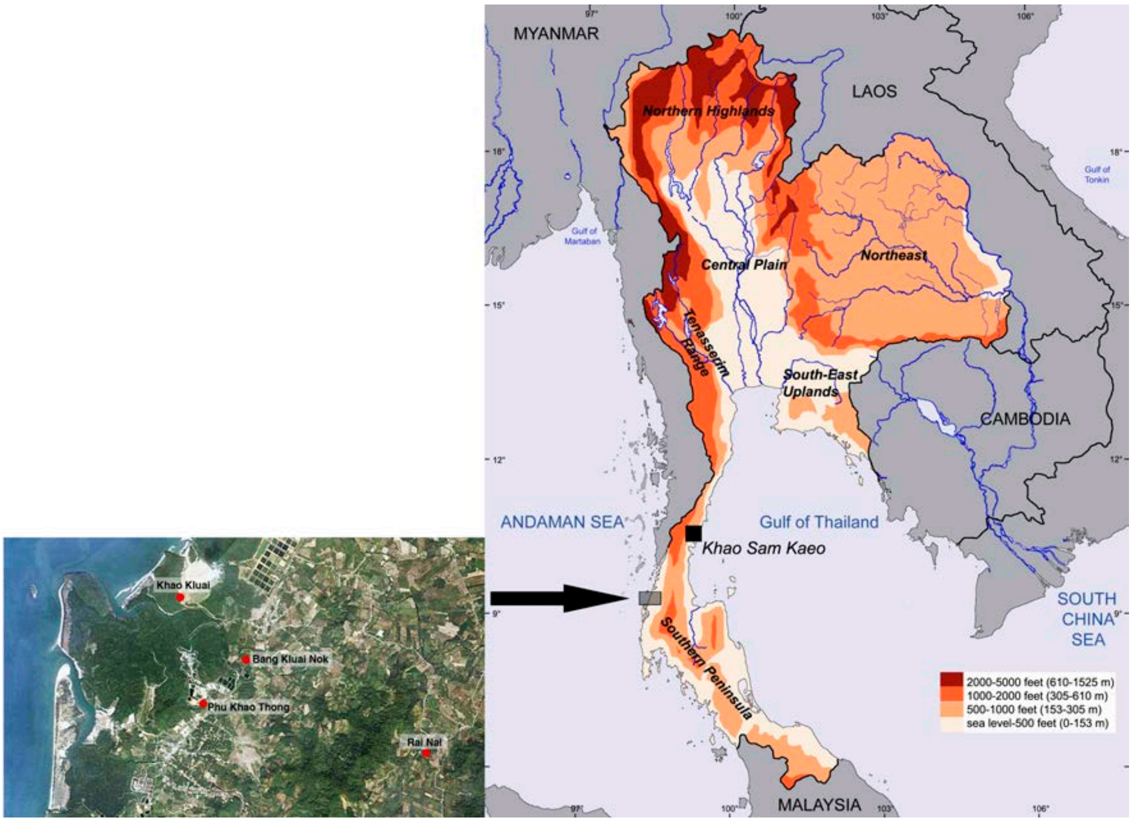


Figure 7.2: Left: Location of the group of archaeological sites belonging to the Phu Khao Thong complex; Right: Location of Phu Khao Thong in Thailand (Map by author; image from Google Maps).

PKT, like KSK, is strategically located close to the coast and is linked to other satellite sites. The working hypothesis of the Franco-Thai Project is that there is a link amongst these Late Prehistoric sites between the west and east coasts of the peninsula with interior sites acting as local supply centres. These local supply centres were not feeder points where direct supply of food to ships and merchants would be taking place (Jacq-Hergoulac'h 2002). These local centres were located along trans-peninsular routes that would have been used to transport goods between the west and east coasts. The current program of research of the Franco-Thai Project is focused on the interior of the peninsula where these local centres may have been located. Some of the local populations in the interior of the peninsula may have been in close contact with entrepôts like PKT and KSK, supplying resources acquired from the forest. These populations living in the interior of the peninsula could also have been familiar with the interior landscapes and routes that allowed for the transportation and dissemination of goods from the coastal sites. So far, the archaeological work has revealed economic relationships based on a network of exchanges as evidenced by the material artefacts. These exchange networks extend beyond the coast of the Thai-Malay Peninsula (see Chapter 6 - section 6.1.2).

The role of PKT in the Thai-Malay Peninsula exchange network was probably as a first point of entry for people, including traders and craftsmen, from the Indian Ocean. PKT would have also been a transit point for those crossing the peninsula or for people having just returned from the east coast. As with KSK, PKT was an entrepôt that appears to have catered to both, the local people and foreign population. It is hypothesised that Indian presence would have been stronger at PKT than at KSK due to its location. One would expect to find more South Asian related goods amassed at PKT as a first point of entry from the Indian Ocean before onward distribution. On the other hand, it is possible that at KSK, which lies in the Gulf of Thailand, a bigger proportion of the travellers or traders came from insular Southeast Asian communities and also from people traveling from the north, including modern-day Vietnam and China. No Chinese related artefacts were found at PKT compared with the finds of Han pottery sherds and mirrors at KSK (Péronnet et al. in preparation) although fragments of Han ceramics have been found in the nearby site, Ban Kluay Nok (Bellina et al. in preparation; Péronnet unpublished report 2008).

But so far, PKT has yielded a larger and more diverse corpus of Indian pottery than at KSK (Bellina et al. in preparation; Bouvet 2012). The PKT Indian pottery types were designated as *Fine Wares 1* and *2* which is similar to those found in KSK in typology and technical descriptions (Bouvet 2012). These include knobbed ware and rouletted ware comparable to those from Arikamedu. Rouletted ware from India and Sri Lanka date *ca.* third to first centuries BC and have been found in other sites across Southeast Asia such as in central Thailand, Bali, Vietnam and North West Java (Bouvet 2012; Chaisuwan 2011). Rouletted ware evidence is significant because as demonstrated through composition analysis, it possibly came from India.

PKT yielded a large amount of glass beads, including unfinished and melted beads (Chaisuwan 2011), which indicates that beads were made on-site. Composition analysis of PKT glass done by Lankton et al. (2006) suggests associations with KSK. Furthermore, analysis of some green and yellow mosaic glass from PKT done by

Lankton shows that the mosaic glass belonged to the Roman-type mosaic glass. Roman intaglios were also found in PKT. Furthermore, glass composition analysis done on potash and m-Na-Ca-Al/Arika glass shows the link between PKT and Arikamedu (Dussubieux et al. 2012). All of these imports provide further evidence of the globalisation that existed during the late prehistoric period. More evidence linking PKT with South Asia are in the form of a lion pendant fragment made from rock crystal and South Asian auspicious symbols made from carnelian.

This evidence from PKT reveals early interactions between populations from South Asia and the inhabitants along the coast of the Andaman Sea. The network extended across the Thai-Malay Peninsula to KSK and probably other sites along the east coast. The archaeobotanical assemblage from PKT will be discussed in this chapter and it will be compared with that of KSK.

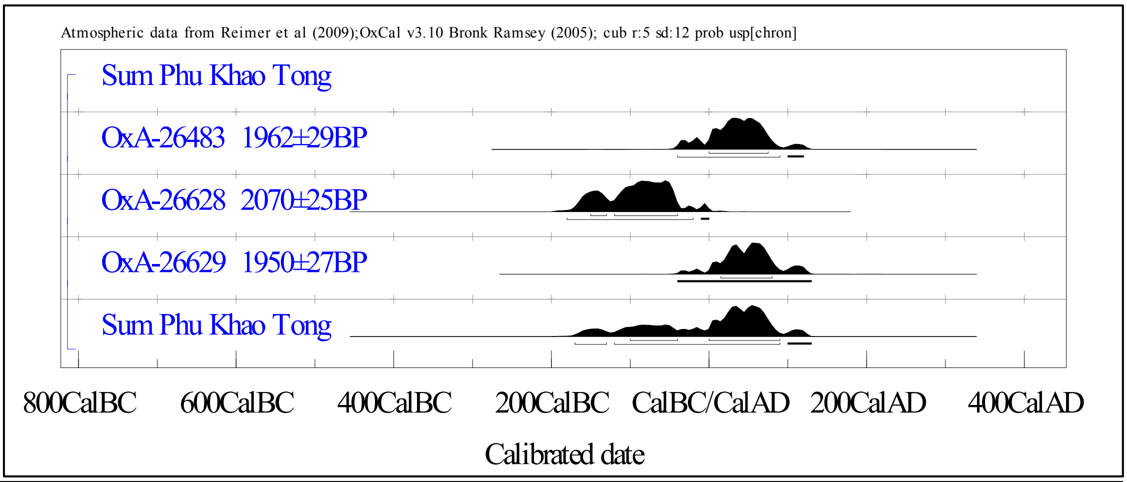
7.2 CHRONOLOGY

As mentioned above, the chronology at PKT has mainly been based on associated artefacts. The rouletted ware found at PKT is dated between the third and first centuries BC. Inscriptions have also been used to establish the chronology at PKT. Tamil-Brahmi script inscribed in pottery was dated to the second century AD and another in Brahmi script dates to the fourth century AD (Chaisuwan 2011).

Some plant remains were sent to the University of Oxford Radiocarbon Accelerator Unit in the United Kingdom for AMS dating and these are listed in Appendix 7.1. Unfortunately, out of the nine samples sent, only three yielded results and these are found in Table 7.1. Six samples were rejected based on low yields of carbon. The samples that yielded results show AMS dates that fit well with the overall chronology of the Late Prehistoric period in the Thai-Malay Peninsula. The Metal Age at PKT probably dates from the third century BC to the early centuries AD and overlaps with the chronology of KSK.

The AMS results at PKT are not only the earliest for mungbean (*Vigna radiata*) and horsegram (*Macrotyloma uniflorum*) in Southeast Asia but also outside South Asia. The rice grain has a later date than the one from KSK (OxA-26626: 199-52 cal. BC) and is an important contribution in understanding the evolution of rice in the Thai-Malay

Peninsula during the prehistoric period. The section on rice (7.5.3.1) shows that the rice found at PKT at this later period was similar to that of KSK suggesting rice from India had not yet been introduced. More studies on rice dating to the beginning of the first millennium and confirmed with AMS dates are needed to understand the transition from dryland to wetland rice agriculture.



Lab no.	section	source	AMS	Calibrated 1-sigma (68.2%)	Calibrated 2-sigma (95.4%)	context
OxA-26483	PKT S2 US3	*Oryza sativa*	1962±29 BP	5-70 AD	41 BC - 120 AD	cultural layer
OxA-26628	PKT S2 US3	*Vigna radiata*	2070±25 BP	148-46 BC	172 - 2 BC	cultural layer
OxA-26629	PKT S7 US4	*Macrotyloma uniflorum*	1950±27 BP	20-80 AD	36 BC - 125 AD	cultural layer

Table 7.1: AMS dates from Phu Khao Thong.

7.3 CONTEXTS

Unlike KSK, the site of PKT was not subjected to an in depth archaeological investigation. Two sections and five test pits were opened primarily to retrieve plant remains and these were located in areas where it was anticipated occupation occurred. As a result, all the samples were taken from test pits and stratigraphic layers where there would have been nearby occupation and, are interpreted in this manner. Material artefacts were not collected from each stratigraphic layer but observations were written down (Table 7.2).

It has been noted that there are fewer finds at the top of slopes possibly caused by movements of soil downwards (Orton 2000). Therefore, soil erosion was another consideration in choosing the location of the test pits and these were opened at different levels of the hill (Figure 7.3). The two sections cleaned and sampled in 2008 were located at the bottom of the hill. At PKT, the TPs are indicated by an 'S' and not 'TP.' Furthermore, phytolith samples were collected from S3 but not macroremains and so this test pit does not form part of the proceeding discussion. S5 samples were not analysed and are therefore also not discussed in this chapter.

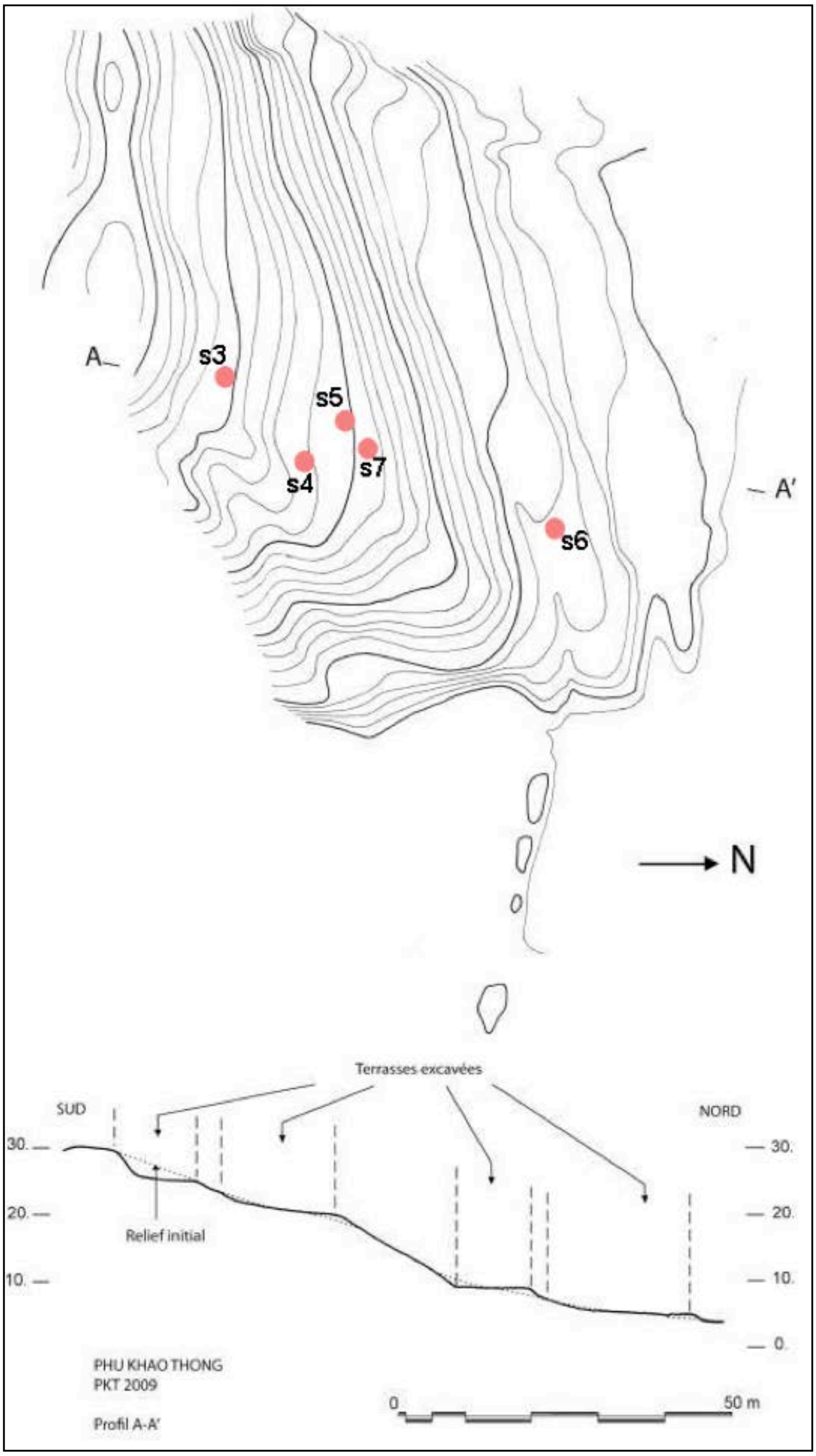


Figure 7.3: Drawing showing the location of test pits opened in 2009. The map does not show the locations of the test pits opened in 2008 because they are located outside the map area (Drawing by Bernard).

In 2008, the team visited PKT and the sections of two looting pits were cleaned and sampled, namely S1 and S2. Because of the nature of the pits, a certain level of contamination involving modern intrusions was expected. The modern contaminants and context security are discussed in section 7.5.2. The sections S1 and S2, and test pit S7 were thoroughly analysed. All stratigraphic layers sampled from S1, S2 and S7 were sorted and identified. Although S4 and S5 had cultural layers, there were fewer material artefacts observed in these two test pits than in S1, S2 and S7. Therefore, S5 was not sorted and only one sample (US2) from S4, which was considered the cultural layer, was analysed. S6 was a test pit that did not yield any material artefacts but it had a posthole. The posthole is evidence for human occupation and in S6 it lies at the lowest layer signifying it belonged to an early occupation period. The posthole contained charcoal and it was the only layer analysed. Context security for the infill of the posthole is confirmed by the complete absence of modern contaminants. However, the period to which the infill belongs has not been established due to lack of AMS dating and associated artefacts. The only plant remain of any importance found in the S6 posthole was a large quantity of *Citrus* rind fragments.

TP	US	Floated (l)	Depth (cms)	Description
S1	surface	-	0-55	top soil, greyish red, big cobbles, heavily rooted
	2	10	55-90	reddish soil with fine gravel and some cobbles, some sherds
	3	10	90-140	dense silty clay
S2	surface	-	0-40	top soil, large gravel, greyish red sandy clay, heavily rooted
	2	20	40-90	yellowish red silty clay with fine gravel, some sherds, many small glass beads, glass fragments
	3	20	90-130	silty red clay, many sherds, bronze fragment, many small glass beads, 1 rock crystal fragment
S4	surface	-	0-20	humus, many roots
	1	10	20 - 30	orange soil, small pebbles and rocks, 1 sherd
	2	10	30 - 60	orange soil with eroded sedimentary rock (violet in colour), sherds, cultural layer
	3	10	60 - 70	bedrock (sedimentary rock), no artefacts
S5	1	10	15 - 30	orange soil with some cobbles, many sherds, cultural layer
	2	10	30 - 41	orange soil with more sedimentary rock, some sherds
	3	10	41 - 50	orange soil with more sedimentary rock, 1 sherd
S6	1	10	25 - 45	orange soil, many roots, some sedimentary rock, no sherds
	2	10	45 - 55	orange soil with more sedimentary rock, no sherds
	posthole	8	65 - 90	posthole dug into bedrock, charcoal
S7	1	10	85 - 110	erosion, brown soil with cobbles, sherds, charcoal
	2	10	110 - 155	dark soil, sherds, charcoal, cultural layer
	3	10	155 - 170	dark soil with cobbles, charcoal, glass beads, sherds, cultural layer
	4	10	170 - 183	dark soil, glass bead, eroded sherds, cultural layer
	5	10	183 - 200	dark soil, raw glass, eroded sherds, charcoal

Table 7.2: Sections and test pits sampled for macroremains and the description of each stratigraphic layer.

7.4 DATASETS

Many of the plant remains from PKT are similar to those from KSK and therefore, these entries are not discussed at length. The details for any plant remains that occur in both KSK and PKT are found in the individual sections discussed in Chapter 6 and in Appendix 6.14. These details include the place of origin, genetic studies, archaeological evidence, plant use, habitats and identification criteria.

A total of eleven samples have been sorted and identified from PKT. The PKT dataset yielded 10,663 number of samples (NSP) and 10,069 number of identified specimens (NISP). Compared to KSK, PKT has a richer dataset with average plant parts per litre of 78.65 compared to 8.74 at KSK. Table 7.3 shows the summary statistics from PKT. However, KSK has a higher taxa diversity overall with 112 identifications whereas PKT has less taxonomic diversity with a total of forty-three identifications. The prevailing view is that preservation issues mean fewer charred remains are found in sites with humid climates, but the high number of archaeobotanical remains found at PKT provides a counterview.

	Total
NSP	10663
NISP	10069
No. of samples	11
Plant parts per litre MEAN	78.66
Plant parts per litre MIN	0.9
Plant parts per litre MAX	294.4
No. of taxa* MIN	3
No. of taxa* MAX	15
* excludes unidentified plant parts, fungal sclerotia, parenchyma & modern seeds	

Table 7.3: Summary statistics of the botanical dataset at Phu Khao Thong. The complete list is found in Appendix 7.2.

Overall, the high number of plant parts in PKT can be attributed to one species, *Acmella paniculata.* This is a weed species that has already been discussed in Chapter 6 under the section on weeds (6.5.6). It accounts for 65.64% of NISP in PKT. Although it is a known weed of rice cultivation, an alternative hypothesis for the high occurrence of this plant in PKT is provided in this chapter (section 7.5.5). It is also probably the case that *A. paniculata* preserves well compared to other taxa although requiring testing with 'real fire' charring experiments.

A total of sixteen species, twenty-two genera and fourteen family groups were identified (Table 7.4 and 7.5). Also, several 'types' were discerned from the assemblage. The number of indeterminate plant parts totalled 1,411 or 13.23% of the total assemblage and these came from all of the eleven samples.

Family	no. of samples	ubiquity (n=11)	ID
Asteraceae	10	90.91%	7, 14, 21, 61
Chenopodiaceae	1	9.09%	101
Commelinaceae	3	27.27%	99
Cyperaceae	4	36.36%	15, 20, 86, 88
Fabaceae	8	72.73%	6, 30, 56, 71, 102, 119, 123
Myrtaceae	8	72.73%	8
Pedaliaceae	1	9.09%	98
Piperaceae	7	63.64%	13
Poaceae	9	81.82%	1,2,3, 64, 78, 79, 103, 105
Polygonaceae	3	27.27%	10
Rosaceae	1	9.09%	100
Rubiaceae	1	9.09%	89
Rutaceae	7	63.64%	35, 40
Vitaceae	1	9.09%	17

Table 7.4: Families to which identified samples belong to in Phu Khao Thong, the number of samples containing them, the ubiquity index and the identification nos. of samples belonging to said Family group.

Family	Genus	Species	ID
Asteraceae	*Acmella*	*Acmella paniculata*	7
	Calendula	*Calendula arvensis*	21
	cf. *Eupatorium*		61
	Mikania	*Mikania* cf. *cordata*	14
Chenopodiaceae	*Chenopodium*		101
Commelinaceae	*Commelina*	*Commelina benghalensis*	99
Cyperaceae	*Cyperus*	*Cyperus* cf. *pygmaeus*	15
	type A		20
	type B		86
	cf. *Eleocharis*		88
Fabaceae	*Cajanus*		58
	Lathyrus	*Lathyrus sativus*	102
	Macrotyloma	*Macrotyloma uniflorum*	30
	Vigna	*Vigna* cf. *umbellata*	56
		Vigna radiata	6
		Vigna cf. *mungo*	123
	type C		119
Myrtaceae			8
Pedaliaceae	*Sesamum*	*Sesamum* cf. *indicum*	98
Piperaceae	*Piper*	*Piper* cf. *longum*	13
Poaceae	*Brachiaria*	*Brachiaria mutica*	105
	cf. *Echinochloa*		103
	Eleusine	*Eleusine* cf. *coracana*	64
	Oryza	*Oryza sativa*	1, 2a
			2b
			2c
			2d
			3
			78
			79
Polygonaceae	*Rumex*		10
Rosaceae	*Rubus*	type C	100
Rubiaceae			89
Rutaceae	*Citrus*		35
			40
Vitaceae	*Ampelocissus*	*Ampelocissus* cf. *ochracea*	17

Table 7.5: The families, genus and species groups identified in Phu Khao Thong.

The family groups with the highest representation are Asteraceae, Poaceae, Fabaceae, Myrtaceae, Piperaceae and Rutaceae (Table 7.4). The assemblages represented by four of these family groups (Poaceae, Fabaceae, Piperaceae and Rutaceae) are mostly coming from cultivars. The Asteraceae assemblage is predominantly *Acmella paniculata* and this is both a weed of rice cultivation but the plant is also consumed as a vegetable. As at KSK, the archaeobotanical assemblage is composed mostly of remains caused by human activity and is therefore considered a representation of human subsistence.

7.5 RESULTS

7.5.1 The Resource Base

The macroremains identified so far have yielded seven domesticated crops and several wild/weedy species (Table 7.6). At PKT as with KSK, there is also evidence of cash crops. Two of the three cash crops are identified to species level whilst the other one is broadly identified to genus level. Approximately eleven types of weeds are represented in the assemblage. Appendix 7.3 is the list of taxa found at PKT.

TAXA	Common name	Domestication centre of origin	Date of domestication
CEREALS			
Eleusine coracana	finger millet	wetern Uganda to the Ethiopian highlands	transferred to India before 1000 BC
Oryza sativa (if *japonica*)	rice	China (Yangtze Basin)	5000-4000 BC
Oryza sativa (if *indica*)	rice	South Asia	2500 BC
PULSES			
Cajanus sp. *(if Cajanus cajan)*	pigeonpea red gram	South Asia: Eastern India / Orissa	by 1400 BC
Lathyrus sativus	grass pea	South-west Asia or south Balkans	transferred to India before 2000 BC
Macrotyloma uniflorum	horsegram	South Asia: Indian peninsula and/or Western India	2600-2000 BC
Vigna radiata	mung bean green gram golden gram	South Asia: Indian peninsula and/or Northwestern India	2600-2000 BC
Vigna mungo	black gram	India including Western Ghats	2500-2000 BC
Vigna umbellata	rice bean	Southeast Asia	unknown
CASH CROPS			
Citrus maxima	pomelo	Southeast Asia	unknown
Piper longum	long pepper	Greater Assam region	unknown
Sesamum indicum	sesame	South Asia	2000 BC

Table 7.6: Seed crops identified at Phu Khao Thong, the regions of origin and dates of domestication (Sources: Blench 2008; Dalby 2002; Fuller 2003, 2011b, 2008b; Fuller and Harvey 2006; Liu et al. 2009; Niyomdham 1991; Smartt and Simmonds 1995).

7.5.2 Modern contaminants and context security

The same methodology used in KSK to determine context security was applied to the samples from PKT. Table 7.7 shows the presence of fungal sclerotia, the percentage of modern seeds in the sample and the proportion of roots present. The results show that samples taken from the cleaned sections of looting pits (S1 and S2) have a high amount of modern contaminants. On the other hand, the quantity of roots is low in S1 and S2 indicating very low levels of bioturbation. It is believed that the modern contaminants that made their way into the sections were wind borne. The sections that were cleared were located inside pits which act as accumulation holes (Figure 7.4). Furthermore, these two sections (S1 and S2) were located underneath a forest canopy and almost all the modern contaminants were composed of *Celtis* sp. seeds (Figure 7.5). Even though it has not been confirmed, this probably means *Celtis* sp. trees were present near the sections when the archaeological team took samples.

Figure 7.4: Left - Image of S1; Right - Image of S2 (Images by Fuller).

Figure 7.5: Photographs of two *Celtis* sp. seeds from Phu Khao Thong S2 US2 (Image by author).

	Presence of fungal sclerotia	% of modern seeds / sample	Presence of roots	Interpretation
PKT08 S1 US2		35.06%	x	section of looting pit cleared
PKT08 S1 US3		43.10%	x	section of looting pit cleared, small sample size (n=58)
PKT08 S2 US2		69.57%	x	section of looting pit cleared
PKT08 S2 US3		3.73%	x	
PKT09 S6 posthole			xx	
PKT09 S4 US2	Y	61.54%	xxx	bioturbation, small sample size (n=26)
PKT09 S7 US1		6.93%	-	
PKT09 S7 US2		4.87%	xx	
PKT09 S7 US3		7.01%	xx	
PKT09 S7 US4		1.18%	xxx	
PKT09 S7 US5		0.35%	xx	

Legend:
- \- none
- x a few roots, 25% or less
- xx many roots, >25-60% of sample is made up of roots
- xxx mostly roots, >60% of sample is made up of roots

Table 7.7: Representation of all modern seeds and fungal sclerotia found at Phu Khao Thong.

The presence of many roots along with fungal sclerotia suggests a high level of bioturbation. The other sample with very high levels of bioturbation, a high proportion of modern seeds and the presence of fungal sclerotia is S4 US2. The sample size of S4 US2 was considered small. This sample contained very few charred remains and had very limited evidence of a cultural layer. The context security for samples from S7 is good with no fungal sclerotia present in any layer and very low percentages of modern seeds. All the stratigraphic layers from S7 yielded cultural remains.

7.5.3 The Economic Crops: cereals and pulses

The economic crops identified at PKT are the pulses *Vigna radiata* (mungbean), *Macrotyloma uniflorum* (horsegram), *Vigna* cf. *umbellata* (rice bean), *Vigna* cf. *mungo* (black gram) and *Lathyrus sativus* (grass pea) and the cereals *Oryza sativa* (rice) and *Eleusine* cf. *coracana* (finger millet). These consist of whole seeds and seed fragments although only one seed of finger millet was retrieved. At PKT, *Oryza sativa* spikelet bases dominate the assemblage although there were more rice grain fragments than at KSK. *Cajanus* sp. was also present at PKT. Pulses not found in KSK were *Lathyrus sativus* and *Vigna* cf. *mungo*. However, the pulse *Lablab purpureus* which was identified in KSK as cf. *Lablab* is not present at PKT. Table 7.8 shows the economic crops identified and a summary of the weeds that occur in the same context defined by their habitat. At PKT, as with KSK, dryland weeds dominate the assemblage with 91% of the samples containing dryland weeds (*Acmella paniculata* taken into account).

	CEREALS		PULSES						WEEDS			
	Oryza	*Eleusine* cf. *coracana*	*Cajanus* sp.	*Lathyrus sativus*	*Macrotyloma uniflorum*	*Vigna radiata*	*Vigna* cf. *mungo*	*Vigna* cf. *umbellata*	*Acmella paniculata**	dryland weeds	wetland weeds	dry & wet weeds
PKT08 S1 US2	x			x		x			x			
PKT08 S1 US3	x				x				x	x		
PKT08 S2 US2	x								x	x		x
PKT08 S2 US3	x			x		x			x	x	x	x
PKT09 S4 US2									x			
PKT09 S6 posthole												x
PKT09 S7 US1	x				x	x			x	x		
PKT09 S7 US2	x		x	x		x	x	x	x	x		
PKT09 S7 US3	x					x			x	x		
PKT09 S7 US4	x				x	x	x		x		x	
PKT09 S7 US5	x	x			x	x			x		x	x
NISP	952	1	1	8	7	82	3	1	6601	38	4	73
no. of samples	9	1	1	3	4	7	2	1	10	6	3	4
ubiquity (n=11)	82%	9%	9%	27%	36%	64%	18%	9%	91%	55%	27%	36%

LEGEND:
no. of samples - refers to no. of samples in the sampled population containing specified taxon
NISP - Number of Identified Specimens
* a known weed of dryland/upland rice cultivation although it is also known to be used as a vegetable in Thailand

Table 7.8: List of cereals and pulses and the weeds found in the same samples found at Phu Khao Thong.

Of the economic crops represented in PKT, rice dominates the assemblage with 82% of the samples containing rice plant parts. However, the pulses have high representation at PKT with the mungbean present in 64% of the samples followed by horsegram at 36%.

7.5.3.1 *Oryza sativa* (L.)

Common names: rice
Thai names: khao

The results of the rice analysis are discussed in this section. It follows a similar format as the discussions on rice at KSK found in Chapter 6 (6.5.3.1). However in this section, the rice remains from PKT are considered in relation to KSK rice remains and to the other crops found in PKT. Details of the identification criteria used to distinguish wild or domesticated rice, *japonica* or *indica* varieties and tropical *japonica* determination are found in Chapters 6 (section 6.5.3.1) and 9 (section 9.3).

	TOTAL	ubiquity
caryopsis	46	63.64%
caryopsis fragment	210	63.64%
spikelet base - domesticated	496	72.73%
spikelet base - wild	35	45.45%
spikelet base - immature	9	36.36%
spikelet base - indeterminate	98	54.55%
lemma	8	27.27%
lemma apex - fractured	33	45.45%
lemma apex - smooth	3	18.18%
husk	11	9.09%
carbonised husk impression	3	27.27%
Total rice plant parts	952	81.82%

Table 7.9: Breakdown of rice plant parts at Phu Khao Thong.

Rice caryopses, spikelet bases, lemmas, husk and husk impressions on charcoal (ID nos. 1, 2, 3, 78 and 79 respectively) were identified in nine samples from five test pits, corresponding to a ubiquity rate of 82% (Table 7.8). The breakdown of rice plant parts is found in Table 7.9.

Rice, the staple at Phu Khao Thong

The high representation of rice at PKT indicates that this cereal was undoubtedly the main economic crop. In both sites, PKT and KSK, rice forms a large component of the entire archaeobotanical assemblage (NISP). Figure 7.6 shows the breakdown of the archaeobotanical remains in both sites with respect to rice.

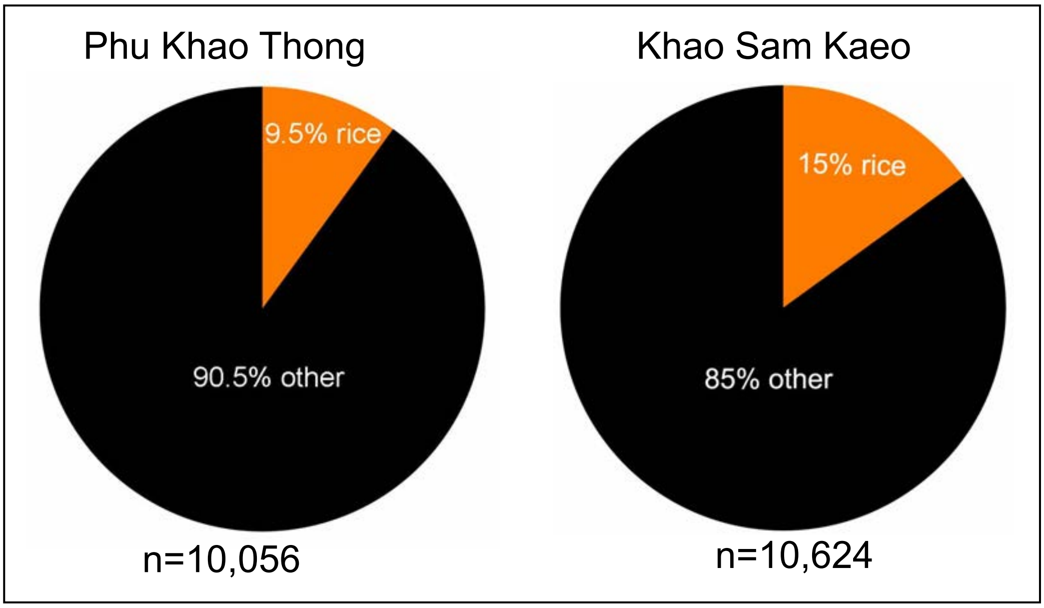


Figure 7.6: The rice evidence at the sites of Phu Khao Thong and Khao Sam Kaeo.

The resource base in both sites shows that rice constitutes 75% and 86% of the assemblage at PKT and KSK respectively (Figure 7.7). The next best represented group of crops are the cash crops followed by one pulse, the mungbean, with 6.4% in PKT (n=1,276) and 1.1% in KSK (n=1,666) of total resource base.

As has been previously discussed in Chapter 6 (section 6.5.3.4) there is a preservation bias against the mungbean due to crop processing. Nonetheless, the archaeobotanical assemblage found at PKT indicates a high representation of mungbean. This leads to the conclusion that mungbean was indeed an important part of the diet in PKT. The charring experiments discussed in Chapter 8 suggest that if only seeds and seed fragments of both mungbean and rice are taken into account, mungbean in 64% of the experiments would be more visible (includes naked rice, see Table 5.3). If husk is taken into account, then rice always has a higher preservation ratio than mungbean. Looking at grains and fragments at PKT only, there is more rice than mungbean (*Oryza* caryopsis: *Vigna* ratio of 100:32; see also Table 8.1). The evidence at PKT suggests there was more rice consumed than mungbean. Based on the charring experiments found in Chapter 8, there is a charring preservation bias in favour of the mungbean and even then a higher preservation of rice is found than mungbean at PKT.

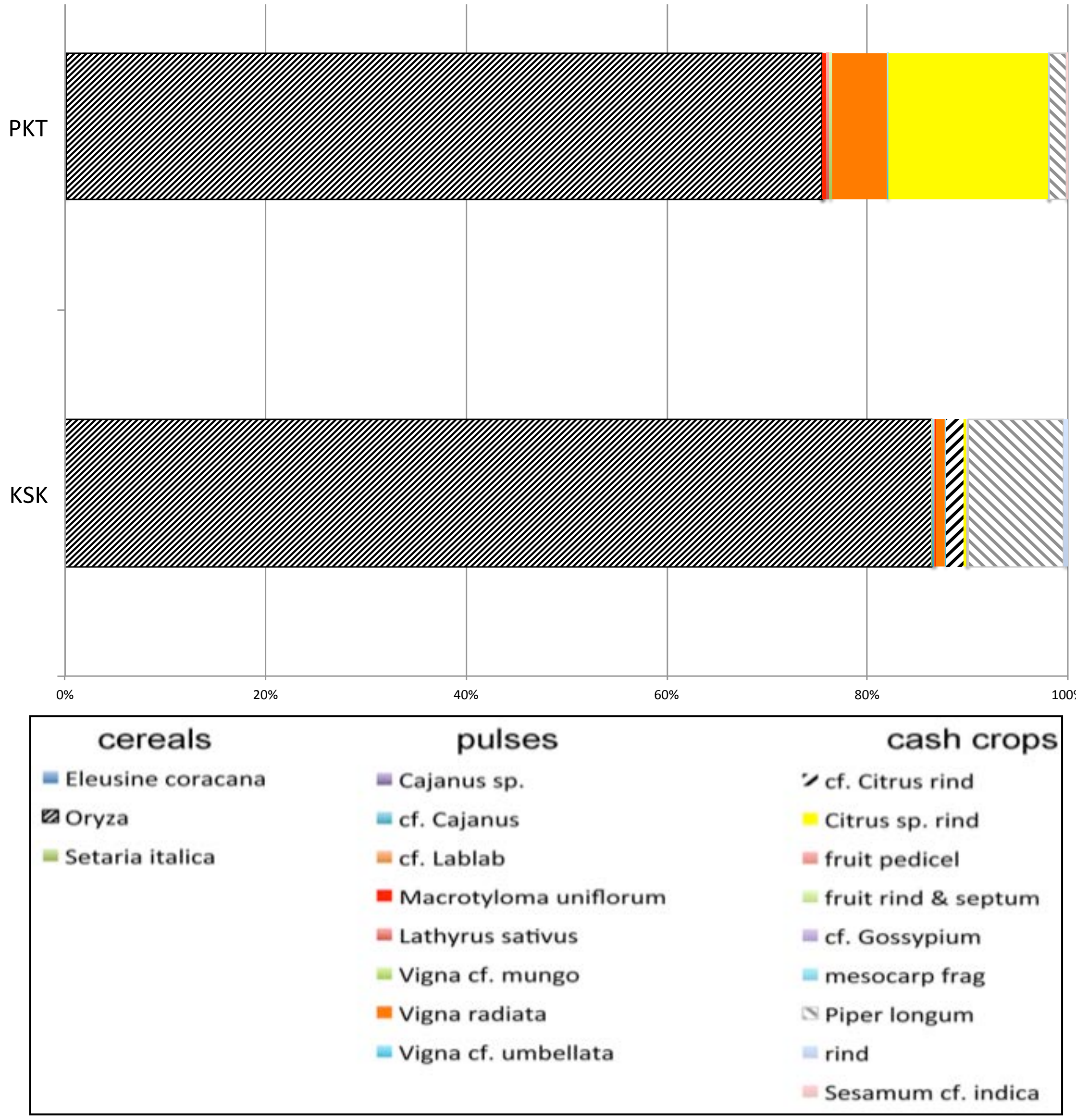


Figure 7.7: Breakdown of the different crops represented at Phu Khao Thong and Khao Sam Kaeo.

At KSK, it has been hypothesised that since all the mungbean remains were cotyledon fragments, mungbeans might have undergone the crop-processing stage of pounding. Pounding is necessary to split mungbeans in the preparation of some dishes such as *dhal*. This extra processing stage in the preparation of mungbeans would increase the chances of preservation, and yet rice predominates the macroremains assemblage at KSK. Although most of the mungbean evidence at PKT is made up of fragments of cotyledons (64.6% and n=53), there are many complete seeds of mungbean (n=11).

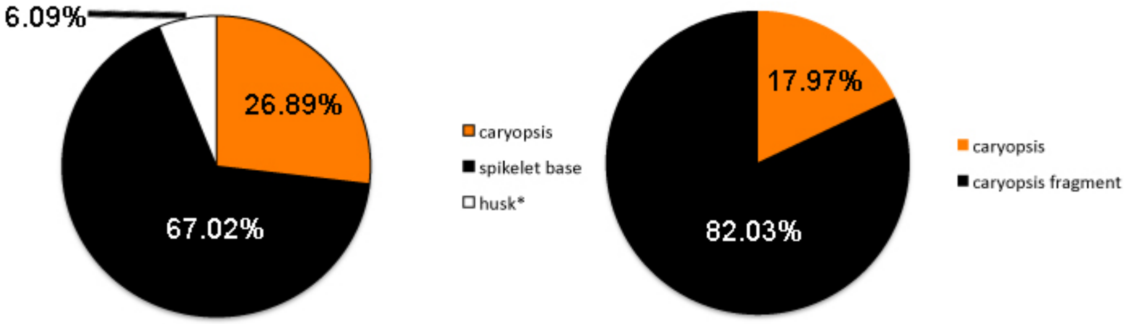


Figure 7.8: Left: rice plant parts found at Phu Khao Thong (n=952). husk* includes the husk impressions on charcoal; Right: share of complete rice grains and fragments found at Phu Khao Thong.

Rice, like the 'pod-threshing' pulses such as horsegram, would have more chances of preservation compared to free-threshing cereals and pulses because it requires several stages of processing. It also follows that processing waste product such as spikelet bases and husk would have more chances of preservation than rice grains although it has been noted that rice grain fragments are usually found in rice processing waste in the first stage of pounding and winnowing. It is definitely the case at PKT, that rice processing waste constitutes the majority of the rice assemblage. Figure 7.8 shows that spikelet bases and husk fragments make up 73.11% of all rice parts found at PKT. Also, 82.03% of rice grains are fragments (Figure 7.8). For each individual context (Table 7.10), spikelet bases dominate the assemblage except in one sample (S2 US3). Because the major component of rice plant parts in PKT is composed of crop processing waste product, it is concluded that the rice remains at PKT are a product of rice processing and not cooking accidents. As at KSK, it is believed that dehusking in PKT took place outside the household. This still holds true today in Thai villages where rice is dehusked outside the house on a daily basis. Alternatively, a traditional rice storage practice in Thailand to guard against weevils, is the use of burnt rice husk including rice spikelet bases mixed with the rice spikelets (Chomchalow 2003). The burnt husk and spikelet bases would still be separated from the rice grain during the crop processing stages of winnowing.

context	ratio
PKT08 S2 US2	50:100
PKT08 S2 US3	100:32.4
PKT09 S7 US1	59.6:100
PKT09 S7 US2	26:100
PKT09 S7 US3	47:100
PKT09 S7 US4	18.4:100
PKT09 S7 US5	62.3:100

Table 7.10: Ratios of *rice grain : spikelet bases* for each context at Phu Khao Thong.

Domesticated rice at Phu Khao Thong

The rice spikelet base abscission scars in PKT were examined to establish the wild or domestication status of the rice found on the site (Figure 7.9). PKT has yielded a total of 638 spikelet bases and after KSK, has the highest amount of spikelet bases in Southeast Asia. The spikelet bases had predominantly domesticated morphology (91.47%; n=493) signifying that rice at PKT was definitely domesticated. Wild-type spikelet bases are present in PKT and also in KSK. Weedy rice is found as a weed of rice cultivation and will be present in varying degrees depending on how advanced cultivation techniques are.

The one dated rice grain from PKT yielded an AMS date of 41 BC-120 cal. AD (OxA-26483). It is a later date compared to the one dated rice from KSK which yielded an AMS date of 199-52 cal. BC (OxA-26626). Although dates and material culture from PKT overlap with those from KSK, all three AMS dates from PKT fall in the latter part of KSKs general chronology. It is therefore consistent that the percentage of domesticated rice in PKT should be slightly higher than at KSK. The higher percentage of domesticated rice spikelet bases found in the archaeological assemblage at PKT compared to KSK shows the increasing trend of domesticated-type rice over time. This trend towards higher percentages of domesticated rice is demonstrated in Chapter 9 (Figure 9.7) with rice remains analysis from sites dating from as early as the sixth millennium BC and ending with PKT in the late first millennium BC. The trend is an increase over time toward domesticated-type rice.

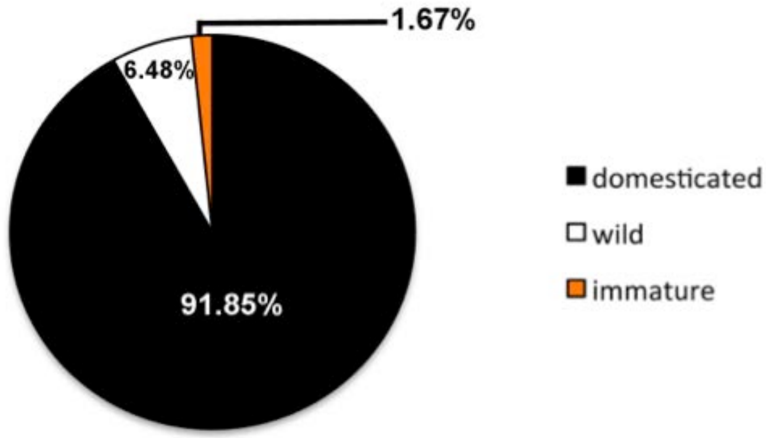


Figure 7.9: *Oryza* spikelet bases found at PKT. Percentages exclude indeterminate spikelet bases.

<u>Rice in Phu Khao Thong is tropical *japonica*</u>

Most of the rice from PKT is short and plump (Figure 7.10). This morphology is normally attributed to *Oryza sativa japonica.* However, this is no reliable method to determine rice subspecies and therefore a morphometric analysis coupled with aDNA analysis is used instead. The morphometric study done at PKT shows that whole rice grains had an average length-width (L/W) ratio of 1.71 (n=22). Out of these twenty-two rice grains, 95.5% had L/W ratios of <2.3. Measurements of L/W falling in the <2.3 group are associated with *japonica* rice whereas L/W ratios above 2.5 are normally *indica* rice (Fuller et al. 2007b). There is variation in these estimates as can be seen in Table 7.11 although generally, lower L/W ratios are associated with *japonica* rice. All the archaeological rice remains from the Metal Age that have been studied by the author show L/W ratios closer to the *japonica*-type than the *indica*-type.

Figure 7.10: Caryopses from PKT S7 US2 showing a plump short morphology (Images by author).

	L/W ratio (AVE)	sample size
Oryza sativa japonica modern samples*	<2.3	45
Oryza sativa japonica modern samples**	2.02	15
Oryza sativa indica modern samples*	2.3 -2.4	141
Oryza sativa indica modern samples**	2.11	20
Oryza sativa indica modern samples***	3.39	200
Khao Sam Kaeo archaeological rice***	1.65	8
Noen U-Loke archaeological rice***	1.82	53
Ban Non Wat archaeological rice***	1.98	38
Phu Khao Thong archaeological rice***	1.72	22
* Fuller et al. 2007; Harvey 2006		
** Tanaka (unpublished report)		
*** Author		

Table 7.11: L/W ratios of modern and archaeological rice.

The aDNA study conducted by Dr. Tanaka was based on chloroplast and nucleotide sequencing. Fifteen grains and fragments of rice from PKT were sent with a DNA extraction success rate of 40%. The chloroplast genotype was successfully identified as *japonica* in six samples from PKT (Table 7.12, for individual samples see Appendix 7.4). The rest of the samples did not yield results either way. The nucleotide sequencing (nuclear genome) did not yield results.

Country	Population name	tested sample	sample condition	Chloroplast genotype			Ch6 region genotype*			
				indica	*japonica*	N/A	-217	H	0	N/A
Thailand	pkt s7 us5	15	whole & broken	-	6	9	1	-	5	9

* Nucleotide sequencing in Ch6 region with "H" as heterozygous type and "-217" and "0" type in Ch6 region.
NA are non-amplification samples by PCR with specific primer.

Table 7.12: Genotype of PKT ancient rice grain population (Adapted from Tanaka unpublished report).

To determine whether there were awns present in the rice from PKT, the lemma apices and their fractures were examined (Table 7.13). The analysis showed that the lemma apiculi in 91.67% of the samples at PKT (n=36) had an angled fracture signifying an awn had been present. Lemma apiculi were only found in test pit S7 but were present in all the layers sampled. Awns normally occur in wild rices but at PKT, the rice has been demonstrated as domesticated through the examination of the rice spikelet bases. It has also been determined that the PKT rice is *japonica* through morphometrics and aDNA. It is therefore postulated that the rice at PKT was awned *japonica* rice, most probably tropical *japonica* rice. Tropical *japonica* is normally grown in dryland systems of cultivation which fits well with the weed analysis at PKT where dryland weeds predominate the assemblage (see section 7.5.6).

context	fractured lemma apiculus	smooth lemma apiculus
PKT09 S7 US1	4	
PKT09 S7 US2	10	
PKT09 S7 US3	9	2
PKT09 S7 US4	8	
PKT09 S7 US5	2	1
TOTAL	33	3

Table 7.13: Lemma apiculi found in PKT classified into having an angled fractured or a smooth end.

7.5.3.2 *Eleusine* cf. *coracana*

Eleusine coracana subsp. *coracana* (L.) Gaertn.
Common names: finger millet, caracan millet, African millet

The wild progenitor of *Eleusine coracana* subsp. *coracana* is *Eleusine coracana* subsp. *africana* found mainly in Africa. Three hypotheses were formed regarding the origins of domesticated finger millet; that it had an African origin with the wild progenitor being *E. africana*, that it was domesticated in India from *E. indica* and lastly, that two separate domestication events occurred wherein *E. africana* gave rise to the African cultivar and *E. indica* to the Indian cultivar (Hilu et al. 1979; de Wet 1995c). Although there has been some contention about the origins of finger millet it is now widely accepted that it is of African origin with an early introduction to India. However, it is still not clear when finger millet was domesticated in Africa or the arrival date to India (Giblin and Fuller 2011). Wild finger millet *E. africana* is closely related to another wild species, *Eleusine indica,* which has widespread distribution including India. Both *E. africana* and *E. coracana* are tetraploids and produce fully fertile hybrids when crossed, whereas *E. indica* is a diploid and based on cytogenetics and morphology, it is considered distinct from *E. coracana* and *E. africana* (de Wet 1995c). The main distribution of domesticated finger millet is Africa and India, where it is an important cereal in both areas.

Wild finger millet is widespread in the eastern and southern African highlands where it is still gathered during periods of scarcity (de Wet 1995c). It is believed that domestication took place in the area covering western Uganda to the Ethiopian highlands (Harlan 1971; de Wet 1995c). Overall, archaeobotanical evidence for finger millet is scarce in East Africa and this has been attributed to preservation issues, including crop processing and tropical climates which lead to physical deterioration of charred remains (Young and Thompson 1999). Although there have been several claims for the earliest finger millet in Africa, these claims have been refuted (Giblin and Fuller 2011). The central Sudan evidence found as impressions in Neolithic pottery at Kadero and dating to *ca.* 5000 BP were misidentified (Giblin and Fuller 2011; cf. Klichowska 1984). Another early discovery from Ethiopia was properly identified based on morphological and anatomical grounds although it was eventually found that the finger millet dated to recent times (Fuller pers. comm.; Hilu et al. 1979). However, the methodology used by Hilu et al. (1979) on the Ethiopian millet was the right approach to identify archaeobotanical remains. Hilu et al. charred modern samples of domesticated finger millet, wild *E. africana* and *E. indica* and compared them with the archaeological material to identify the Ethiopian remains. Therefore, the earliest finger millet in Africa using the correct identification criteria and having robust dating belongs to the start of the first millennium AD in northern Ethiopia (D'Andrea 2008), with a similar aged find from Kursakata near Lake Chad (Klee et al. 2000). Larger quantities of evidence date to the later first and early second millennium AD in Rwanda (Giblin and Fuller 2011) and southeast Kenya (Helm et al. 2012; Fuller, pers. comm.).

In India, there have been several archaeological reports of *Eleusine coracana* and these are found in Appendix 7.5. However, early published finds dating to the mid-third millennium to the second millennium BC have been questioned by Fuller et al. (2004) and Hilu et al. (1979) based on the lack of clear identification criteria. It has been noted by Fuller (in press) that finger millet is probably the most widely misreported millet. Perhaps the oldest accurately identified finger millet in India is from the Chalcolithic in Senuwar dating to *ca.* 1200-600 BC. Another early find is the single finger millet grain from Hallur in India dating to the Neolithic Phase III (*ca.* 1050-900 BC; see Fuller et al. 2007c). The Hallur millet has been unequivocably identified as the domesticated type following precise identification criteria which included the shape and size of the grain, the presence of a large scutellum and the surface pattern of the pericarp (Fuller et al. 2004).

In Southeast Asia, finger millet is cultivated in Indonesia as a cereal and although it was reported growing in Malaysia in the 1930s by Burkill (1935), the cereal was not of any significance. It had been introduced experimentally in 1917-19 in the Thai-Malay Peninsula and although it had some success, it did not become an important crop (Burkill 1935). It is also found as a weed of rice cultivation in India, Indonesia, and Vietnam (Moody 1989). Weedy *Eleusine coracana* is known to be an upland weed (Pope 1999) and the preferred habitat of the domesticated form is well suited for dry farming (Weber 1991). In Thailand, finger millet is reported together with foxtail millet as an agricultural crop grown by forest villagers that normally use shifting cultivation to grow rice alongside minor crops (Boonkird et al. 1984). This pattern of finger millet in upland and shifting cultivation is also typical of northeastern India, the Western Ghats, parts of Yunnan and Taiwanese hills. Although this crop has not been reported in any archaeological site in Southeast Asia, finger millet would have reached Thailand in prehistoric times through contacts with India. PKT is the first reported find of finger millet in Southeast Asia and the earliest find outside South Asia although only one grain was found.

Finger millet is normally eaten as a cereal although it is considered poor man's food or a 'famine' crop (Burkill 1935; Weber 1991). The grain is also used to brew traditional beer in India and Africa (particularly Uganda, Ethiopia, Malawi, Zambia and Zimbabwe) or it is ground into flour to make bread in India or for porridge in both Africa and India (Kimata and Sakamoto 1992). Finger millet is also eaten as sprouts or popped (Hoare in fao.org). In Indonesia, the young plants are eaten as a vegetable, either raw or steamed, or the grains are pounded and made into porridge (Ochse 1977). Other uses of finger millet are as green fodder or hay (www.ecocrop.fao.org).

Finger millet is known to have high yields and has the advantage of maturing quickly. It can therefore be sown during short wet seasons in dry regions or as part of crop rotation during a short period (Burkill 1935). It can withstand cool climates but grows best in hot climates. This is potentially a reason for its importance as a cereal in Africa and in India. It requires annual rainfall between 500-1,000 mm. It grows in many types of soil and it has a higher tolerance to pests and diseases than many other cereals (Dalby 2002; www.fao.org). It grows in altitudes up to 2,500 m. In rainfed cultivation systems in India, it is often grown together with other cereals (*Panicum*) and pulses (*Vigna*) (Weber 1991). Fuller (pers. comm.) found finger millet and *Panicum sumatrense*, growing either together or adjacent to each other as typical shifting cultivation crops in the Western Ghats of India. Furthermore finger millet has a long storage life. According to published reports, it can be stored for up to five years, as reported in Uganda (Young and Thompson 1999), up to ten years (www.ecocrop.fao.org) or fifty years (Weber 1991).

	length (mm.)			width (mm.)			thickness (mm.)		
Eleusine coracana	mean	range	10% shrinkage	mean	range	10% shrinkage	mean	range	10% shrinkage
fresh IoA reference collection w/ pericarp (n=1)	1.5		1.35	1.4		1.26	1		0.9
fresh Garhwal collected by Fuller (n=25)*	1.236		1.112	1.364		1.228	1.384		1.246
fresh Bellary, Karnataka collected by Fuller (n=25)*	1.352		1.217	1.388		1.249	1.436		1.292
fresh Ouaka, Central African Republic collected by F&H1 (n=20)*	1.335		1.202	1.575		1.418	1.465		1.318
fresh Axum, Ethiopia collected by Phillipson (n=20)*	1.405		1.265	1.37		1.233	1.38		1.242
fresh Digital Atlas of Economic Plants w/ pericarp	2		1.8	2		1.8			
fresh Ochse 1977		2-2.5	1.8-2.25						
fresh Hilu et al. 1979		1.2-1.8	1.08-1.62						
fresh Kew gardens database		1.5-2.5	1.35-2.25						
charred from archaeological site PKT w/ pericarp (n=1)				1.2			1		
charred from archaeological site Ojiyana (n=1) [Chalcolithic]	3			2.5					
charred from HLR.98B [Neolithic Phase III] (n=1)	1.2			1			0.9		
charred from archaeological site Rojdi (n=1,326) **		1.31-1.67			0.83-1.19				
mineralised from archaeological site Musanze 2, Rwanda (n=6) ***	1.40	1.19-1.75		1.318	1.01-1.72		1.37	1.05-1.53	
charred from archaeological site Musanze 2, Rwanda (n=1) ***	1.32			1.35			1.16		
charred from archaeological site Karama, Rwanda (n=2) ***	1.1	1.09-1.11		1.495	1.47-1.52		1.15	1.11-1.19	
charred from archaeological site Musanze 3, Rwanda (n=6) ***	1.683	1.32-2.1		1.66	1.52-1.86		1.51	1.25-1.82	
charred from archaeological site Nguri cave, Rwanda (n=5) ***	1.446	1.35-1.64		1.366	1.16-1.52		1.342	1.11-1.59	

* collections housed in the Institute of Archaeology, UCL
** Weber 1991 has dating issues, may be Late or Medieval Rojdi
*** first to second millennium AD (Giblin & Fuller 2011)
Sources: Fuller et al. 2004; Pokharia 2008b; Weber 1991; www.kew.org/data/grasses-db/

Table 7.14: Modern and archaeological measurements of finger millet including a shrinkage correction factor.

Finger millet is a free-threshing cereal, which means it has fewer crop processing stages than other cereals that retain their husk, such as rice. This implies fewer chances of preservation relative to cereals which require pounding to free the husk from the grain. It is expected that there is a preservation bias against this cereal in the archaeological record because of crop processing but also as mentioned below because of the nature of its thick pericarp which may work against charring and consequently, be less visible in the archaeobotanical assemblage.

The identification criteria for finger millet include the shape of the seeds which are described as globose or subglobose and angular. The pericarp has smoothly curved rows of granulae or pustules (Fuller 2002; cf. Weber 1991). It has a small depressed circular hilum below the scutellum in the dorsal view where a noticeably shallow and circular embryo is also found. The embryo length measures *ca.* 1/3 of the total grain length. The ventral side does not have any features.

Grain measurements found in Table 7.14 show that after applying a 10% shrinkage corrective factor caused by charring, modern finger millet measures *ca.* 1.08-2.25 mm long, 1.26-1.8 mm wide and 0.9-1.32 mm thick. The sample from PKT was not complete and the length cannot be measured. Because of this, the embryo has not been measured in relation to the length of the seed. The width is slightly smaller compared to the modern samples after applying the shrinkage corrective factor. However, the sample identified by Fuller from Hallur (HLR.98B) also has a smaller width than the comparative modern material. Experiments to see the effects of charring on finger millet are needed to see if the width shrinks by a higher percentage than the length of the grain. The charring experiments would also be crucial in understanding preservation biases against this cereal. Very few remains are recovered from archaeology and Fuller (in press) has questioned whether its thicker and possibly oily pericarp, causes the full destruction of caryopses when they come into contact with fire.

The PKT grain complies with the morphological description. The caryopsis is globose and it has a shallow circular embryo although the area where the hilum would have been has broken off (Figure 7.11). The caryopsis has an adhering pericarp which was observed under the microscope with x45 magnification and oblique lighting. The pusticulate surface of the pericarp is discernable.

Figure 7.11: Left: image of the dorsal view of archaeological finger millet from PKT S7 US5; Center: image of the dorsal view of modern uncharred finger millet from the IoA Reference Collection. The circular embryo can be seen in both specimens at the top of the grain; Left: close-up at x45 magnification showing pericarp surface (Images by author).

7.5.3.3 *Vigna radiata* (L.) Wilczek var. *radiata*
Common names: mungbean, green gram, golden gram
Thai names: thua thong, thua kheaw

Detailed information on the origins, ecology and archaeological evidence of the mungbean are found in Chapter 6 (6.5.3.4). At PKT, mungbeans are an economic crop with the second highest frequency and are found in 64% of the samples. As has been discussed in relation to rice in section 7.5.3.1, it is posited that the mungbean given the preservation biases that affect this pulse was an important cultivar at PKT.

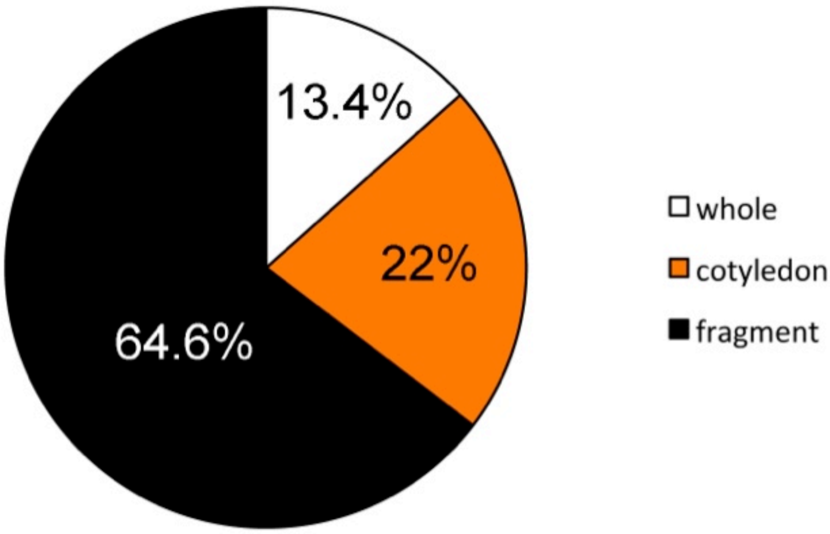


Figure 7.12: Breakdown of mungbean evidence at PKT (n=82).

At PKT, unlike KSK, whole seeds of mungbean were recovered. The breakdown is found in Figure 7.12. The majority of the samples from PKT is made up of fragments and split cotyledons (86.6%) and this could mean that, as at KSK, there was pounding involved in the processing of mungbeans. Such pounding is a necessary step in the preparation of some dishes which require split beans, such as the Indian dish *dhal*, but not essential to other consumption because mungbean is a 'free-threshing' pulse. However, the presence of whole mungbeans (Figure 7.13) in the assemblage may also indicate that mungbeans were prepared in several ways at PKT. Perhaps some of the culinary preparations involved the parching of seeds that could result in the preservation of whole grains (Fuller and Harvey 2006).

Figure 7.13: Photograph of a whole mungbean with adhering testa from Phu Khao Thong S1 US2. From left to right: two proximal views and the lateral view. (Images by author).

The mungbeans in PKT, although smaller than the average charred modern remains, are larger than the KSK mungbeans and closer in size to modern measurements (Table 6.14 in Chapter 6). Some fall within the range of modern measurements. The intermediate size of mungbeans recovered at PKT between KSK and modern mungbeans can be seen in Figure 7.14. Figure 7.14 is a plot of the L/W ratios of mungbeans from PKT, KSK, South Asian sites, Berenike in the Red Sea and charred modern mungbeans from the IoA reference collection and from unpublished work by Fuller and Harvey.

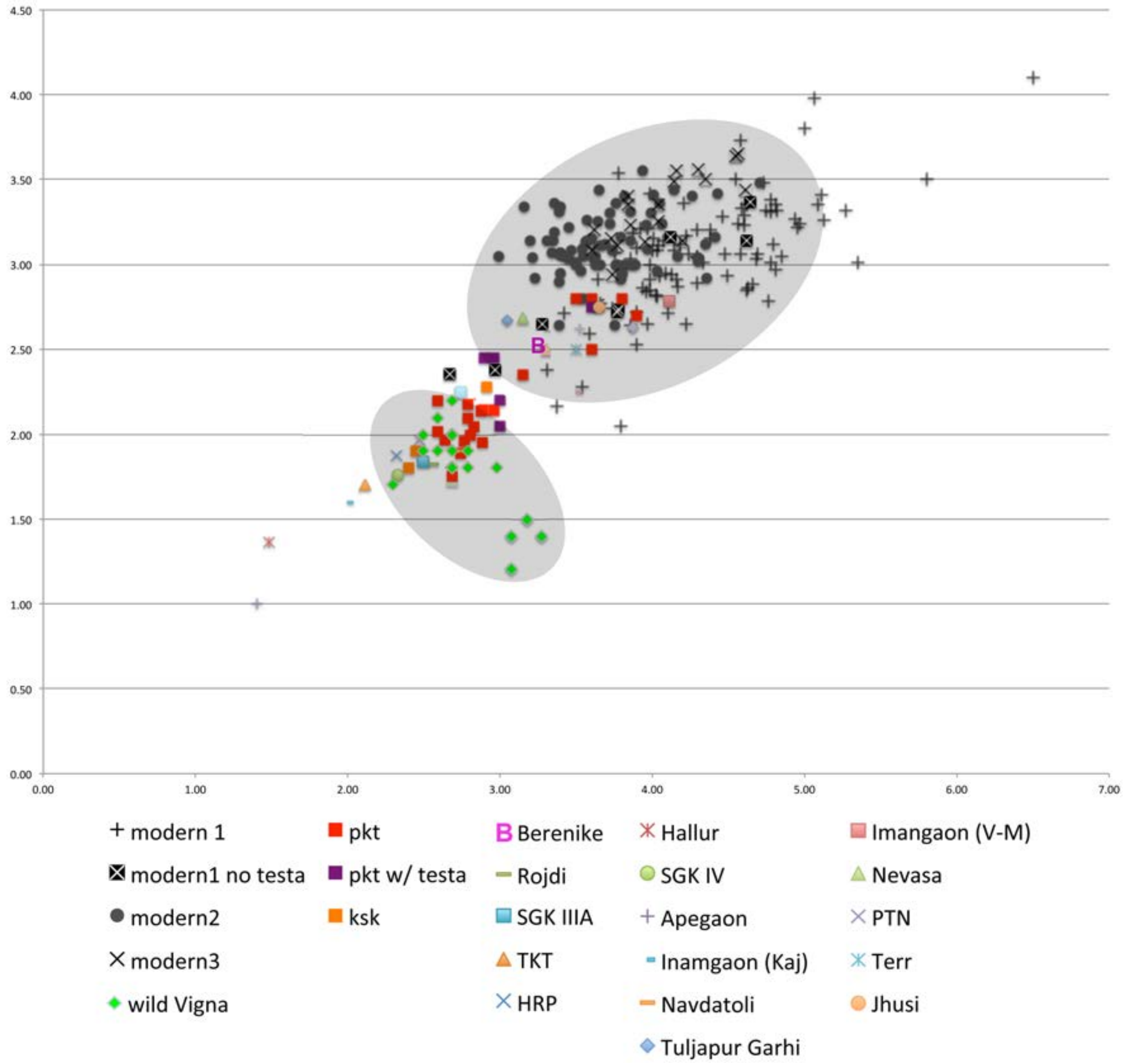


Figure 7.14: Scatterplot of L/W measurements from archaeological mungbeans in Phu Khao Thong and Khao Sam Kaeo, archaeological sites from South Asia (Rojdi, Sanganakallu IIIA and IV [SGK], Tekkalakota [TKT], Hanumantaraopeta [HRP], Hallur, Apegaon, Inamgaon (Kaj and V-M), Navdatoli, Tuljapur Garhi, Nevasa, Paithan, Terr and Jhusi), Berenike (pink B), modern mungbeans from the IoA reference collection (modern1 and modern1 no testa) and from Fuller and Harvey unpublished (modern2 and modern3), and wild mungbeans from Fuller unpublished. The x-axis corresponds to length and the y-axis corresponds to width, the shaded area shows the clustering of modern mungbean measurements. The L/W measurements of archaeological mungbeans from South Asia and Berenike are averages.

There is one direct AMS date [172-2 cal. BC (OxA-26628)] available for the mungbean in PKT but none for KSK. However, bones coming from KSK TP57 US 11 yielded an AMS date of 359-57 cal. BC (WK21175). The bones were found in a pit cut into US12 which is one of the layers in KSK that yielded mungbeans. More mungbeans were found in KSK TP57 in the deeper layer US16. Therefore, from the associated date coming from KSK TP57 US11 and the general chronology of KSK, it may be inferred that the mungbeans in KSK are older than the ones from PKT. If this is the case, and mungbeans were cultivated in PKT and areas nearby, this could be explained by an increase in seed size over time after mungbean arrived in Thailand. This is consistent with the *'domestication syndrome'* (as defined in Chapter 9) of pulses where one of the main domestication traits is an increase in the size of the seed (Fuller and Allaby 2009). When the pods of wild legumes mature, they shed their seeds by twisting and splitting (*ibid.*). The loss of natural seed dispersal is another important domestication trait and for mungbeans, this means that the pods do not dehisce when mature. However, even with domesticated mungbean, if there is a delay in harvest, the pods eventually shatter (Figure 7.15) (www.agritech.tnau.ac.in). Loss of natural seed dispersal is not archaeologically visible, but if there is chronological depth increases in seed size over time can be tracked. The increases in seed size may be related to better cultivation practices and more fertile soils (Fuller et al. 2010b). Alternatively, it could also mean that a larger variety of mungbean was introduced at a slightly later time from India to Peninsular Thailand. Unfortunately, as demonstrated above in Figure 7.14, more evidence of mungbeans spanning different time periods are needed to get a better picture of mungbean size changes over time in Thailand.

Figure 7.15: A mature mungbean pod that has naturally dehisced as a consequence of drying, twisting and splitting. The sample was taken from a rice field in Northeast Thailand where a few mungbean shrubs were cultivated. It was left to naturally dry and shatter after normal harvesting time (Photo by author).

Criterion used in the identification of mungbeans includes the measurement of the plumule (see Chapter 6 section 6.5.3.4). When the plumules in the PKT mungbeans were visible, these were measured against the length of the cotyledon (Figure 7.16). The plumule lengths ranged from 60-70.59%, which roughly corresponds to the identification criteria where mungbeans have a plumule length corresponding to 3/4 of the length of the cotyledon. Since there is adhering testa in some of the seeds, future work involves taking SEM micrographs in order to examine the surface pattern. The testa surface, if preserved well, would show elongated cells arranged in wavy bands (Chandel et al. 1984). The testa of black gram, on the other hand, has randomly arranged spherical cells (Figure 7.17).

Figure 7.16: Mungbean cotyledons from Phu Khao Thong with visible plumules. Left: S7 US2; Right: Sand US5. The plumules are highlighted in the photographs at the bottom. (Images by author).

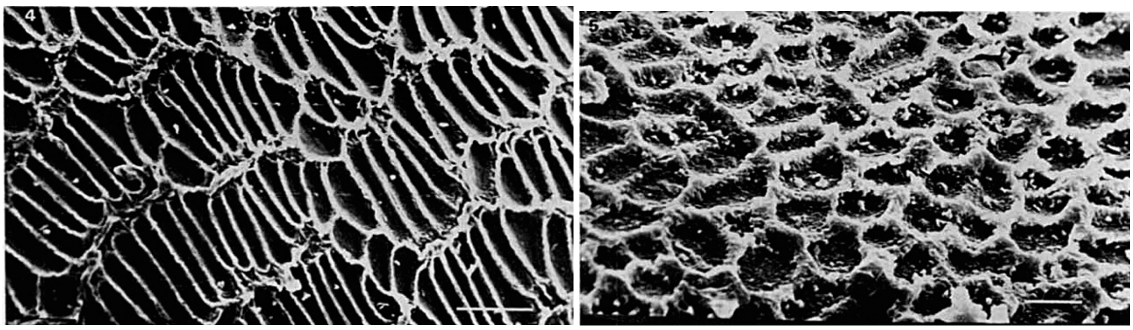


Figure 7.17: SEM micrographs of the testa surface pattern. Left: *Vigna radiata;* Right: *Vigna mungo* (Source: Chandel et al. 1984).

The mungbeans at PKT are significant as it represents the largest assemblage of this Indian pulse in Southeast Asia. Furthermore, the AMS date from a mungbean recovered from S2 US3 has now yielded the earliest evidence of mungbean outside of South Asia dating to 172-2 cal. BC (OxA-26628).

7.5.3.4 *Macrotyloma uniflorum* (Lamarck) Verdcourt

Common name: horsegram

Detailed information on the horsegram is found in Chapter 6 (6.5.3.5). In PKT, the horsegram is found in higher frequencies than at KSK and also has a higher ubiquity rate as it is found in 36% of the samples at PKT compared to 2% at KSK. It represents 6.93% of all identified pulses found at PKT (n=101). Figure 7.18 shows the breakdown of the pulse assemblage in PKT compared to KSK. At PKT there were more pulses in the archaeobotanical assemblage than at KSK. The assemblage in both sites is dominated by the mungbean. All the other pulses in PKT, including the horsegram, are minor components of the assemblage. All of the pulses except for *Vigna* cf. *umbellata* (ricebean) were transferred to Southeast Asia from India as has been demonstrated in Chapter 6 and as will also be shown in this chapter with respect to the two new pulses found in PKT, *Lathyrus sativus* (bitter vetch) and *Vigna* cf. *mungo* (black gram). There is also a greater amount of indeterminate Fabaceae fragments in PKT than at KSK. These Fabaceae fragments could not be identified because they were too small and although some features were present to identify them as legumes, there were not enough characteristics to identify them to genus.

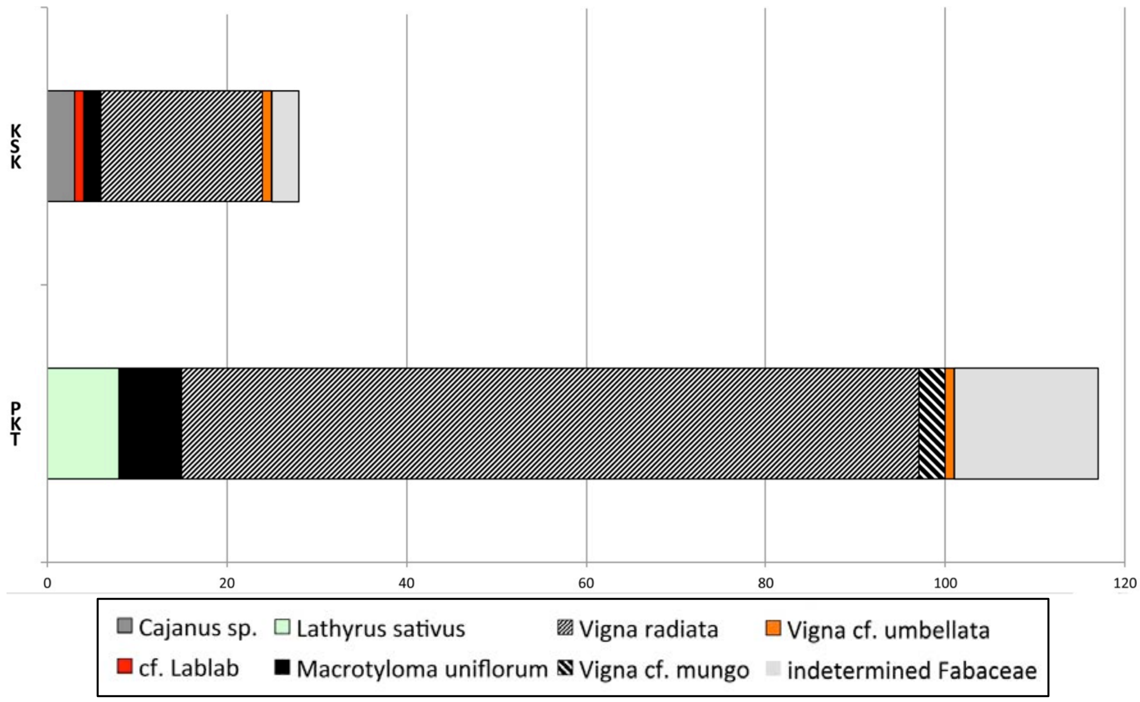


Figure 7.18: Breakdown of pulses by species including indeterminate legumes from PKT (n=117) and KSK (n=28).

Although a whole horsegram seed from KSK was sent to the Oxford Radiocarbon Accelerator Unit for AMS dating, it yielded no results. On the other hand, one horsegram seed from PKT S7 US4 produced an AMS date of 36 cal. BC-125 cal. AD (OxA-26629). Fortunately, at KSK the only AMS date coming from a botanical sample is from the same context as one of the two horsegrams. A single rice grain from TP128 US11 at KSK was dated to 199-52 cal. BC (OxA-26626). Due to the associated date at KSK and the general chronology, it is believed that the horsegram from PKT dates to a later period than KSK. Therefore, the evidence from both sites shows there was continuity in the use of horsegram for at least two or three centuries. However, the relatively low frequency of horsegram compared to mungbeans signifies that it was not favoured as much. As discussed in Chapter 6, horsegram has a preservation bias in its favour compared to mungbean and if both pulses were consumed in equal quantities, it is expected that horsegram would be more visible in the archaeological record. This is clearly not the case in PKT or in KSK. It is also likely that horsegram was not cultivated in either site but rather it was imported from India. Some pulses like pigeonpea, mungbean and horsegram can be stored dry for long periods of time. This means that long distance transport would not have been a problem.

At PKT and KSK, horsegram was found as whole seeds, in fact only one fragment was found at PKT. This may signify that horsegram had not been pounded in either sites. One of the crop processing stages of 'pod-threshing' pulses is pounding the pods to remove the seeds (Fuller and Harvey 2006). It is very likely that this stage had taken place where the horsegram was cultivated, probably in India. Broken seeds may have been winnowed or picked out before any maritime translocation since a broken testa would make the seeds more susceptible to fungal or bacterial infections. Alternatively, today in Tamil Nadu, India, the horsegram plants are harvested with a sickle, spread and left to dry on the threshing floor after which they are beaten with pliable sticks so as not to damage the seeds (www.agritech.tnau.ac.in). The seeds separate from the pods because of the beating and are winnowed to remove the waste product. Beating with a stick replaces pounding. The clean seeds are then dried and stored. Either method of crop processing would produce clean whole seeds ready for transport.

Furthermore, in Tamil Nadu, the processing of horsegram to improve seed quality includes the 'grading' of seeds. Grading is done with the use of sieves with 3.2 mm perforations. The plump and filled seeds are retained in the sieves whereas broken, damaged and small seeds infected by fungi fall through the sieve (www.agritech.tnau.ac.in). Perhaps at PKT and KSK, grading also took place although not necessarily with a sieve. If some pulses were transported over long distances by sea, improper storage could cause fungal infections. The damaged seeds would be inedible and therefore need to be picked out. If damaged or infected seeds were placed into fires together with other crop-processing by-product (e.g. rice husk, rice spikelet bases), there would be a chance for preservation and this could explain the existence of whole seeds of horsegram in PKT and KSK.

7.5.3.5 *Vigna* cf. *mungo*

Vigna mungo (L.) Hepper
Common names: black gram, urd bean, urad bean
Thai names: thuaa dahm

Black gram derives from its wild progenitor *Vigna mungo* var. *silvestris.* Although wild black gram is found in India, Myanmar and Thailand (Seehalak et al. 2006), it was domesticated in India, which is the primary centre of genetic diversity (Figure 7.19) (Tomooka et al. 2002). A secondary centre of diversity exists in Central Asia (Arora and Mauria 1989). Black gram is an important crop in India and it is also widely cultivated in Southeast Asia particularly in north Malaysia, the Philippines, Myanmar and Thailand. In the period 1980-1985, the greatest producer of black gram in the world was India although the biggest exporter was Thailand. Indian cultivation is solely for local consumption whereas Thailand exports to Japan, where black gram sprouts are preferred to mungbean sprouts. Black gram can be stored for longer periods than mungbean, is more digestible and does not cause flatulence (Brink and Belay 2006; Fery 2002). According to Tomooka et al. (2002), black gram spread from India into other tropical areas with Indian population migration. The present study confirms Tomooka et al.'s hypothesis with respect to Southeast Asia. It appears that the Southern Peninsula was the route, or one of the routes, for the dispersal of Indian domesticates, including black gram.

The earliest finds of black gram in South Asia are from Rojdi dating to *ca.* 2600-2000 BC and Balathal dating to *ca.* 2500-2000 BC (see Appendix 6.7) (Kajale 1996; Weber 1991). These sites are located in Gujarat and Rajasthan respectively, areas where the wild progenitor *Vigna mungo* var. *silvestris* is still found but where wild mungbean

(*Vigna radiata* var. *sublobata*) is not present (Fuller 2007b). Since the earliest black gram evidence is in areas where wild progenitors still occur, domestication possibly took place in this general area. Seehalak et al. (2006) indicate a single domestication event for black gram. The archaeological evidence for black gram in Southeast Asia is similar to the other Indian pulses found at PKT and KSK, it has not been reported in any site. PKT is the first site where black gram has been discovered, it was not found at KSK.

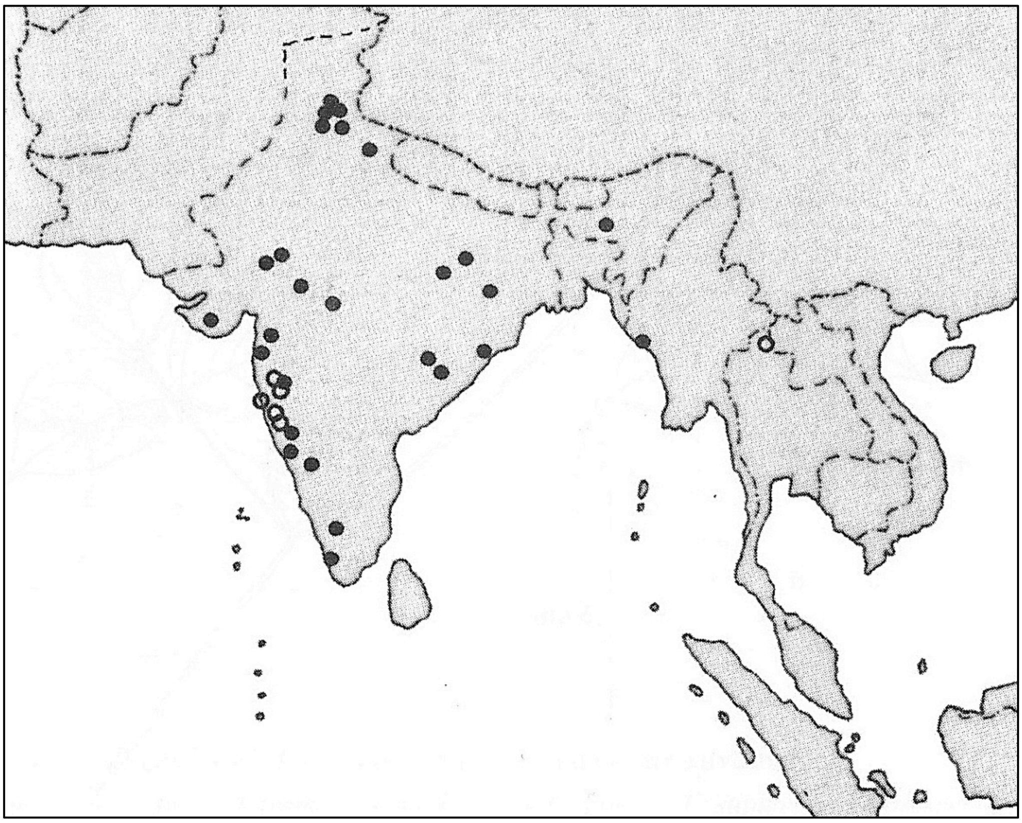


Figure 7.19: Distribution map of *Vigna mungo* var. *silvestris* with 'o' symbolising Tomooka's direct collection and '•' symbolising herbarium specimens (Source: Tomooka et al. 2002).

The black gram is a warm season crop and grows well in average temperatures of 25-35°C. It is drought resistant and grows in altitudes up to 2,000 m (Tomooka et al. 2002). It cannot withstand frost and does not grow well in the wet tropics. It grows in areas with an annual rainfall of 600-1,000 mm though it favours annual rainfall below 900 mm. The west coast of Peninsular Thailand, where PKT is located, has a very high annual rainfall averaging 2,725 mm. This suggests that black gram would not grow well in PKT and the surrounding areas. However, it has been known to grow in higher rainfall areas during the dry season (Brink and Belay 2006). Black gram has a short maturity period averaging 90 to 120 days which means it can be cultivated after the rice harvest. Burkill (1935) reports that black gram was used as an experimental crop many times in Malaya but it was not successful. As Burkill points out, the experiments deemed successful were conducted with mungbean and not black gram. The high humidity and precipitation in PKT would have made this pulse difficult but not impossible to cultivate. Black gram is grown in modern-day Southern Thailand (Benjakul and Visessangun 2001). Mungbean is a pulse with similar ecological needs as black gram and it can be grown as a summer or autumn crop in the tropics (Siemonsma and Lampang 1989). Since it is believed that cultivation of mungbean occurred in both sites, PKT and KSK, it could be postulated that black gram may also have been cultivated. Since black gram has not been found in KSK, it is possible that it arrived at a slightly later date than the mungbean and horsegram, with the arrival of more Indian travellers to PKT. Alternatively, it is equally plausible that black gram was not adopted as a cultivar in PKT since it is reported to only have been introduced in central Thailand in the 1950s (Seehalak et al. 2006). Only three complete seeds were found in PKT suggesting very limited use of this pulse. What is needed are more archaeobotanical studies from early sites dating to the Late Prehistoric period to ascertain if black gram was cultivated after its initial introduction.

The black gram (also known as urdbean) in modern-day India is subject to specific ritual use and prohibitions (Simoons 1998). According to Simoons, the 'urd ban' arises because the colour black is associated with impurity and pollution. The urdbean is used in many rites to counter the sinister and death, such as offerings to a Brahmin to counter the evil influence of Śani, but it is prohibited as an offering to higher deities. However, the 'urd ban' like other food prohibitions in India is not meant to be observed by entire classes, such as Brahmins (*ibid.*).

Unlike the horsegram which is considered a poor man's pulse, black gram is one of the most 'highly prized' pulses in India and is eaten by the Hindu high caste (Tomooka et al. 2002). Black gram is used in similar ways to the mungbean. The dried seeds are consumed as a pulse, boiled and eaten either whole or made into a paste. The seeds may be fermented, milled and pounded into flour to make breads and biscuits, or the seeds are split (Lawn 1995). Like the mungbean, the split seeds of black gram are used in the preparation of *dhal* in India. Immature pods and bean sprouts are eaten as a vegetable. It is also used as fodder, cover crop, green manure and in traditional medicine. The flour of black gram can also be used as a soap substitute (Brink and Belay 2006).

	ave. length (mm.)		width (mm.)		thickness (mm.)	
	Vigna mungo	*Vigna radiata*	*Vigna mungo*	*Vigna radiata*	*Vigna mungo*	*Vigna radiata*
MODERN						
fresh Digital Atlas of Economic Plants w/ testa	5-6	4-6	3-4	3-4		
fresh Fuller & Harvey 2006	4.586	3.775	3.791	3.1605	3.4	3.09811
population 1	4.55	3.8975	3.737	3.074	3.4195	2.31-3.15
population 2	4.678	3.5145	3.978	3.0985	3.436	2.64-3.27
population 3	4.466	3.566	3.505	3.0755	3.271	2.8-3.42
population 4		3.9		3.2913		3.2-3.61
population 5		4.027		3.296		2.39-3.7
ARCHAEOLOGICAL						
charred from archaeological site PKT						
w/ testa	3.97	3.09	3.19	2.38	2.96	2.69
no testa	4.375	3.03	3.1	2.23	2.925	2.45
charred from archaeological site Rojdi [2200 BC] (n=18)	3.52	2.57	2.53	1.82		
charred from archaeological site Golabai Sassan [n=6] (1300 BC)	2.667	1.6-2.8	1.865	1.3-2.49		
charred from archaeological site Tuljapur Garhi [n=10] (1100 BC)	3.33	3.1-3.9	2.75	2.6-3		
charred from archaeological site Ojiyana [Chalcolithic]	3.5-4	3-3.5	2-2.5	2-3	1.5-2	1.5-3
Source: Fuller & Harvey 2006, unpublished; Pokharia 2008b; Weber 1991						

Table 7.15: Comparison of measurements of modern and archaeological *Vigna mungo* and *Vigna radiata.*

As discussed in Chapter 6 under the mungbean heading, the general shape and size of *Vigna radiata* and *V. mungo* overlap (Fuller et al. 2004). The shape ranges from ovate to rounded and cylindrical. Although size is a difficult criterion to use when identifying these two pulses because of the domestication syndrome where pulses increase in size over time dependent on their stage of domestication (e.g. initial or late stage), in general, modern black gram is relatively larger than mungbean. Table 7.15 shows modern and archaeological black gram and mungbean measurements either done by the same researcher or in the same site in order to avoid human error. Both the modern and archaeological measurements show that black gram is normally larger than mungbean. Published and unpublished measurements of modern and archaeological black gram are found in Appendix 6.14 (ID no. 123). The PKT seeds fall within the range of measurements for black gram.

Figure 7.20: Images of the two *Vignas* displaying the hilum. From left to right: *Vigna mungo* proximal and lateral view, *Vigna radiata* proximal and lateral view (Images from Digital Atlas of Economic Plants 2010).

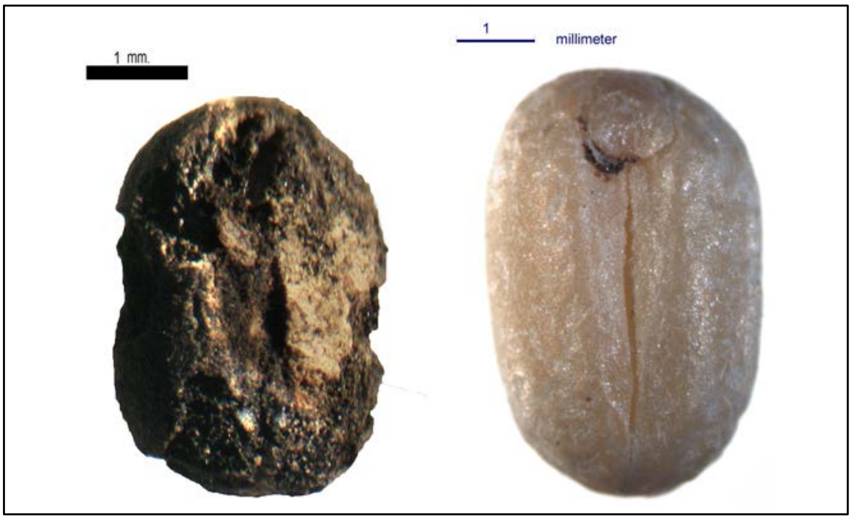


Figure 7.21: Image of black gram from Phu Khao Thong with a visible hilum scar compared to a modern sample without the testa which also shows the hilum scar (Images: Left - by author; Right - Digital Atlas of Economic Plants 2010).

If whole seeds are available, the most distinctive characteristic of the black gram is the raised hilum with an encircling lip (aril). From the lateral view, the hilum is non-concave or raised, whereas the mungbean's hilum is flush with the testa and the lip is absent (Figure 7.20). Unfortunately, the hilum does not preserve readily although the hilum scar is sometimes visible, as the case of samples from PKT, leaving a large circular shallow depression where the hilum would have been (Figure 7.21). If the cotyledons are split, then the best method for identification is to compare the length of the plumule with the total length of the cotyledon. Plumules of black gram normally measure half of the length of the cotyledon whereas those of the mungbean measure 3/4. At PKT, all three seeds were whole and therefore, the plumule was not measured.

Like the mungbean, black gram is a free-threshing pulse indicating a preservation bias against this pulse. Given the difficulties in cultivating black gram in areas with very high precipitation and the small amount of black gram found at PKT, it is likely that the small quantity is not a result of preservation bias against black gram but rather limited use of this pulse at PKT. It was therefore probably not cultivated in PKT.

7.5.3.6 *Lathyrus sativus* (L.)

Common names: grass pea, chickling pea, chickling vetch, blue vetchling, Indian vetch, Indian pea, dogtooth pea, grass peavine, Lathyrus pea, riga pea, wedge peavine

Grass pea is considered a minor pulse of traditional agriculture cultivated in southwest Asia, the Mediterranean basin, Ethiopia and northwest India (Kearney and Smartt 1995; Zohary et al. 2012). It is currently important in areas where food shortages occur frequently such as India, Bangladesh, Pakistan, Nepal and Ethiopia (Mahler-Slasky and Kislev 2010). The origin is unknown although it might have been domesticated from the wild *Lathyrus cicera* (L.) which is distributed in the Mediterranean basin, northern Africa and southwest Asia (Brink and Belay 2006; Zohary et al. 2012). Kislev (1989), however, believes that grass pea was domesticated in the Balkans where most early finds and where the largest volumes in later periods occur. Fuller et al. (2012a) have suggested that *Lathyrus* should perhaps be regarded as an additional founder crop in the Near East as several sites in southeastern Turkey have produced finds of this crop in the Middle PPNB when the earliest domesticated cereals, peas and lentils occur However, since one cannot determine the domestication status of these early grass pea seeds, it is not until *ca.* 8500-7500 cal. BP at Gritille in Turkey, where a large amount of seeds were found (n>800), that grass pea is considered a cultivated crop (Zohary et al. 2012). It may not be possible to distinguish between *Lathyrus sativus* and the wild *Lathyrus cicera* in the archaeobotanical record because of the wide size and shape variability of the grass pea (Mahler-Slasky and Kislev 2010). Grass pea seeds can measure from 3 to 15 mm and the smaller ones may be confused with the seeds of the wild *L. cicera* in an archaeobotanical assemblage *(ibid.)*. The best method for differentiating between species is the examination of the testa, if present in archaeobotanical remains (*ibid.*).

The grass pea was introduced to South Asia as part of a crop package that included wheat, barley, peas, lentils and chick pea (Fuller 2002, 2006a; Fuller and Madella 2001). This agricultural package was established in South Asia by the start of the period of Harappan urbanism, *ca.* 2500 BC (Fuller 2006). Appendix 6.7 lists the sites in South Asia where grass pea was found. Grass pea is widely represented in the archaeobotanical record in South Asia, although to a lesser extent in South Indian sites, from as early as the mid-third millennium BC to the historic period. Grass pea has never been reported in Southeast Asia, and PKT is the first site with evidence for this pulse.

In PKT, whole seeds, cotyledons and fragments were found in three samples. Their shapes and sizes showed great variability. Variability in size and shape is distinctive of the grass pea (Figure 7.22) even when the seeds from the same plant are examined. The seeds are generally wedge shaped or angular although they can also be globular. From the lateral view grass pea is squared and from the proximal view, it is triangular (Figure 7.23). The hilum is situated towards the broader part of the seed on the proximal view. The seeds from PKT fall within the range of modern and archaeological seed measurements (Table 7.16).

	length (mm.)			width (mm.)			thickness (mm.)		
Lathyrus sativus	mean	range	20% shrinkage	mean	range	20% shrinkage	mean	range	20% shrinkage
modern Mahler-Slasky & Kislev 2010		3-15	2.4-12						
modern Brink & Belay 2006		4-7	3.2-5.6						
charred from archaeological site PKT no testa (n=6)	4.29	3.5-5		3.22	2.7-3.9		3.02	2.45-3.6	
charred from archaeological site Rojdi [2000 BC] (n=86)		2.16-2.98			2.03-2.81				
charred from archaeological site Kanmer (n=1) [Mature Harappa]	2.23			2.3			2.2		
charred from archaeological site Jhusi (n=6) [Neolithic]	3.5	3-4		3.4	3-3.8		1.65	1.5-1.8	
charred from archaeological site Ojiyana [Chalcolithic]		3-6			3-5			2-4	
Source: Pokharia 2008a, 2008b; Pokharia et al. 2011:Weber 1991									

Table 7.16: Measurements of modern and archaeological *Lathyrus sativus.*

Figure 7.22: Modern seeds of *Lathyrus sativus* displaying size and shape variability (Source: Digital Atlas of Economic Plants in Archaeology 2012).

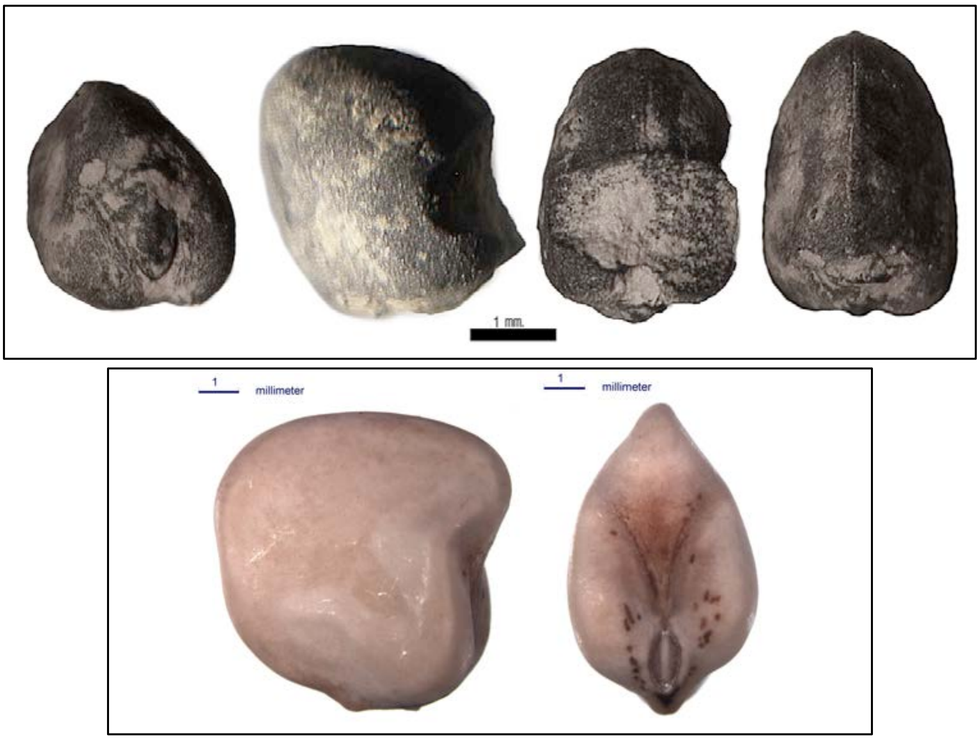


Figure 7.23: Top: Images of a whole grass pea seed from Phu Khao Thong S1 US2; Bottom: Images of a modern grass pea (Top images by author; bottom images from Digital Atlas of Economic Plants 2010).

Grass pea contains a neurotoxic amino acid (*β*-*N*-oxalylamino-*α,β*-diaminopropionic acid [ODAP]) of which 70% may be removed by soaking or boiling the seeds in water for one hour (Jansen 1989; Kearney and Smartt 1995; Mahler-Slasky and Kislev 2010). This toxin causes lathyrism, an irreversible crippling disease, when grass pea is consumed in great quantities (Muehlbauer and Tullu 1997). It is therefore, a pulse consumed by the poor or in times of famine, in India and Ethiopia. Burkill (1935) calls it the cheapest of pulses from India. Grass pea grows in tropical areas in maximum altitudes of 3,500 m. It is an attractive crop despite its toxicity because it is suited to dry climates, grows well in poor and waterlogged soils, can withstand moderate salinity and is both very drought and flood resistant. It can grow in areas with annual rainfall ranging from 320 to 3,000 mm (Muehlbauer and Tullu 1997). It is also resistant to many pests and can be grown both as a winter crop (Near East) and a summer crop (central Europe) (Mahler-Slasky and Kislev 2010). It also requires very limited management such as weeding (Weber 1991).

Grass pea is mainly used as fodder, even if it is also poisonous to animals. When used for human consumption, the grass pea is eaten as a pulse, boiled or roasted, whole, split or ground into flour to make bread (Muehlbauer and Tullu 1997). In Ethiopia and Eritrea, it is made into a sauce (Brink and Belay 2006). In India, the split seeds are made into *dhal*. Immature leaves and fruits are also eaten as vegetables (Jansen 1989). Grass pea is also used as a forage crop and for green manure.

Grass pea is neither cultivated nor consumed in modern-day Thailand. Like the horsegram, it was introduced into Peninsular Thailand in the Late Prehistoric period but it does not appear to have persisted as a cultivar. As early as the fifth-fourth centuries BC, Hypocrates knew about the ailment where those who consumed grass pea *'became impotent in the legs* (Dastur and Iyer 1959).' Unsurprisingly, given its toxicity, the crop has not been adopted in Thailand.

7.5.3.7 *Vigna* cf. *umbellata*

Vigna umbellata (Thumb.) Ohwi and Ohasi
Common name: ricebean
Thai names: thua daeng, thua pae / thua ae, ma pae / ma pee

As at KSK, only one seed of ricebean was found at PKT. The shape of the ricebean cotyledons from PKT was comparable to modern samples and drawings. The cotyledons split open during handling and the plumule was examined (Figure 7.24). In modern ricebean samples, the length of the plumule measures less than half of the cotyledon and the PKT seed also measured less than half of the cotyledon. The measurements of both modern and archaeological ricebeans are found in Chapter 6 (Table 6.16). It is also argued in Chapter 7 that ricebean which was found in KSK may be in the early stages of domestication. This also seems to be the case in PKT, considering the intermediate size of the seeds compared to modern analogues after applying the -20% shrinkage correction factor (Table 6.16). It is reported that the seed weight of ricebean has increased due to domestication 15-fold compared to wild ricebean (Isemura et al. 2010). However, weight cannot be evaluated using charred remains and therefore, seed size has been used instead as a proxy for weight increase.

Figure 7.24: Left: images of the cotyledons of *Vigna umbellata* from Phu Khao Thong S7 US2; Centre image: the plumule highlighted in red; Right: drawing of the plumule shape and length in relation to the cotyledon (Images by author; drawing by Fuller).

Although ricebean is consumed in modern-day northern India and is known as 'sutri' or 'ghurush,' according to Burkill (1935), it is more important in Burma. In India, it is reported as a pulse eaten by tribes in the eastern and northeastern mountainous areas (Arora et al. 1980). The date and route of introduction for ricebean into India from Southeast Asia is unknown as it has not been reported in the archaeobotany from either region. KSK and PKT are the earliest finds. Although there is no evidence to prove this, it is a possibility that ricebean might have been introduced to India on return voyages from Peninsular Thailand. However, because it is believed that ricebean was domesticated in northern Thailand (Seehalak et al. 2006), it is postulated in this study that ricebean was brought into cultivation in Peninsular Thailand from the north of Thailand.

A northern route is an alternative route of dispersal from Thailand to India. Ricebean is widely grown as a lowland crop after the rice harvest in an area covering Indo-China, southern China, Bangladesh and northeast India (Pearman 2012). A traditional method of preparation is cooking ricebean with rice (Arora et al. 1980; Isemura et al. 2010;

Pearman 2012), hence the name ricebean (Fery 2002). Because of its close association with rice, it is a pulse that may have spread from Southeast Asia to north India at a later period with rice, possibly *aus* rices, via Burma and Bangladesh. The hypothesis on the late spread of *aus* rices from Southeast Asia to India is described in 'thrust 10' in Fuller et al. (2010). This hypothesis needs to be confirmed with archaeobotanical and ethnographic studies from the north of Thailand to northeast India including Burma and Bangladesh. The ethnographic studies should help determine the extent of similar culinary uses for this pulse (i.e. cooking with rice).

7.5.4 The Cash Crops:

PKT has evidence of some of the cash crops also found in KSK, namely *Citrus* sp., cf. *Citrus* and *Piper* cf. *longum.* It also has the first evidence of *Sesamum indicum* in Southeast Asia. Table 7.17 is the complete list of cash crops found at PKT.

sample	*Piper* cf. *longum*	*Citrus* sp. rind	cf. *Citrus* rind	*Sesamum* cf. *indicum*	mesocarp fragment	context
PKT08 S1 US3	1					dense silty clay, upper layer had sherds
PKT08 S2 US2	1	37				high volume of cultural material
PKT09 S4 US2	2					cultural deposit / layer
PKT09 S6 posthole			158			posthole dug into bedrock
PKT09 S7 US1	1	1				cultural deposit / layer
PKT09 S7 US2	6	2			1	cultural deposit / layer
PKT09 S7 US3	4	2		1		cultural deposit / layer
PKT09 S7 US4	7		1			cultural deposit / layer
PKT09 S7 US5		1				cultural deposit / layer
no. of samples	7	5	2	1	1	
ubiquity (n=11)	63.64%	45.45%	18.18%	9.09%	9.09%	
NISP	22	43	159	1	1	

LEGEND:
no. of samples - refers to no. of samples in the sampled population containing specified taxon
NISP - Number of Identified Specimens

Table 7.17: Cash crops found at PKT and their context.

7.5.4.1 cf. *Citrus* / *Citrus* sp.

Citrus rinds identical to those found at KSK are also found in PKT. They are found in 63.64% of the samples sorted and identified at PKT. *Citrus* rinds are mostly found in two samples, 'S2 US2' and in 'S6 posthole.' These two samples do not contain high frequencies of other economic crops, in fact, 'S6 posthole,' contains only the *Citrus* rinds, a few weeds, five Myrtaceae seeds and unidentified plant remains.

Posthole infills will most likely include parts of the primary fill used to stabilise the post when the structure was first constructed, and secondary fill which includes charcoal and organic matter from the surrounding floor (Engelmark 1985; van Vilsteren 1983). At

PKT the evidence seems to indicate there may have been a fire that destroyed the structure since the posthole infill had a large amount of charcoal which may have represented the post itself. Charcoal analysis would help determine if all the wood found in the infill was all from the same species and would therefore have been one piece of wood from the post. It is therefore possible that charred material in the posthole infill was carbonised at the same time the structure burnt, if it burnt. The *Citrus* rind may have been lying near the posthole and found its way into the posthole if there was cleaning and sweeping involved after the fire.

Two types of rind are found in PKT. Both types of rind, cf. *Citrus* and *Citrus* sp. were also found in KSK contexts. The glandular cell structure in *Citrus* sp. is very similar to modern uncharred *Citrus maxima* rind (see Figure 6.31 for the KSK material) whereas cf. *Citrus* (Figure 7.25) is similar to a few charred *Citrus* specimens including *Citrus maxima.* The glandular cells expand during the oxidised charring process causing bulging (see Appendix 6.10). More charring experiments using reducing conditions and variable temperatures and lengths of time are necessary to narrow the identification to species.

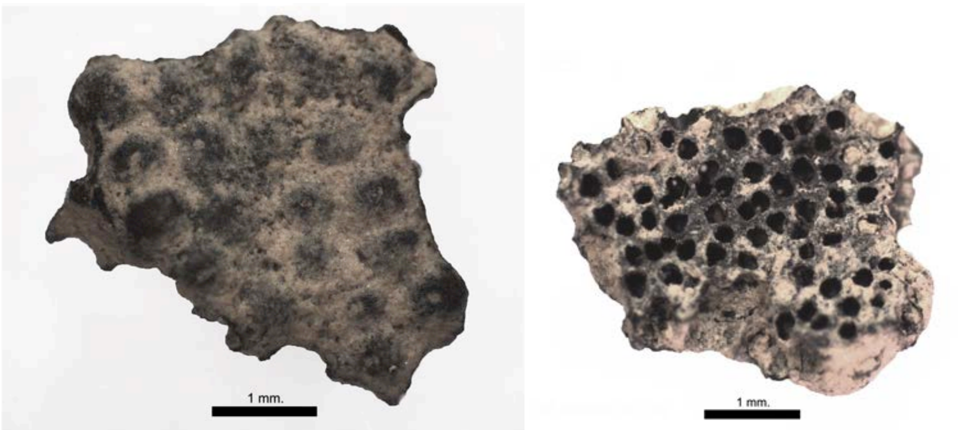


Figure 7.25: cf. *Citrus* rind fragment, front and back, from PKT S6 posthole (Image by author).

7.5.4.2 *Piper* cf. *longum*

Piper longum L.
Common name: long pepper
Thai name: phrik-hang; dipli and dipli-chuak (peninsular) refer to *Piper retrofractum*

Long pepper plant remains were found in 63.64% of all samples at PKT although not in high frequencies. As at KSK, the long pepper at PKT probably come from South Asia.

The long pepper plant remains matched those from KSK which were narrowed to be most similar to *Piper longum.*

7.5.4.3 *Sesamum indicum*

Sesamum indicum (L.)
Common names: sesame, benne, beniseed, gingelly, sesami nigrum semen (pharmaceutical)
Thai names: ngā

It is now accepted that sesame was domesticated in South Asia although it was once contended to be of African origin (Bedigian 2004; Bedigian and Harlan 1986; Blench 2003; Cappers 2006; Fuller 2003; www.database.prota.org [PROTA]; van der Veen 2011; Zohary et al. 2012; cf. Burkill 1935; Hutchinson 1974; www.ecocrop.fao.org). It was brought to the Near East from India as early as the third millennium BC (Bedigian 2003; van der Veen 2011). The wild progenitor was not firmly identified until recently. Based on morphological, genetic and phytochemical similarities, the wild progenitor of sesame is now confirmed to be *Sesamum orientale* var. *malabaricum* Burm. [=synonym: *S. mulayanum* Nair] which grows in the western part of the Indian peninsula and parts of Pakistan (Bedigian 2004, 2010; Bedigian and Harlan 1986; Fuller 2003). Figure 7.26 shows the distribution of *S. malabaricum* in South Asia.

The dispute on the origins of sesame are due to the early occurrence in the archaeological record of sesame in both the Near East and in South Asia, as well as the distribution of most wild species of *Sesamum* in Africa, with a few species in South and Southeast Asia (Bedigian 2010; Zohary et al. 2012). However, it appears that only the Indian wild *Sesamum* was brought into cultivation. Having been found as early as the third millennium in Mesopotamia in the site of Abu Salabikh, it is considered the oldest oilseed used in southwest Asia (Bedigian 2004). There are several other finds ranging from the third to first millennium BP including the desiccated funerary offerings in King Tutankahmun's tomb dated to *ca.* 1325 BC (Zohary et al. 2012). Written evidence also exists in the form of Sumerian cuneiform texts dating to *ca.* 2400 BC mentioning an oilseed, possibly sesame [še-giš-ì] (Bedigian 2004; Bedigian and Harlan 1986). A Linear B catalogue of aromatics dating to the fourteenth century BC from the Mycenaean palaces includes sesame in the list (Dalby 2002). All these early finds in Egypt and southwest Asia are considered imports. Pliny mentions sesame as an import from India (Blench 2003) and the '*Periplus of the Erythraean Sea*' dating to the first century AD mentions sesame oil as an import from the Gulf of Cambay to Arabia and Africa (Schoff 1974).

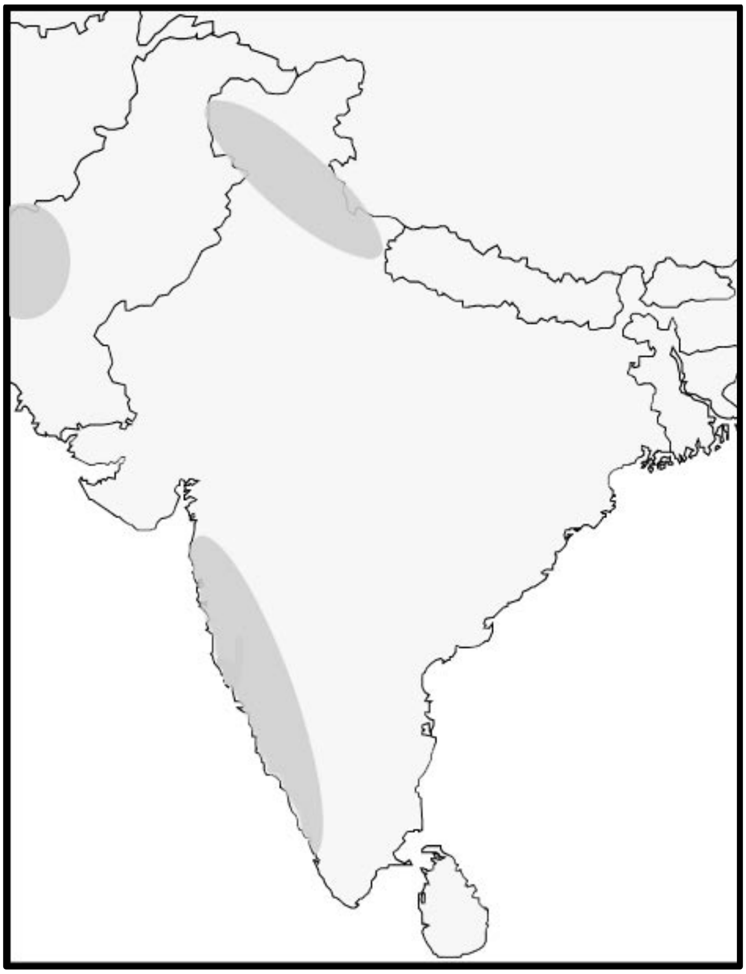


Figure 7.26: Map of South Asia with shaded areas being the approximate areas for the distribution of the wild *Sesamum malabaricum* (Source: Fuller 2003; Map source: www.abcteach.com).

The earliest finds of sesame are from Harappa, Pakistan, Miri Qalat, Baluchistan, and Kanmer, Gujarat, all dating to *ca.* 2500-2000 BC (Bedigian 2004; Fuller 2003; Pokharia et al. 2011; Zohary et al. 2012). The spread of sesame east of India remains largely undocumented except for a textual reference dating to the Chinese Han Dynasty *ca.* 2200 BP (Fuller 2003; Qiu et al. 2012). A Chinese textual reference [*Pen Ts'ao Kang Mu* - Standard Inventory of Pharmacology] from *ca*. mid-first millennium BP mentions the introduction of sesame to China during the Western Han Dynasty (Qiu et al. 2012). However, the earliest confirmed finds from China are from the 'Thousand Buddha Grottoes' in Boziklik, Xinjiiang dating to 1290-1400 cal. AD [BAI10696] (Qiu et al. 2012). One sesame seed was discovered in PKT. This seed in PKT is important as it is so far the earliest evidence of sesame to the east of India. This evidence signals the beginnings of circulation of sesame east of India on its way to introduction into Han China.

In Thailand, the hill tribes grow sesame as a cash crop and cultivate it in swidden fields (Anderson1993). It is also used as offerings by shamans or in ceremonies, for example the Lahu make small rice cakes mixed with pounded sesame (Anderson 1993). Burkill (1935) believes sesame arrived in Malaya at an early period although he also mentions that not much is grown in Malaya and as an important comestible, it is imported. As with the Near East where the evidence is that sesame is imported, the one seed found at PKT probably represents importation of sesame to Peninsular Thailand and is probably evidence of the earliest introduction from India. Although sesame is grown in modern-day Thailand, it is normally found in the drier areas in the north. More work in the northwest of Thailand and in proto-historic sites in Peninsular Thailand is needed to determine when sesame came into cultivation.

Sesame can be grown in altitudes up to 1,800 m and even 2,000 m in the Himalayas (Ecocrop). It is cultivated as a rainfed crop in tropical and sub-tropical environments, is relatively drought resistant and can grow in areas with 300-400 mm of annual rainfall although optimal annual rainfall is 500-1,000 mm. It can also grow in a variety of soil types and can resist temperatures up to 40°C (Bedigian 2004).

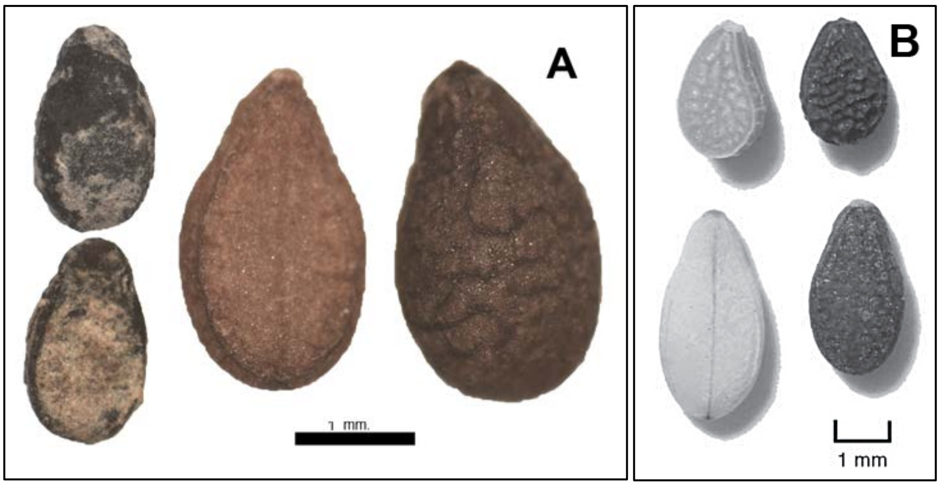


Figure 7.27: A - Left hand is the archaeological seed from PKT S7 US3, the top image is the dorsal view and lower image is the ventral view; Centre and Right - two modern sesame seeds from the IoA reference collection, the centre image shows the ridge on the ventral side (Images by author). B - comparisons between wild and domesticated sesame, Top are *Sesamum malabaricum* and below are *Sesamum indicum* (Source: Fuller and Allaby 2009).

Sesame is mainly cultivated for its use as an oilseed crop. It is rich in antioxidants, these have the advantage of delaying rancidness (Bedigian and Harlan 1986; Cappers 2006). The seeds are eaten raw or roasted and they are used in confectionaries or ground to a paste (van Wyk 2005). The oil is not only used for cooking but in perfumery, dyeing, and to make Chinese black ink (Burkill 1935). Young leaves are used in soup. The seeds and leaves are also used for soap and shampoo and the bark and stems are used for fuel.

	length (mm.)		width (mm.)		thickness (mm.)	
Sesamum indicum	mean	range	mean	range	mean	range
fresh Digital Atlas of Economic Plants w/ testa		2-4		1-2		
fresh Digital Atlas of Economic Plants no testa	3		2			
fresh PROTA		2-3				0.5-1
charred from archaeological site PKT no testa (n=1)	1.7		1		0.6	
charred from archaeological site Kanmer (n=29) [Mature & Late Harappa]	2.64	2.5-2.78	1.58	1.48-1.68	1.25	1.2-1.3
charred from archaeological site Jhusi (n=1) [Neolithic]	3.5		1.8		0.8	
charred from archaeological site Ojiyana (n=8) [Chalcolithic]		2-3		1.5		1.0
dessicated? from archaeological site Xinjiangi (n=20) [620 BP]	3.3	3-3.5	1.9	1.7-2.1	0.8	0.8-0.9
Sources: Pokharia 2009a; Pokharia et al. 2011; Qiu et al. 2012						

Table 7.18: Measurements of modern and archaeological sesame from published sources.

The seed coat may be smooth, ribbed or granular (Bedigian and Harlan 1986; Ecocrop; Fuller 2003). At high magnification, the testa epidermis can show warty projections or honeycomb-like depressions (Qiu et al. 2012). The wild progenitor *S. malabaricum* (Figure 7.27[B]), on the other hand, has a reticulate or highly rugose seed coat and may have slight wings (Fuller 2003; Fuller and Allaby 2009; Fuller pers. comm.). Sesame seeds have a flattened obovoid or drop-like shape with a wider semicircular base distal from the hilum and pointed, although not sharply, proximal to the hilum. When the testa is present, a narrow ridge can be seen all round the seed (Figure 7.27). The sesame seed from PKT has a small amount of seed coat still adhering although at high magnification one can barely discern a granular pattern and SEM imagery is necessary to view the epidermis properly. The seed is obovoid and flattened with a narrow ridge around it seen from the ventral view (Figure 7.27). The size of the PKT seed is small but conforms with some of the modern measurements (Table 7.18). Since no charring experiments have been conducted which would indicate the range of shrinkage for sesame, a shrinkage factor has not been applied to the modern measurements.

7.5.5 *Acmella paniculata:* weed of agriculture or vegetable?

Acmella paniculata (Wall. ex DC.) R. K. Jansen
Common names: para cress
Thai names: phakkhrat (central); phakphet (northern); phaktumhu (peninsular); phak khraat huawaen

The weed of rice cultivation *Acmella paniculata* (para cress) is an important taxon that has contributed to our understanding of the cultivation regime in both PKT and KSK. It is represented in both assemblages in high frequencies and ubiquity rates, and is consistently associated with rice (Table 7.19).

Site	*Acmella paniculata* ubiquity rate	co-occurrence w/ *Oryza**	co-occurrence w/ *V. radiata*	co-occurrence w/ pulses
Khao Sam Kaeo	62.5% (n=88)	93.02% (n=43)	60% (n=5)	70% (n=10)
Phu Khao Thong	90.91% (n=11)	100% (n=9)	100% (n=7)	100% (n=7)
* same results for total cereals				

Table 7.19: Ubiquity rate of *Acmella paniculata* at KSK, as well as its co-occurrence with rice, mungbeans and total pulses.

The Pearson Correlation Coefficient between *A. paniculata* and some cultivars such as rice, pulses and *Citrus* rind was calculated and the results are found in Table 7.20. The null hypothesis that there is no correlation between the samples in the population was rejected in all cases except between *Citrus* rind and *A. paniculata.* Therefore, between rice and *A. paniculata,* rice and pulses, and pulses and *A. paniculata,* it is accepted that correlation exists between the samples and there is a high degree of correlation. All the pulses found at PKT are dryland crops and it is possible that *A. paniculata* is also a weed of cultivation for pulses growing in dryland conditions. *A. paniculata* is reported as a dryland / upland weed of rice cultivation in Thailand and other Southeast Asian countries (Moody 1989). It is also known as one of the dominant weeds of cultivation in modern-day Vietnamese upland maize fields and soybean fields (Wezel 2000). This means that it may be an indicator not only of dryland rice cultivation but dryland cultivation systems in general.

Variable vs. Variable	R	Ho
Acmella paniculata vs. *Oryza*	0.87	rejected
pulses ALL vs. *Acmella paniculata*	0.95	rejected
pulses ALL vs. *Oryza*	0.95	rejected
Citrus rind vs. *Acmella paniculata*	0.62	accepted
Ho is there is no correlation between samples in the population		

Table 7.20: Pearson Correlation Coefficient results at PKT using the variables *Acmella paniculata,* rice, pulses and *Citrus* rind.

Because of the high frequencies in the assemblage, this taxon needs to be discussed in more detail. In Chapter 7, the role of *A. paniculata* as a weed, particularly of upland / dryland and possibly swidden rice cultivation, was discussed. However, it is very likely that *A. paniculata* was also an economic crop in Peninsular Thailand and this will be discussed below.

The first difficulty encountered with *Acmella paniculata* is nomenclatural. The plant has been erroneously named and described in many publications causing much confusion (PROSEA). The botanist Jansen (1985) points out that *Acmella paniculata* was originally named *Spilanthes paniculata* by Koster and Philipson (1950). Koster and Philipson in turn had corrected the Linnaen species *Spilanthes acmella* (L.) to be *Blainvillea acmella* and therefore Jansen opts for the combination nomenclature *Acmella paniculata.* However, Jansen's nomenclature has not been consistently used in publications since then and instead, the synonym *Spilanthes paniculata* appears in most publications. In this study, the species name *Acmella paniculata* is used since the botanical taxonomic description accurately describes the samples from KSK and PKT. Information gathered from the synonym *Spilanthes paniculata* is also used. Appendix 7.6 is a list from publications of *Acmella spilanthes* (=synonym *Spilanthes paniculata*), the closely related *Spilanthes iabadicensis* (=synonym *Spilanthes acmella*) and other *Spilanthes* species that may be confused with the archaeological samples. *Spilanthes iabadicensis* is the closest species with which *Acmella paniculata* may be confused. The website 'www.theplantlist.org' is a collaborative effort between the Royal Botanic Gardens, Kew and the Missouri Botanical Gardens. It provides a list of accepted Latin names of plant species and all the synonyms also used. *Acmella paniculata* in 'theplantlist.org' is considered the accepted name with the list of synonyms including *Spilanthes paniculata.* Appendix 7.7 shows different drawings of *Acmella paniculata* by authors using synonyms. These line drawings are then compared to a photograph of *Acmella paniculata* collected in Chiang Mai province.

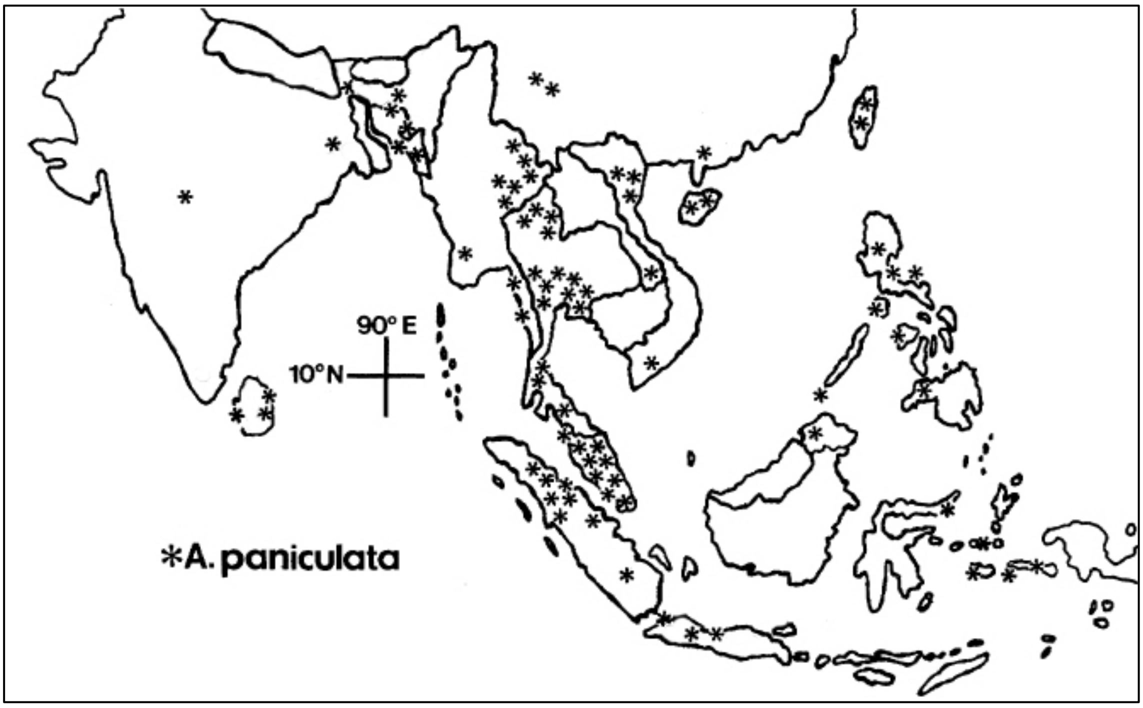


Figure 7.28: Distribution of *Acmella paniculata* (Adapted from Jansen 1985).

The next point of confusion is the presumed place of origin of *Acmella paniculata.* Some publications place the origins of *Spilanthes paniculata* in tropical America (Ochse 1977; Soerjani et al. 1987) but following Jansen (1985) the distribution of *Acmella paniculata* is throughout Southeast Asia, India, Sri Lanka and southern China (Figure 7.28). The same problem with the origin of *Spilanthes acmella* is encountered wherein some publications identify it as Southeast Asian and others as tropical American. It is hoped that in the future the archaeobotanical studies will help botanists clarify some of these points of contention by showing that the species existed in Southeast Asia long before American plants were introduced into the region.

Identification of the seeds from PKT and KSK was made using morphological characteristics described in the botanical literature, published images and modern reference collections from the Weed Science Group in the Department of Agriculture, Thailand and those collected by the author in Chumphon and Chiang Mai provinces.

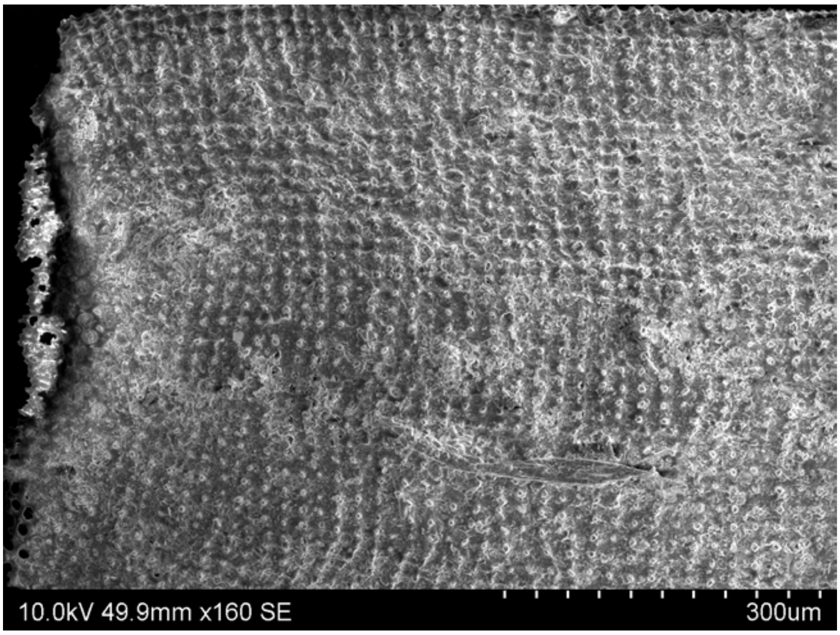


Figure 7.29: SEM micrograph showing the surface pattern of an archaeological seed of *Acmella paniculata* from KSK TP57 US6 (Image by author).

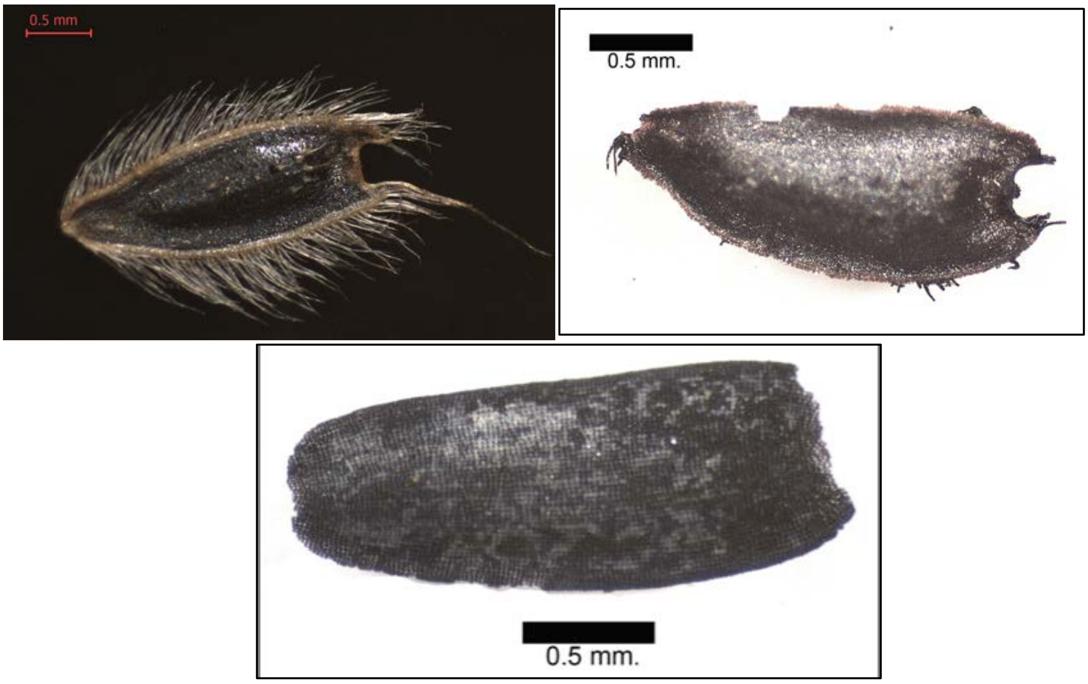


Figure 7.30: Top - images of modern *Acmella paniculata* (=synonym *Spilanthes paniculata*), Left - fresh sample; Right: charred at 250°C for 6 hours in reduced conditions; Bottom - archaeological sample from KSK TP132 US16 (Images by author).

Whole achenes and fragments thereof were found at PKT and KSK. Their state of preservation is very good and again, it would be important to conduct charring experiments using *A. spilanthes* together with other weed species and rice to determine preservation bias. It is very likely that *A. paniculata* has a preservation bias in its favour.

The achenes are ellipsoid, slightly asymmetrical and somewhat truncated at the base. The base of all the achenes is consistently broken off. Using a low powered microscope, the surface is tuberculate and under high magnification, the surface of the achenes shows the tubercules or pustules in a regular linear arrangement (Figure 7.29). The achenes measure *ca.* 2 x 0.8 x 0.3 mm. Table 7.21 is the list of comparative measurements from publications and modern reference collections. According to Jansen (1985) the achenes are 2.2 to 2.9 mm long, 0.8-1 mm wide, a surface which is sparsely or densely tuberculate, pappus of 2 bristles and moderately ciliate (Figure 7.30). Mature achenes have cork-like margins.

		length (mm)		width (mm)	
sample		mean	range	mean	range
*Spilanthes acmella**		2.06	2-2.12	1.004	0.967-1.07
	001	2.05		0.967	
	002	2.12		0.975	
	003	2		1.07	
*Spilanthes acmella***		1.8	1.77-1.83	0.7095	0.699-0.72
	004	1.77		0.699	
	005	1.83		0.72	
*Spilanthes paniculata****		2.178	1.91-2.37	1.023	0.871-1.16
	006	2.37		0.96	
	007	2.02		0.996	
	008	1.91		0.871	
	009	2.33		1.13	
	010	2.26		1.16	
Acmella paniculata (Jansen 1985)			2.2-2.9		0.8-1
Spilanthes paniculata (PROSEA)			2-3		
Spilanthes iabadicensis (PROSEA)			1-1.15		
Phu Khao Thong (n=10)		2.11	2-2.35	0.88	0.8-1.0
Khao Sam Kaeo (n=2)		2.07	2.04-2.1	0.802	0.8-0.804
* fresh sample from Katsesart; measurements are uncharred					
** immature, garden sample from Katsesart; measurements are uncharred					
*** ref. coll Dr. Siriporn; measurements are uncharred					

Table 7.21: Measurements of modern samples of *Acmella paniculata* (=synonym *Spilanthes paniculata*), *Spilanthes acmella* (=synonym *Spilanthes iabadicensis*) and archaeological samples from PKT and KSK.

The archaeological seeds do not have any of the pappus nor hairs. Likewise, the cork-like margins are also not present. However the tuberculate surface is very visible. Some modern seeds of *Acmella paniculata* were charred under reduced conditions and the seeds generally retained their form although the pappus and most of the hairs burnt off and the cork-like margins became less visible (Figure 7.29). Also, the tuberculate surface became more visible and matched the archaeological remains perfectly (Figure 7.31).

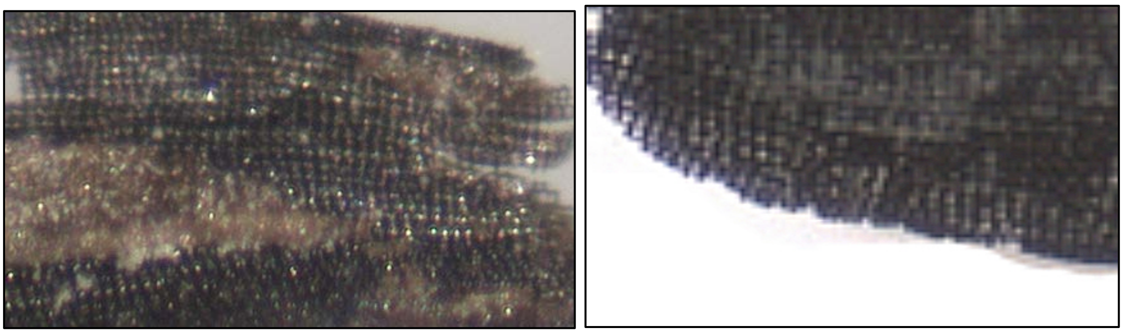


Figure 7.31: Tuberculate surface from the charred modern sample of *Acmella paniculata* on the left and from KSK TP132 US16 (Images by author).

		name	synonym	uses & trade
GROUP *Acmella paniculata = Spilanthes paniculata*	Anderson 1993	*Spilanthes paniculata*		used for flavouring rice liquor by hill tribes; it is one of several local plants dried, pulverised and mixed with finely crushed rice; hill tribes use it for food and medicine; the Mien use the leaves for toothaches
	Kar &Borthakur 2008	*Acmella paniculata*		Karbi tribe from Assam eat the leaves boiled; habitat: crop field; it is traded in the markets (cost Rs. 5/-per bundle); also used in traditional medicine for stomach aches
	Ochse 1977	*Spilanthes ocymifolia* (Lam.) A.H. Moore		young leaves & topshoots eaten raw or steamed
	PROSEA	*Spilanthes paniculata* Wall. ex DC.	*Spilanthes pseudo-acmella* auct., (L.) Murr. *Spilanthes acmella* auct., non (L.) Murr.	young leaves and flower heads eaten, leaves eaten raw or boiled in Thailand & Indonesia; traditional medicine esp. for toothaches; market vegetables in Thailand & Indonesia
	Rethy et al. 2010	*Spilanthes paniculata Wall. ex DC.*		tender shoots are used as vegetable; inflorescence is used for toothaches by tribal communities in Northeast India
	Soerjani et al. 1987	*Spilanthes paniculata* Wall. ex DC.	*Spilanthes ocimifolia* auct., non A.H. Moore *Spilanthes pseudo-acmella* auct. non (L.) Murr.	cure for toothache
GROUP *Spilanthes acmella = Spilanthes iabadicensis*	Burkill 1935	*Spilanthes acmella* (L.) Murr.	var. *oleracea*	as a pot-herb, Malays do not use it but var. *oleracea* is eaten raw & steamed in Java, anaesthetic, cure for toothache; in India for headaches, tongue paralysis and throat problems; decoctions for purges and bladder stones, in Java the dried heads are sold in markets used for sore mouth or sprue
	Ochse 1977	*Spilanthes acmella* (L.) Murr.		young leaves & topshoots eaten raw or steamed, popular article of commerce
	Pardo de Tavera 2000	*Spilanthes acmella*		in the Philippines it is used by herbal doctors as a remedy for itch, psoriasis and treatment of ulcers
	PROSEA	*Spilanthes iabadicensis* A.H. Moore	*Spilanthes acmella* auct., non (L.) Murr.	young leaves and flower heads eaten, leaves eaten raw or boiled in Thailand & Indonesia; traditional medicine esp. for toothaches, market vegetables in Thailand & Indonesia
	SEPASAL Kew	*Spilanthes acmella*		used for food in particular the leaves (condiments, relishes and chutneys) and inflorescences (famine food)
GROUP *Spilanthes sp.*	Flora of China	*Acmella oleracea* (L.)	*Spilanthes oleracea* (L.)	medicinal, insecticidal and horticultural purposes
	Ochse 1977	*Spilanthes oleracea* (L.) Jacq.		toothache remedy

Table 7.22: List of uses of *Acmella paniculata, Spilantes acmella* and other species from the *Spilanthes* genus.

The common name of *Acmella paniculata* is para cress. Para cress is a plant known throughout Southeast Asia as both a weed of cultivation and a useful plant eaten as a vegetable and used in traditional medicine. The most commonly cited use in traditional medicine is for toothaches by tribes in northeast India, Thailand and Indonesia. However, as a food item, the immature leaves and inflorescences are eaten raw, steamed or boiled as a vegetable and these are sold in local markets. In fact, during a research trip to Chiang Mai and Mae Hong Song, the rice farmers interviewed always pointed out para cress as a useful plant that was eaten. The Mien tribe from Thailand also uses para cress in the preparation of rice whiskey (Anderson 1993). A list of uses is found in Table 7.22.

Therefore, the possibility exists that *Acmella paniculata* or para cress was not only a weed of rice cultivation but was also eaten and used medicinally at PKT and KSK during prehistoric times. Since young inflorescences are eaten as a vegetable, it is possible that some were thrown away and in the process of burning waste were charred. If the inflorescences were actually, immature infructescences this could explain the large quantities found in PKT and KSK. Para cress produces many seeds and it flowers all year round (PROSEA). Inflorescences normally have *ca.* 90-200 florets (Flora of China). There also appears to be a preservation bias towards good preservation of para cress although charring experiments are needed to confirm this.

7.5.6 Weeds of cultivation

In Chapter 7, the weeds found in association with rice at KSK were predominantly dryland weeds. In PKT, there was less weed taxa diversity (n=11) than at KSK (n=26) but as at KSK, the highest ubiquity rate is of *Acmella paniculata* where 90.91% of the PKT samples contained this weed (Table 7.23). This was followed by the dryland weed *Mikania* cf. *cordata* at 36.36% and cf. *Rumex* which is classified as being both a dryland and wetland weed. The wetland weeds were found in low frequencies. The weed assemblage in PKT is therefore comparable to KSK. In both sites, the top three weeds found are the dryland weeds, *A. paniculata* and *Mikania* cf. *cordata,* and a weed that is found in both wetland and dryland habitats, cf. *Rumex*. There are three new taxa found in PKT but not found in KSK and these are *Chenopodium* sp., cf. *Eleocharis* and cf. *Echinochloa.*

As discussed in section 7.5.5, *Acmella paniculata* could have also been an economic crop in PKT and KSK. It is not uncommon for some weeds of cultivation to also have value as food items. In fact, IRRI provides a few weed recipes in its website including one for pickled dayflower (*Commelina benghalensis*) [Appendix 7.8], another weed found in PKT. When *A. paniculata* is excluded from the weed analysis at PKT, the remaining weeds in the assemblage still indicate dryland habitats. Table 7.24 lists the co-occurrence of weeds and some of the economic crops which may have been cultivated in PKT. The weeds that co-occur most commonly with rice and the pulses are two dryland weeds *(Acmella paniculata* and *Mikania* cf. *cordata*).

	Family	Species	weed ubiquity*	co-occurrence w/ *Oryza*** (n=9)	co-occurrence w/ *V. radiata* (n=7)***
DRYLAND					
	Asteraceae	*Acmella paniculata*	90.91%	100.00%	100.00%
	Asteraceae	*Mikania* cf. *cordata*	36.36%	44.44%	42.86%
	Asteraceae	cf. *Eupatorium*	18.18%	22.22%	14.29%
	Chenopodiaceae	*Chenopodium* sp.	9.09%	11.11%	14.29%
	Commelinaceae	*Commelina benghalensis*	9.09%	11.11%	14.29%
	Poaceae	*Brachiaria mutica*	18.18%	22.22%	28.57%
WETLAND					
	Cyperaceae	*Cyperus* cf. *pygmaeus*	9.09%	11.11%	14.29%
	Cyperaceae	cf. *Eleocharis*	18.18%	22.22%	28.57%
BOTH WET & DRY					
	Poaceae	cf. *Echinochloa*	9.09%	11.11%	14.29%
	Polygonaceae	cf. *Rumex*	27.27%	22.22%	14.29%

* ubiquity rate all samples (n=11)
** same results for total cereals (n=9)
*** same results for total pulses (n=7)

Table 7.23: Breakdown of weed flora according to habitat and ubiquity rate at PKT, as well as co-occurrence of each weed with rice, mungbeans and total pulses.

	Species	*Oryza*	*Eleusine* cf. *coracana*	*Lathyrus sativus*	*Macrotyloma uniflorum*	*Vigna* cf. *mungo*	*Vigna radiata*	*Vigna* cf. *umbellata*
DRY	*Acmella paniculata*	x	x	x	x	x	x	x
	Mikania cf. *cordata*	x		x	x	x	x	x
	cf. *Eupatorium*	x			x		x	
	Commelina benghalensis	x					x	
	Chenopodium sp.	x					x	
	Brachiaria mutica	x			x	x	x	x
WET	*Cyperus* cf. *pygmaeus*	x		x	x		x	
	cf. *Eleocharis*	x	x		x	x	x	
WET & DRY	cf. *Echinochloa*	x	x		x		x	
	cf. *Rumex*	x		x	x		x	

Table 7.24: Weeds that are found in samples containing some of the economic crops at PKT.

Of the two weeds that are found in wetland habitats, only cf. *Eleocharis* is reported to be a weed of rice cultivation. Table 7.25 is the list of weeds found at PKT and the type of cultivation systems in which they are normally found. Not all of the weeds are reported as weeds of rice in Thailand although six of the weeds found in PKT and in association with rice are known to be weeds of rice cultivation. Furthermore, most of the weeds found in rice fields occur in upland cultivation systems. 80% of the weeds that were identified to species level are upland weeds of rice cultivation.

Family	Species	reported as weed of rice in Thailand	dry-seeded	upland	wet-seeded	transplanted	deepwater	rainfed	wetland	remarks
Asteraceae	*Acmella paniculata*	✔		✔				✔		*Spilanthes paniculata* are synonyms; weed also reported in shifting cultivation
Asteraceae	*Mikania* cf. *cordata*	✔		✔						thickets and forests
Asteraceae	cf. *Eupatorium*			✔						most *Eupatorium* that occur in Asia are in hill slopes; very similar morphology to *E. odoratum* which is a native of the Americas, species that occurs in Thailand & native to Asia is *E. lindleyanum*
Chenopodiaceae	*Chenopodium* sp.			✔						*C. acuminatum* and *C. ficifolium* are native to tropical Asia, chenopods are known as dryland weeds in millet cultivation
Commelinaceae	*Commelina benghalensis*	✔	✔	✔				✔		prefer moist conditions; shifting cultivation weed
Cyperaceae	*Cyperus* cf. *pygmaeus*							✔	✔	dessicated pools & ditches, riverbanks, open wet places in cultivated ground; synonym of *Cyperus michelianus* subsp. *pygmaeus*
Cyperaceae	cf. *Eleocharis*	✔	✔		✔	✔			✔	*E. acutangula* and *E. dulcis* are found in transplanted rice fields; ; ecology of all *Eleocharis* from Peninsular Thailand are found in wet habitats (*E. acutangula, E. spirales, E. ochrostachys, E. dulcis, E. congesta, E. geniculata* & *E. retroflexa*)
Poaceae	*Brachiaria mutica*	✔	✔	✔	✔	✔		✔		prefer poorly drained soil, found along paddy and water courses
Poaceae	cf. *Echinochloa*	✔	✔	✔	✔	✔	✔			*E. colona* occurs in upland but also wetland rice cultivation; *E. crus-galli, E. crus pavonis* and *E. glabrescens* occur in transplanted rice cultivation systems; *E.picta* and *E. stagnina* are found in dry-seeded rice fields; *E. colona* and *E. crus-galli* are in the top 10 list of most troublesome weeds of rice in Asia
Polygonaceae	cf. *Rumex*			✔					✔	dry/wet; *Rumex crispus* found in Thailand reported in shifting cultivation and wetland cultivation systems

Sources: Flora of Thailand; GRIN; Galinato et al. 199; www.irri.org; Maxwell et al. 1987; Moody 1989; Noda et al. 1985; Smitinand 1986; Soerjani et al. 1987; Suwanketnikom 1980; Weber et al. 2010; Zhang & Hirota 2000.

Table 7.25: List of weeds found in PKT, the type of cultivation system in which they are most likely to be found and some observations regarding the habitat they prefer.

Figure 7.32 shows the breakdown of the weed assemblages in PKT and KSK with and without *A. paniculata.* Because *A. paniculata* predominates the assemblage, the weed assemblage shows an overwhelming amount of dryland habitat weeds in both KSK and PKT. When *A. paniculata* is removed from the analysis, KSK still displays a majority share of dryland weeds whereas at PKT, the group 'wetland and dryland' are more represented in the assemblage. The wetland weeds at PKT are negligible and at KSK they do not represent weeds of cultivation. A next stage in the weed analysis would be to try to identify the weeds in the group 'wetland and dryland' to species in order to also identify their specific habitat.

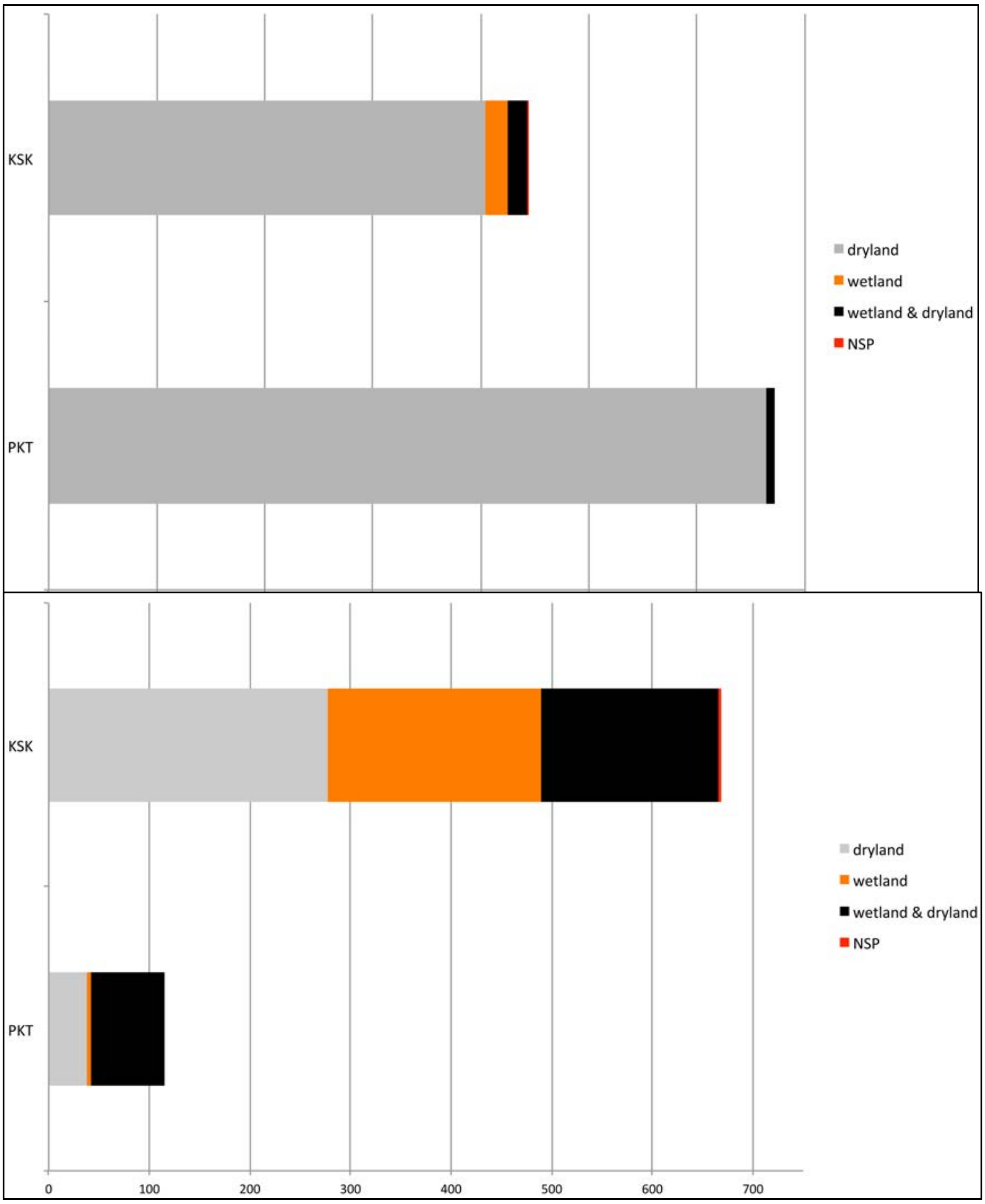


Figure 7.32: Breakdown of the weed assemblages at PKT and KSK. Top - includes the weed *Acmella paniculata*; Bottom - excludes the weed *Acmella paniculata.*

7.6 DISCUSSION: East of India and West of Khao Sam Kaeo

A high ubiquity rate of a few taxa exists in both sites, indicating low diversity. This suggests that there was focused cultivation or the consumption of only a few species. Rice was the most important crop in both sites. It was the main cereal cultivated and consumed. Based on morphological and genetic analysis, the type of rice in both sites was *japonica* rice. Although the Indian populations that travelled and settled at PKT and

KSK between the fourth and first centuries BC brought with them a crop package, they did not bring with them *indica* rice. There would have been no requirement for *indica* as *japonica* rice was already cultivated in Peninsular Thailand. However, the Indian population did bring with them their preferred crops which at PKT and KSK consisted mainly of pulses. In particular, mungbean seems to have been the most important pulse. Together with rice, the high frequency of mungbean at PKT indicates it was an important part of the diet.

Of significance are the much higher frequencies and ubiquity rates of Indian pulses at PKT compared to KSK. Table 7.26 shows the breakdown of Indian pulses at both sites. Perhaps higher frequencies suggest PKT, being the first point of contact and entry from the Indian Ocean, would have higher visibility of Indian crops than at KSK. New crops may have been introduced first at PKT before being distributed further afield. Some of these new crops found at PKT but not at KSK are the pulses, black gram and grass pea, the cereal, finger millet, and the cash crop, sesame. It is postulated that some of the crops that were introduced from India to entrepôts like PKT were distributed to other places where Indian settlers were present, such as KSK. Therefore greater volumes and higher taxa diversity of crops arriving from South Asia would necessarily be found at the point of entry and PKT exemplifies this.

	PKT			KSK		
	counts	presence analysis	ubiquity (n=11)	counts	presence analysis	ubiquity (n=88)
Cajanus spp.	1	1	9.1%	3	1	1.14%
cf. *Lablab*	0	0	-	1	1	1.14%
Vigna radiata	82	7	63.6%	18	5	5.68%
Macrotyloma uniflorum	7	4	36.4%	2	2	2.27%
Vigna cf. *mungo*	3	2	18.2%	0	0	-
Lathyrus sativus	8	2	18.2%	0	0	-

Table 7.26: Breakdown of Indian pulses found at PKT and KSK.

There was not enough evidence to indicate that all pulses found in KSK and PKT were cultivated. There is only evidence of mungbean cultivation. However, it is likely that the local people or the Indian settlers would have initially attempted to grow all the crops that were brought over from South Asia. Some, such as the mungbean, were more successful than others. There may have been several reasons for not adopting some of the Indian crops. One obstruction may have been unsuitable rainfall, since the western part of Peninsular Thailand where Ranong province is located has higher annual rainfall than other parts of Thailand. Culinary preferences and taste also may have influenced the adoption of some of these introduced crops. Mungbean was cultivated in both PKT and KSK and is the most popular pulse in modern-day Thailand. Although archaeobotanical evidence is needed to substantiate this, it is hypothesised that mungbean cultivation continued from its introduction until modern times in Thailand,. Food preparation traditions play an important role in the adoption or popularity of certain food items, and in modern Thailand the versatility of mungbean in its preparation (i.e. boiled, steamed, ground into a paste, ground into flour for vermicelli, roasted, bean sprouts eaten raw or fried) is a reason for its popularity. Such versatility may also have been a reason for its adoption in the Late Prehistoric Period. During the Late Prehistoric Period, the mungbean probably catered to both the Indian immigrants and local people's tastes. The local populations may have started cultivating this crop in order to supply the Indian populations but eventually, it also became part of the local diet. On the other hand, horsegram may have catered to the Indian populations only, as evidenced by the lack of consumption of this crop in modern-day Thailand possibly signalling the non-adoption of this crop when it was first introduced in the Prehistoric Period. Although horsegram has advantages as a robust crop during cultivation, its association with poverty in South Asia may have played a role in its non-adoption. Horsegram was also not adopted in Malaya when it was reintroduced in the 1900s as an experimental cover crop.

Culinary preferences and food traditions play a role in the type of crops adopted by local populations. This is best illustrated with the 'sticky cereal zone' in Asia. A clear geographic division exists between the consumption and cultivation in East and Southeast Asia of sticky varieties of cereals, and an absence of sticky varieties in South Asia (Fuller and Rowlands 2011; Fuller and Castillo, in press). Sticky cereal varieties contain low amylose starch but higher amylopectin. In the 'sticky cereal zone' (also 'glutinous rice zone' and 'glutinous endosperm starch' culture area), in East and Southeast Asia, one finds sticky varieties of Asian domesticates such as rice and foxtail millet, but also of introduced cereals such as maize and barley. These introduced cereals were not originally sticky but evolved to have sticky mutations in eastern Asia suggesting an active selection process affected by taste and cultural preferences. Iconic foods, whether inherited or constructed are embedded with identity which led Avieli (2005) to conclude that 'food is nationalism.' This theme is exhibited by differences in tastes and preferences amongst groups of people living in modern states. In Thailand for example, a regional division exists between the Thai-Lao of Isan who consider sticky rice and fermented fish as part of their ethnic group identity and the central Thai who prefer boiled rice and fish sauce (Lefferts 2005). In fact, sticky rice is seen as peasant food by the central Thai (Anderson 1993; Lefferts 2005). On the other hand, in Laos, where no prejudice against sticky rice exists, sticky rice is preferred over normal rice by both urban and rural dwellers (Roder et al. 1996). In other Southeast Asian countries where sticky rice is consumed, it appears to be eaten by ethnic groups and not in the entire country.

Food in India is known to grade a person's caste rank and is dependent on customary rituals and sectarian values (Khare 1992). Food is imbued with social and spiritual meaning, and not just material substance. One iconic food from India is *dhal*. *Dhal* refers to both the preparation of pulses (split and hulled) and dishes made from the split pulses that have a soup-like consistency (Larouse Gastronomique 2001). Although many pulses in India are consumed and prepared in the same way, such as for *dhal,* it appears that some pulses are consumed more by the high caste Hindus (e.g. black gram) and others are for the poor (e.g. horsegram and grass pea). Merchants and craftsmen probably belonged to the Vaiśya and Śûdra caste respectively, the latter considered the lowest and most impure of the caste system with only the untouchables below them (Simoons 1998). Indians belonging to these two castes probably represented the majority of the people that travelled to Peninsular Thailand in the Late Prehistoric Period. They would have brought with them food items they would have normally used in their place of origin. These included many pulses that can be used in the preparation of *dhal.* Mungbean, horsegram, pigeon pea, and hyacinth bean can all be used to make *dhal* and were found in PKT (excluding hyacinth bean) and KSK. However, the introduction of one pulse, the black gram, may represent the entry of a new social level of Indian people travelling to Southeast Asia, the Brahmins, although there is no archaeological evidence to demonstrate this. The urdbean is used in many Hindu rites to counter the sinister and death, such as offerings to a Brahmin to counter the evil influence of Śani (Simoons 1998). And thus its new presence (only at PKT somewhat later than *dhals* at KSK) could be associated with an expansion of the social range of Indian castes in Southeast Asian enclaves. It is not until the third century AD that written evidence of the presence of Indian-Brahmins is recorded in a polity / city-state called Tun-sun (also Dunsun) (Wheatley 1961). However, this does not of course mean that Brahmins did not come to Peninsular Thailand at an earlier date.

Another similarity between PKT and KSK is the existence of cash crops. Cash crops demonstrate a network of exchange between Peninsular Thailand, South Asia and probably the rest of the Southeast Asian region with PKT and KSK acting as entrepôts. As at KSK, the evidence of *Citrus* rinds at PKT probably represents local *Citrus* species that were cultivated in PKT or nearby. The greatest quantity of evidence of charred rinds comes from a posthole infill which shows that *Citrus* was peeled and consumed in the settlement area. At PKT and KSK, Indian populations probably supplied long pepper for trade and not for personal consumption, although settlers may have brought some for their own use. Spices have long been associated as articles of trade and luxury (van der Veen 2011). Spices were valued not only as comestibles but as key ingredients for medicine, preservatives and aromatics (*ibid*). Spices have played an important role as specialty and luxury products in early trading ports such as in Berenike and Quseir al-Qadim in Egypt dating to the Roman period (Cappers 2006; van der Veen 2011) and in the later international trade economies such as to northwestern Europe and to China between 1250 and 1350 AD (Abu-Lughod 1989).

Most of the plant remains found were preserved in PKT and KSK as a result of burning waste products, waste product used for kindling, or secondary deposition of charred waste product, but not cooking accidents. The composition of the economic plant parts in the archaeobotanical assemblages of PKT and KSK is comprised mostly of crop processing by-products and specifically, of rice spikelet bases. Other crop processing by-products found in both sites include rice husk and weeds of cultivation. Fragments of economic crops are possibly also part of the crop-processing waste as discussed in section 7.5.3.1. The rice processing stages, pounding and winnowing, were probably done routinely outside the household, swept into a pile and burned.

The weed assemblage is comprised mostly of weeds that grow in dryland habitats and are also reported as weeds of rice cultivation. So one can say, in both PKT and KSK, the rice cultivation system was dryland and possibly shifting cultivation. The weed *Acmella paniculata* dominates the entire archaeobotanical assemblage and although it has been shown to occur as a weed in upland rice cultivation, it is equally plausible that this weed was also consumed as a vegetable.

The analysis of the archaeobotanical assemblage at PKT shows that similarities exist with KSK in the subsistence resource base, the formation processes that resulted in the preservation of plant remains and the cultivation regime that was practiced. However, there are also differences between the two sites, most notably the higher frequencies of Indian pulses as well as the slightly higher diversity of crops introduced from the west found in PKT. One of the roles of PKT as part of an exchange network was as a first point of entry for produce arriving from South Asia but also a last point of exit for local products on return voyages to South Asia.

CHAPTER 8
Charring Experiments: Interpretation

8.1 INTRODUCTION

This chapter addresses issues of preservation bias in the archaeological record by discussing the results of the Primtech08 charring experiments together with the archaeobotanical results from KSK and PKT. As mentioned in Chapter 5, the following discussions should be viewed as relative outcomes, relationships or patterns due to the many factors that influence carbonisation and preservation of plant remains. These factors cannot be replicated in their entirety when conducting charring experiments.

8.2 CEREAL HUSK

Garton (1979) mentions that husks withstand more severe heating conditions than grains. However, other and indeed most experiments with husked cereals (cited in Table 5.1) conclude that grains survive better than glumes. The Primtech08 experiments using husked cereals (Ex1 and Ex2) show that for the small cereals at least one foxtail millet grain or fragment charred in 87.5% of the experiments and all experiments had at least one broomcorn grain or fragment. On the other hand, husk was only found in 75% of the experiments for both millets. This bias towards grain preservation, however, may not necessarily be true for rice. Further experiments focusing on the time and temperatures when destruction of cereal husks occur may be necessary, especially to compare rice to other cereals. Boardman and Jones (1990) consider it unlikely that the destruction of grain will occur while other parts are preserved. The majority of the Primtech08 experiments show that both the grain and husk of cereals char but of the total remains of rice and broomcorn millet, husk fragments predominate. In the case of foxtail millet, three out of five experiments showed a higher grain to husk ratio.

It was found that in all eight Primtech08 experiments where husked rice was charred, most retrieved remains were husk (Figure 8.1). The high number of husk fragments compared to caryopses and spikelet bases can be explained by the nature of fragmentation and whether the component parts are recognised. Whereas there can only be one rice spikelet base per rice spikelet, there can be several fragments of husk and caryopses. Rice spikelet bases are robust and even in a very deteriorated state can be identified. In the case of husk (Figure 8.2), small fragments even those measuring *ca.*

0.5 mm can be identified as long as the pointed tubercules which give husk its chequerboard pattern, have not deteriorated as a consequence of charring to make them unrecognisable. Caryopses fragments measuring less than 1 mm become harder to identify as rice.

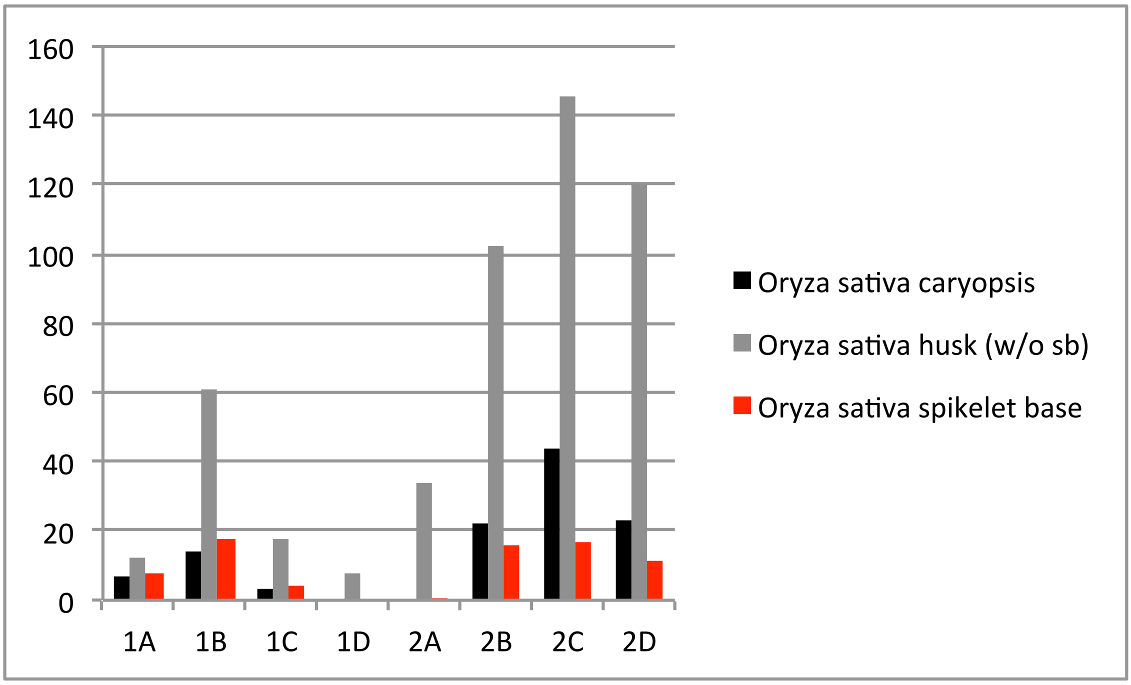


Figure 8.1: Rice plant remains divided into component parts from Ex1 and Ex2.

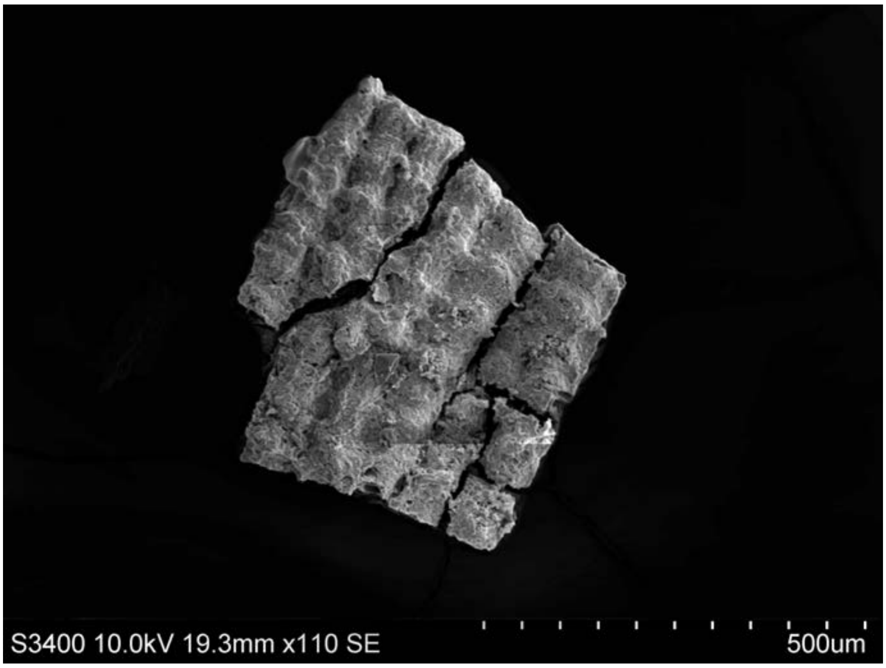


Figure 8.2: Small fragment of charred rice husk from Khao Sam Kaeo (tp117 us4). The fragment shows the distinctive chequerboard pattern which makes it identifiable (Image by author).

The ratios of rice husk to millet husk in all Primtech08 experiments are consistently greater by as much as 25:2, when rice is compared to both foxtail and broomcorn millet. This suggests that in a site where rice, foxtail and broomcorn millet are processed and consumed, rice husk will probably be more visible than the husk of the two millets. If the utricle or bract sheath is taken into account, the cereal with the most visibility is job's tears (Figure 8.3). The ratio of job's tears' utricle to rice husk is greater in all eight experiments. At KSK and PKT, no job's tears were found but foxtail millet grains were identified. In KSK there were no fragments of foxtail husk which makes it impossible to compare frequencies of foxtail millet husk with the rice husk fragments in this archaeological site.

Figure 8.3: Three SEM images of charred *Coix lachryma-jobi* (job's tears) from experiment 1A. From left to right: grain without utricle, grain with adhering utricle and utricle (Images by author).

Some studies on rice waste products have suggested that lemmas and paleas do not survive charring very frequently (Harvey and Fuller 2005). This may also be the conclusion at KSK and PKT though other possibilities are explored below. But this is not the case at the site of Khok Phanom Di (KPD) where the majority of rice remains were husk and husk impression fragments (Thompson 1996). Although rice husk recovered through flotation at KPD was fragile and poorly preserved, it was still recognisable. Garton concludes in her charring experiments that even though the husks were fragile after charring they would be archaeologically visible given the right burial conditions (1979). This seems to be the case at KPD. If flotation techniques use 500 μm or larger mesh, most if not all, rice spikelet bases would be lost in the process. This would bias results towards higher number of grains and husk measuring 1 mm and larger. This, however, was not the case in KPD where the smallest mesh size used was 250 μm. Although rice husk was recovered through flotation, Thompson (1996) points out that most were not charred and were not found as discrete units. Instead these were silicified remains of the lemmas and paleas, and were visible in the soil matrix. Rice husk impressions were also recovered with flotation in larger numbers than husk fragments. In the case of KPD, the recovery technique seems to have affected the amount of husk retrieved from the site. At KSK and PKT, no remains were found with the naked eye during excavation and no rice husk remains were visible as lenses in the soil.

8.3 RICE SPIKELET BASES

Rice spikelet bases are unique and each can act as a proxy for one rice spikelet since there is only one spikelet base per rice spikelet, i.e. they provide an MNI. In seven of eight experiments using husked cereal (Ex1 and Ex2), at least one rice spikelet base survived and in 62.5% of the cases more than a fourth of the spikelet bases from the entire sample were charred. This generally suggests that rice spikelet bases are robust and tend to preserve well through charring (Figure 8.4). This is attested in both KSK and PKT where rice spikelet bases comprise 76% and 67% respectively of all rice parts (Figure 8.5). A total of 1,215 and 637 rice spikelet bases were found in KSK and PKT respectively. The representation of rice spikelet bases at these two sites is much higher than that which appears in the charring experiments (Table 5.7). It is believed that the spikelet bases in KSK and PKT are dehusking waste products [the term milling is used to refer to dehusking by both Yen (1982) and Thompson (1996) and are used interchangeably in this chapter] as discussed later. Charring is one of many steps towards the preservation of plant remains, other taphonomic factors should be taken into consideration such as crop-processing or further fragmentation and disintegration caused by recovery through flotation (Thompson 1996). Also, further experimentation would be helpful to see if rice spikelet bases can withstand higher temperatures or longer heating times than rice husk.

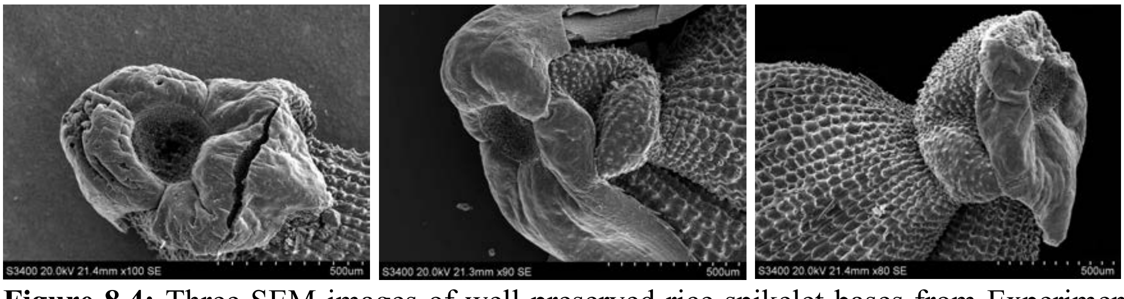


Figure 8.4: Three SEM images of well-preserved rice spikelet bases from Experiment IA (Images by author).

In the Primtech08 experiments, some of the rice husk, job's tears utricle and parenchyma fragments were found to be white and ashy. The husk fragments and job's tears utricles were identifiable and therefore tabulated here. The parenchyma fragments were not identifiable. However, these ashy fragments would probably not survive 2000 years of post-deposition. Between the time of deposition and recovery, taphonomic factors such as soil type, extreme humidity, erosion, and bioturbation affect the preservation of plant remains (Johannessen 1988; Popper 1988). On the other hand, none of the retrieved rice spikelet bases were ashy. This observation indicates that the spikelet bases are more robust than husk.

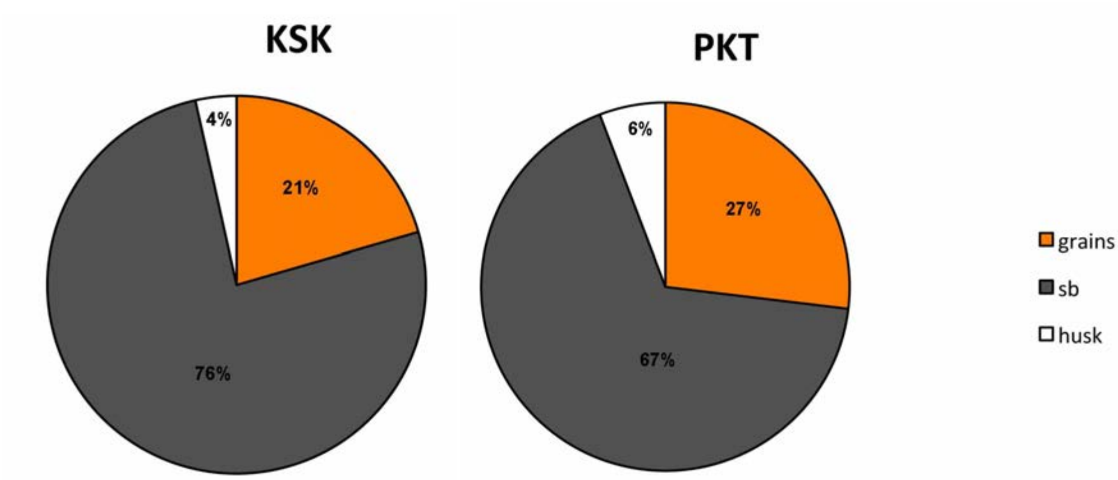


Figure 8.5: Percentages of rice part components in KSK and PKT.

It is believed that at KSK and PKT, both crop-processing and the more robust nature of spikelet bases than husk, affects the amount of rice spikelet bases that are found in the archaeobotanical assemblages. Waste products including rice spikelet bases arise after the second winnowing stage done after pounding. In present-day Thailand, rice is stored as spikelets in storage houses called '*yung*' (Figure 8.6) as mentioned before.

Figure 8.6: A *yung* or rice storage house exterior and interior showing rice stored as spikelets. Photographs taken in Bang Luk, Chumphon N 10°33’38.5” / E 99°10’13.9” (Images by author).

Rice is then taken from the *yung* to dehusk. This forms part of the household routine and the amount taken as well as the number of times per day or week when rice is dehusked mainly varies in relation to the size of the family. For example, Cham Nien, a farmer from Bang Luk, Chumphon said that in the past the amount of rice to be dehusked was measured with a can (biscuit can size). This would be enough for 10 persons for 3 days. Nowadays, she says that one sack of rice is taken by motorcycle to the factory for milling. Once the sack is consumed, they take another one. Yen (1982) found that milling is done on a daily basis in Thailand because rice is considered tastier if milled daily (also, Thompson 1996). Traditionally, dehusking was done by pounding with a mortar and pestle. This method is still used in some villages such as Ban Non Wat. Figure 8.7 shows one of the villagers demonstrating the dehusking process using a wooden mortar and pestle. In the northern uplands there are some villagers that still use the foot mortar and pestle (Thompson 1996).

Figure 8.7: Image on the left is a villager at Ban Non Wat demonstrating the dehusking stage using a wooden mortar and pestle. Middle photo is a close-up. Photo to the right is a Karen villager from Mae Hong Son demonstrating the use of the foot mortar and pestle (Images by author).

Prior to pounding, the husked rice is winnowed to remove immature and unfilled husked rice as well as weeds (Figure 8.8a). The rice spikelet bases from this batch were examined and morphologically were of the domesticated and not the immature type which means they are mostly mature but unfilled grains. The weeds were the same size or larger as the unfilled husked rice. After winnowing the rice, the remaining husked rice retained in the winnowing basket is placed in the mortar and pounded to detach the husk from the grains. What remains in the mortar is a mixture of husked and dehusked, whole and fragmented rice grains, husk including rice spikelet bases and a few weeds (Figure 8.8b). There are fewer weeds present in the pounded rice left in the mortar than the waste product coming from the winnowing prior to pounding. Also, the weeds are the same size or smaller than rice grains.

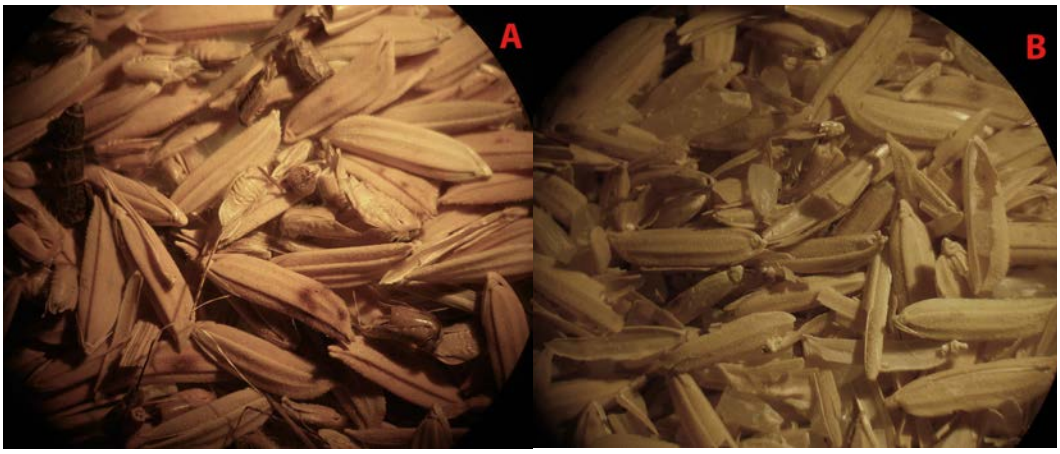


Figure 8.8: The rice and rice waste product from crop processing activities. [A] is from the winnowing stage before pounding and is mostly composed of immature and unfilled husked rice and large weeds. [B] is what is found in the mortar after the first pounding (Images by author).

The pounded rice is then normally placed in large flat baskets to separate the grains from the husk by weight (Figure 8.9). During the dehusking and winnowing because of varying weights, waste products are separated. The lightest waste products are the lemmas and paleas, which often get blown by the wind when winnowing. Chickens and other birds often linger around the area where winnowing takes place for easy pickings consisting mostly of husk and very small grain fragments. Figure 8.10 shows the winnowing waste products on the ground comprising of mostly husk, spikelet bases, very small rice grain fragments and a few weeds.

The remaining component rice parts are retained in the basket. The basket is then shaken in order to further separate the rice components. In one end of the basket closest to the person winnowing is the husked grain, the heaviest (Figure 8.11). On the other end lie the lightest waste products, the husk and rice spikelet bases that did not get blown away and small fragments of dehusked rice grain (Figure 8.12a). This waste product at the farthest end of the basket (Figure 8.12a) is very similar to the winnowed waste on the ground (Figure 8.10) except there are very few weeds retained in the basket and the rice husk is more fragmented than what is found on the ground, also

Figure 8.9: Photographs showing the winnowing sequence as demonstrated by a villager at Ban Non Wat. The top right photograph clearly shows the wind blowing the light fraction composed mostly of husk to the ground (Images by author).

there are more rice spikelet bases retained in the basket. In the middle of the basket lie mostly dehusked whole and fragmented rice grains, some husk and rice spikelet bases (Figure 8.12b). The waste product can be collected to use for animal feed or as kindling, of which some may survive in the archaeological record. A good ethnographic model for rice processing is Thompson (1996) though there is no mention of the stage when rice spikelet bases become waste products.

Figure 8.10: The winnowing waste found on the ground after the first pounding (Image by author).

Figure 8.11: Winnowing basket showing rice components grouped in different parts of the basket. In this particular photograph, the unhusked rice is the heaviest fraction. In the middle lie rice grain fragments. Unfortunately, a photograph of the contents of the entire basket was not taken (Image by author).

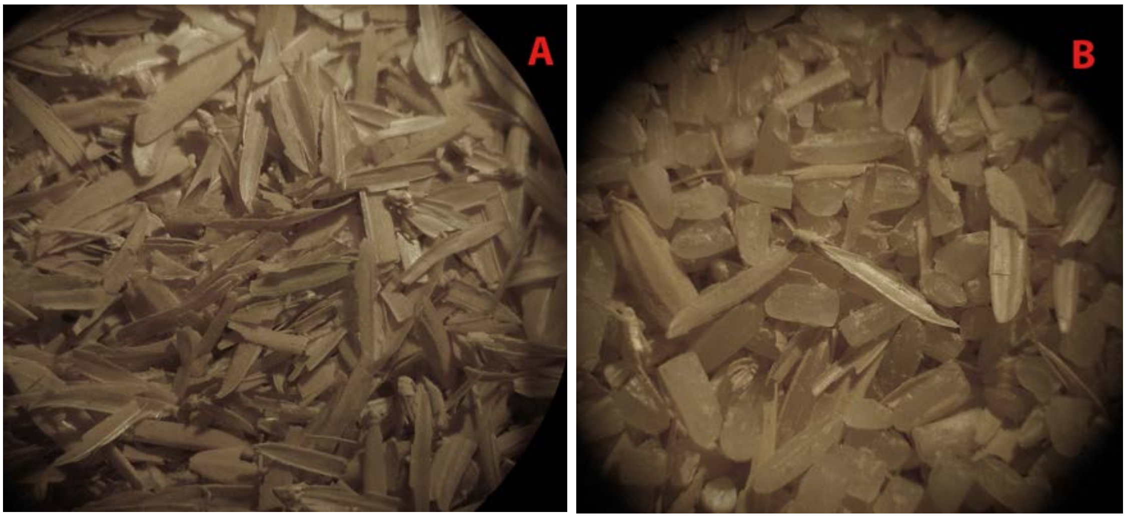


Figure 8.12: Component rice parts from the first pounding and winnowing found in the basket. [A] is waste product including husk and rice spikelet bases in the far side of the basket. [B] is mostly dehusked and some husked rice whole and fragmented, husk and spikelet bases retained in the middle of the basket (Images by author).

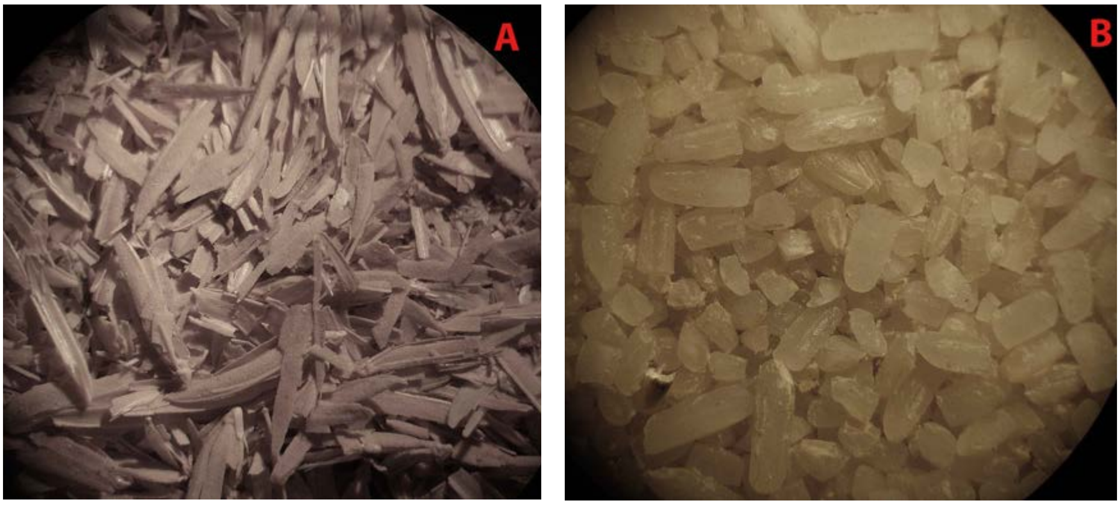


Figure 8.13: Component rice parts from the second pounding and winnowing. [A] is waste product including husk and rice spikelet bases on the ground. [B] is dehusked rice whole and fragmented retained in the far end of the basket (Images by author).

A second stage of pounding and winnowing takes place. The contents of the basket after winnowing are returned to the mortar and pounded a second time. The waste product found on the ground generated in this second round of pounding and winnowing is composed of mostly husk, rice spikelet bases and very small fragments of rice grain (Figure 8.13a). In the far end of the basket away from the person winnowing are the dehusked whole and fragmented rice grains with very few husked grains (Figure 8.13b). The few remaining husked grains in the basket will then be cleaned out by hand.

Figure 8.14: A scene during the winnowing stage with chickens and a pig benefitting from the waste product blown to the ground. Taken in a Karen village, Mae Hong Son (Image by author).

The ratio of *Oryza* caryopsis : *Oryza* sb (Table 5.4) show that in half of the experiments, the grains preserve better than spikelet bases whereas in the other half, it is the inverse. This would suggest that there is no real preservation bias in favour of one or the other. An explanation for a larger ratio of rice spikelet bases to grains at both KSK and PKT (100:27 and 100:40 respectively) is that, as mentioned above, spikelet bases are a processing waste from dehusking and the grains were consumed and therefore not charred. There is a low percentage of husk present in both archaeological sites, 4% at KSK and 6% at PKT of total rice parts (Figure 8.5) than found at Primtech08. An explanation for a low proportion of husk at both KSK and PKT could be that the husk would have been gathered to use for ceramic temper after the crop-processing stages involved in dehusking: pounding and winnowing. Another explanation is that the husk or chaff together with small grain fragments since it is the lightest waste product and would have blown away by winnowing and been eaten by chickens or birds or fed to other animals such as pigs (Figure 8.14). A third explanation for the low proportion of husk at KSK and PKT is that though the husk and spikelet bases seem to preserve, spikelet bases are more robust and can withstand post-deposition factors and retrieval by flotation better than husk.

8.4 MUNGBEAN BIAS

Whole rice caryopses do not preserve as well as whole mungbeans. However, when one takes into account fragments and rice spikelet bases but not rice husk, more rice turns up in the samples. Mungbeans have an overall higher preservation ratio compared to the two millets, foxtail and broomcorn excluding their husk. The ratio of mungbeans to soybeans shows that whilst in half of the Primtech08 experiments mungbeans preserve better in the other half, it is soybeans. However, whenever soybeans were used in the experiments (Ex1 to Ex3), at least one whole soybean preserved in each experiment. Another charring experiment involving pulses shows that even when higher temperatures are reached in open fires, pulses still preserve (Jupe 2003).

Figure 8.15: Charred mungbeans from Experiment 4C (L) and Khao Sam Kaeo (tp57 us16) (Images by author).

At KSK and PKT, mungbeans were the second most common economic crop after rice. Their preservation state is good as the cotyledons are normally whole with a visible embryo. The mungbeans in the Primtech08 experiments mostly preserve as whole seeds with testa (Figure 8.15). Not a single whole mungbean was found in KSK whereas 86.6% of the mungbean assemblage at PKTwas made up of split cotyledons and fragments. This could again be due to other taphonomic issues, particularly food processing. Mungbeans are cooked whole or split to make *dhal* and perhaps at both archaeological sites, mungbeans were prepared as *dhal.*

The mungbean to rice ratios from the Primtech08 experiments are compared with the KSK and PKT results in Table 8.1. The same general trend of more rice parts charred for every mungbean (*Vigna* : *Oryza* all <1) is seen in most of the experiments and in all the archaeological data from KSK and PKT. However, when just the rice caryopses are taken into account, the archaeological evidence still suggests higher preservation rates of rice against mungbeans, contrary to the general results of the experiments. A possible explanation for the higher frequencies of rice at KSK and PKT than mungbean is that mungbean which is a larger seed than rice is more visible with the naked eye and if it was to fall out of a pot, it would be spotted and returned to the pot more readily than rice so avoiding charring and being eaten instead. However, the archaeological plant remains in both KSK and PKT suggest that preservation is due to crop processing and not cooking accidents, for both rice and mungbeans. This is best illustrated by the large proportion of rice spikelet bases found in both archaeological sites compared to clean or naked grains. On the other hand, mungbeans are 'free-threshing,' which does not produce as much waste product and loss of seeds as 'pod-threshing 'types (see Chapter 7 section 7.5.3.4). However, if the mungbeans were prepared as *dhal* then pounding would be involved in the processing stage which could result in the accidental loss of seeds. Since both rice and mungbean plant parts are believed to have preserved as a result of crop-processing, this signifies that rice was more frequently used at KSK and PKT than mungbeans. The archaeological ranking of rice, then mungbeans, followed by other economic crops shows a real pattern in food use.

	1A	1B	1C	2A	2B	2C	2D	4A	KSK	PKT
Vigna:Oryza caryopsis	100:64	100:64	100:19		100:88	59:100	65:100		5:100	32:100
Vigna:Oryza caryopsis & sb	79:100	92:100	100:38	100:5	83:100	46:100	47:100		1.17:100	9.2:100
Vigna:Oryza all	42:100	26:100	67:100	60:100	19:100	13:100	10:100		1.12:100	8.6:100
Vigna:Setaria	100:9	100:100	100:31	100:62	100:84	100:62	100:53	100:100	100:11	
Oryza caryopsis:Oryza sb	88:100	78:100	75:100		100:73	100:39	100:48		27:100	40:100
Oryza caryopsis:Oryza husk	58:100	23:100	17:100		22:100	30:100	19:100		100:17	100:22
Oryza:Setaria	100:7	100:92	100:83	8:100	100:70	100:29	100:25		100:1	

Table 8.1: Results of charring experiments compared to the actual archaeobotanical evidence from Khao Sam Kaeo and Phu Khao Thong.

8.5 THE SMALL MILLET GRAINS

The preservation bias for foxtail and broomcorn millet grains is clear from the Primtech08 experiments. Generally, more foxtail millet grains preserve than broomcorn millet grains if both these are husked. This is the case in six out of seven of the experiments with at least twelve or more foxtail millet grains and fragments charring for every broomcorn millet grain or fragment. When naked grain is used in the experiments, the general trend shows a slight bias towards broomcorn preserving over foxtail. This observation may be relevant to Chinese archaeobotany where *Setaria* almost always outnumbers *Panicum* in reported archaeobotanical assemblages from the Yellow river region (see, e.g. Lee et al. 2007; Fuller and Zhang 2007; Song 2011).

When comparing the preservation of grains of millets to rice, we again see a clear bias in favour of rice. In the experiments using husked cereal, the ratio of rice to broomcorn is consistently greater across all experiments except in 2A where there is the same number of grains charred for both species and in 1D where no rice caryopsis was found but one grain of broomcorn charred.

More significantly, no rice remains charred when the naked cereals were used in the experiments (Ex3 and Ex4) but some grains of both foxtail and broomcorn grains did char. The relative frequencies for the two millets appear to be lower when these are charred naked (Table 5.7). This is consistent with the observations by Bowman (1966), Garton (1979) and Märkle and Rösch (2008) that the glumes seem to protect the grain when charring.

8.6 CONCLUSION

Some experiments were conducted to replicate each other (Ex1 and Ex2; Ex3 and Ex4) and one would have expected similar results. However, as cited earlier in Chapter 5, one of the problems when doing the experiments was human error. This meant some of the experiments were discarded and so contributed to a lack of comparability, at least between Ex3 and Ex4. Also, the varied results coming from the comparable experiments illustrates that perhaps there is no single predictable process by which seeds are charred especially under fire conditions, but there is instead considerable random variability in the real world. Some broad conclusions have been drawn and compared to the archaeological remains from KSK and PKT. The Primtech08 experiments have been particularly useful in understanding the differential preservation of rice, rice parts and the small millets, foxtail and broomcorn. Also, the lack of preservation of rice when naked was of particular interest as it may be the case that most of the charred rice grains found in archaeobotanical assemblages had started out as husked spikelets. This would signify a further preservation bias in the archaeological record as only unprocessed or at least unhusked rice would eventually preserve. This in turn would point towards the main source of archaeological rice grains being loss of spikelets from threshing or which failed to be threshed in dehuksing or were discarded in waste, as opposed to clean grains of cooking accidents or dehusking products. By contrast rice spikelet bases can be expected to be preserved from dehusking by-products as well as the breakdown of whole charred rice spikelets. The question then arises as to 'how underrepresented is rice in the archaeological record?'

CHAPTER 9
Rice in Prehistoric Thailand

9.1 INTRODUCTION

This chapter is a review of what we know so far about rice in Thailand during prehistory and of the general trajectory of the domestication of rice, the theories that have been proposed for the spread of rice, the current genetic evidence and new insights in the history of rice in Thailand.

I begin this chapter with a review of the background of rice, specifically the domestication syndrome, followed by the methods used in distinguishing wild from domesticated rice. A section on rice in Thailand follows and provides a summary of the rice evidence so far reported. The rest of the chapter incorporates sections on the origins and spread of rice, genetic and morphometric studies including archaeogenetics. Using all the different sources of information from the above-mentioned sections, a new view on the spread of rice in Thailand is proposed.

There are very few archaeobotanical studies published from Thai archaeological sites making it difficult to have a clear picture of the history of rice in Thailand. Available data show that rice was the ubiquitous cereal in prehistory and particularly during the Metal/Iron Age as manifested in the sites of Khao Sam Kaeo and Phu Khao Thong (herewith KSK and PKT respectively). This signifies either the importance of rice as a crop or a preservation bias, both topics considered in this dissertation (see Chapters 5 and 8 for discussions on preservation bias using charring experiments).

The origin and spread of rice have been the focus of many studies consistently pointing towards the Yangtze valley as the first centre of rice domestication (Crawford and Chen 1998; Fuller et al. 2010; Glover and Higham 1996; Vaughan et al. 2008). There are differing views on whether there were one or more domestication events, including a separate *Oryza sativa indica* origin and these views will be briefly discussed in this chapter (Fuller et al. 2010; Molina et al. 2011). Also, the dates when rice is purportedly fully domesticated have been revised from the original 10000 BP to 6500 BP (see Anping 1998; Fuller et al. 2007a; Fuller et al. 2009b; Zhao 1998; Zhao and Piperno 2000) due to developments in archaeobotany especially the examination of spikelet base rachilla scars to differentiate between wild and domesticated forms (Fuller et al. 2009b; Thompson 1996). Wild rice naturally disperses its seeds when ripe making the actual gathering of rice a protracted exercise. For archaeobotanists, the key domestication trait of rice is the non-shattering of the spikelets which allows farmers to have a single harvest.

Current genetic studies are now crucial in discussions of origins and spread of rice agriculture but are likewise divided as to whether rice domestication had single or multiple origins (He et al. 2011; Molina et al. 2011; Sang and Ge 2007). Genes responsible for non-shattering have been identified but also post-domestication genes responsible for other traits such as stickiness and fragrance to name a few (Purugganan 2010). These studies on post-domestication genes help us understand food choices based on cultural preferences. Sticky and fragrant rices have distinct geographical boundaries, with sticky rices found in East and Southeast Asia but not in South Asia, and display strong selection pressure (Olsen et al. 2006). The selective pressures for sticky rice for example are probably a result of food preparation traditions. DNA studies on modern rice are paving the way for aDNA studies. The first aDNA study on rice in Thailand is reviewed in this chapter as part of an effort to piece together the history of rice in Thailand. Finally, combining the evidence from archaeobotany and genetics, I propose a new hypothesis on the spread of rice in Thailand.

9.2 BACKGROUND ON DOMESTICATION OF RICE

This section is an introduction to rice to help the reader in the discussions that follow. Figure 9.1 is a scanning electron microscope (SEM) image of an awned *Oryza sativa* spikelet showing some component parts discussed in this chapter and throughout the dissertation.

Domestication syndrome

Cultivation is the process by which humans, plant, harvest and re-plant. Plant domestication, on the other hand, involves genetic changes in the plant brought about by the continuous manipulation of these plants by humans, as well as other factors such as environment and climate. Genetic changes manifest themselves phenotypically and are observed as morphological features. The domestication syndrome is defined as a suite of modifications found in domesticated species that differ from their wild progenitors such as seed shattering, reduction of awns, dormancy, grain size and synchronization. Studies on the domestication syndrome are plentiful in the literature (for example Fuller and Allaby 2009; Fuller, Allaby and Stevens 2010; Gepts and Papa 2002; Zohary et al. 2012). Some of these domestication traits can be examined in archaeological material such as loss in natural seed dispersal, reduction in seed dispersal aids and increase in grain size, whereas others cannot.

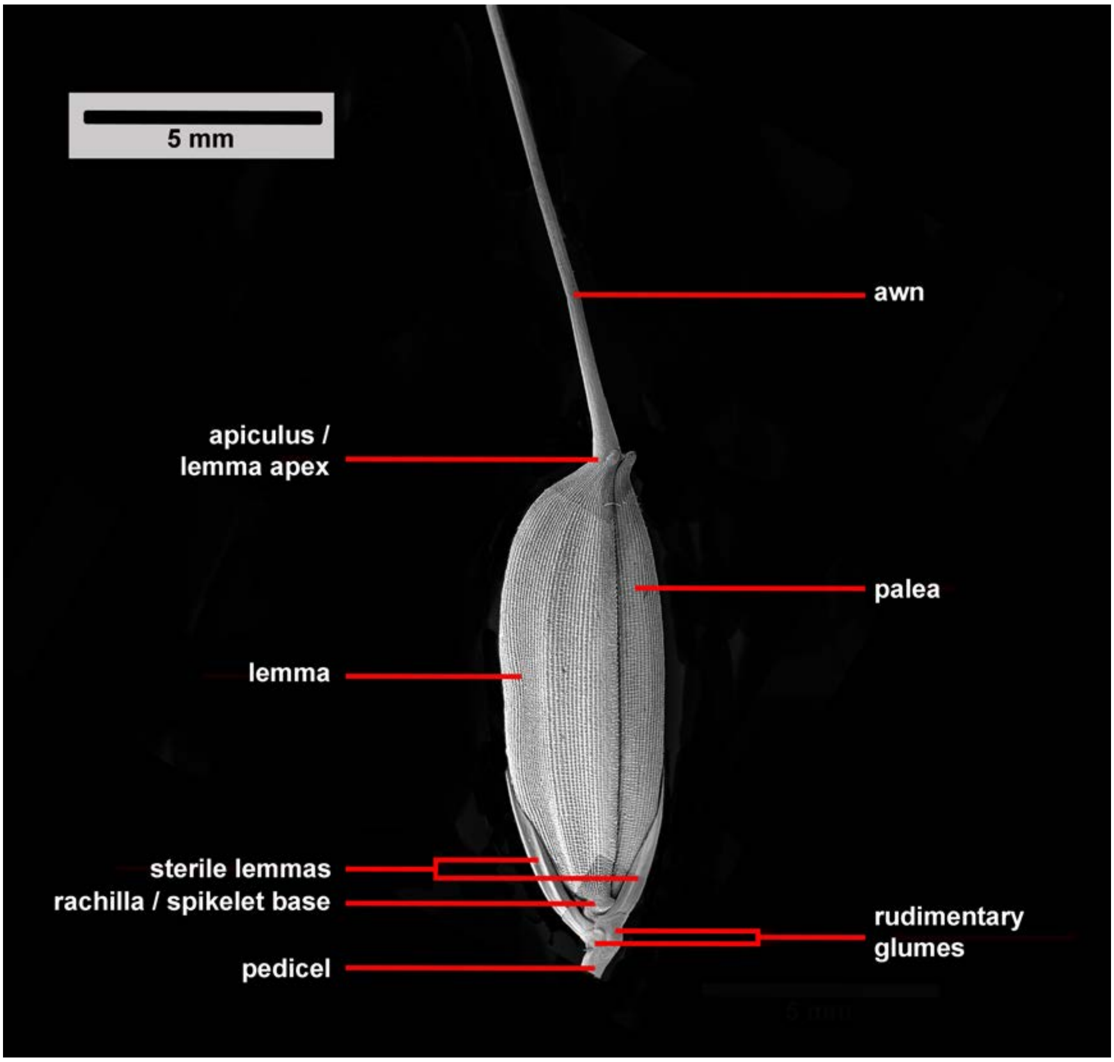


Figure 9.1: A composite scanning electron micrograph of an awned *Oryza sativa* spikelet showing component parts. Rice sample from the Institute of Archaeology reference collection: *Oryza sativa* Nigeria OS6 (Image by author).

Domesticated plants lose their ability to disperse their seeds naturally. Domesticated rice possesses a *non-shattering rachis* which allows humans to harvest rice without losing the grain in the process whereas wild rice would dehisce when mature and fall to the ground making it difficult to harvest. Threshing domesticated rice is therefore necessary to detach the spikelet from the rachis. A study of the rachilla scar found in rice spikelet bases determines the status of domestication as discussed in the next section.

Increase in grain size from wild to domesticated cultivars is also a diagnostic trait, though not as reliable a trait as non-shattering (Zohary et al. 2012). It is hypothesised that gains in grain size are mainly due to better soil management, including soil conditions, soil disturbance and deeper burial (Fuller, Allaby and Stevens 2010). It would therefore follow that in better managed cultivation systems (i.e. intensification) and more fertile soils, the proportion of immature rice grains would also decrease. In order to study increases in rice grain size one requires a long chronology to ascertain these changes. To determine the amount of immature rice grains in cases where archaeological rice grains are scarce, such as in KSK and PKT, a possible proxy is the examination of rice spikelet bases to determine the ratio of immature vs. domesticated rice spikelet bases in the assemblage compared to other assemblages from different periods.

Awned apiculi are normally found in wild rices. Awns are a dispersal aid that allows the mature grain to embed itself in the soil (Fuller and Allaby 2009). Although a reduction in the size of awns and their absence is normally associated with domesticated rice, there are still some domesticated rice varieties where the awns persist (Table 9.1). Examination of the rice lemma apex and the scar where the awn breaks off will show whether an awn had been present or not. The next section '**Differentiating wild from domesticated rice**' provides more details on the archaeological analysis of lemma apices.

Loss of dormancy results in crops germinating whenever the seed is wet and planted, instead of waiting for favourable conditions to occur (Fuller and Allaby 2009; Zohary et al. 2012). Loss of germination inhibition in domesticated crops results in thinner seed coats and lighter seed coat colour. Wild rice is red in colour whereas domesticated rices most often have a white pericarp, although it is not clear that this is related to dormancy (some domesticated rices with reduced dormancy also have a black/dark purple pericarp). However, the colour of the pericarp is impossible to determine in charred remains and likewise, seed coats in pulses do not generally preserve making this domestication trait difficult to spot archaeologically (Fuller and Allaby 2009).

Clade/ taxon	Cultivar group / ecotype	Geography	Cultivation system	Comments
Subspecies *Indica*				
***indica* group**	*Aman*	Bengal/ Bangladesh	Deep water. Upland & irrigated, long seaons (Mar-Nov)	
	Rayada group	Bengal/ Bangladesh. Similar types in Southeast Asia	Floating rices, deepwater	Early elongation ability in intercalary meristems, controlled by one major gene from *rufipogon* (Hattori et al. 2007).
	Cereh / Tjereh	Indonesia	Lowland rainfed	Usually red pericarp . Note some 'gundil varieties fall here (Oka 1988: 151)
	Typical *Indica* of Southeast Asia, "10th-month rice" of Vietnam	Southeast Asian plains	Lowland	Incl. rare Black-pericarp glutinous *indica* (in Laos & Thailand: Prathepha 2007)
	Chinese xian⍰⍰, some Japanese upland rice	China, Korea, Japan	Upland, shortseason	Introduction events unknown, likely multiple
	1st cropped rice	Taiwan	Lowland. Sown winter and harvested by summer.	Related to above(?);
***aus* group**	*aus,* dry, short season (Mar-July)	Bengal to Assam, Bangladesh	Lowland, dry	Centre of diversity: Bangladesh
	Boro, irrigated, winter (Oct.-Jan.)	Bengal, Bangladesh	Lowland, dry	
	Deepwater *aus, Ashwina* group	Bangladesh, Bengal, Manipur	Deepwater rice, offseason. Grown in stagnant permanent water.	See Oka 1988: 151
	Champa rice; "fifth-month rice"	Vietnam, Thailand	Lowland, dry, rainfed, short season	introduced to China c. 1100 AD from S. Vietnam (Barker 2011)
	Some upland *indica* types of China, Taiwan, japan.	China, Taiwan, Japan	Dry/upland, shortseason	Heritage from Champa rices (above) (cf. Ishikawa et al. 2002). These are included in traditional Chinese xian⍰⍰
Subsp. *Japonica*				
Tropical *japonica* group (syn. *javanica*)	Basic "tropical japonica"		Probably lowland, floodplains, rainfed	Probably close the original rices of the Lower Yangtze. Includes glutinous (*wx*) types that evolved secondarily
	bulu (=javanica)	Indonesia, Philippines	Lowland, dry (rainfed)	Awned (*bulu* means "hair")
	gundil (= javanica)	Indonesia	Lowland, dry (rainfed)	Awnless
	nuda	SW China	Dry, lowland or upland	Awnless
	American Long-grain	Mississippi Basin	Lowland, irrigated	Awnless
	African upland	West Africa	Upland, rainfed	Awnless; distinct from African rice *Oryza glabberima.*
	Black rice, Lao *khao kam*	Laos, Vietnam, Thailand	Upland rainfed	Black-pericarp glutinous (*wx*)
Temperate *japonica* group (syn. sinica)	Chinese *jing*⍰⍰	China, Korea, Japan	Lowland, usually irrigated	Included are many glutinous (*wx*) and some non-glutinous (*WX*) .
	Short-grained California rice	California	Lowland, irrigated	
	Risotto, paella rices	Mediterranean Europe	Lowland, irrigated	Italian *Arborio* is a glutinous (*wx*) type; Carnaloni is non-sticky (WX). (cf. Cortois et al. 2011)
	Dian-Chi Lake deepwater rice	Yunnan	deepwater	Recently extinct (Oka 1988: 217)
Aromatic group [= *frag*]	e.g. Indian *basmati,* Iran *sadri,* Thai jasmine, *hom* rices of Laos	SE Asia, South Asia, Iran	Mostly lowland, irrigated	Mainly derived from temperate *japonica* *BADH2* mutation group (Kovach et al 2009). Lao fragrant rices include waxy and non-waxy (Appa Rao et al. 2006a)

Table 9.1: Summary of Asian rice variation including the subspecies, geography, cultivation system and characteristics of the different varieties of *Oryza sativa.* (Source: Fuller and Castillo in press).

Synchronous tillering and ripening involves even maturation across all branches of the plant (Fuller, Allaby and Stevens 2010). In the case of domesticated rice, the panicles ripen uniformly and at harvest time, the grains from the same panicle and entire plant are mature. Harvesting can then take place as a single event. Wild rice panicles, on the other hand, would ripen at different stages and the mature grains would shed and fall to the ground making it difficult to gather. This is another domestication syndrome trait not visible archaeologically although immature rice spikelet bases compared to wild and domesticated ones might give some indication of whether wild rice was being gathered immature to avoid losses in grain harvest (Fuller et al. 2008).

Brief note on taxonomy

There are two main subspecies of *Oryza sativa* namely *indica* and *japonica* and five distinct groups based on genetic distance and population structure according to Garris et al. (2005): *indica, aus, tropical japonica, temperate japonica* and *aromatic* (Figure 9.2). From their study, it appears that temperate *japonica* was derived from tropical *japonica,* and aromatic rices are closer to *japonicas* in their nuclear and chloroplast DNA. On the other hand, *aus* and *indica* had a closer evolutionary relationship to each other than to the others in the group.

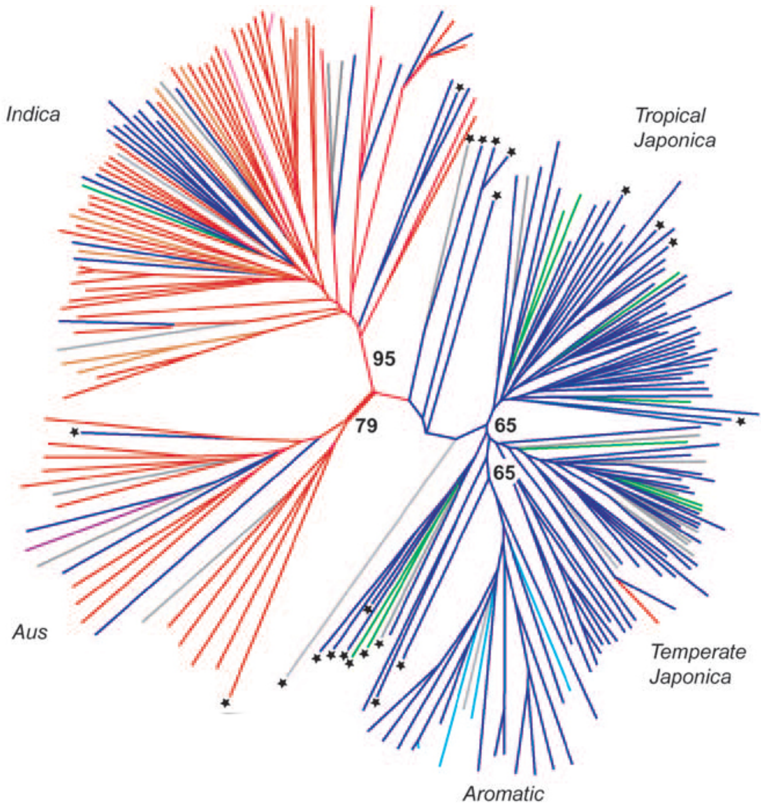


Figure 9.2: Unrooted phylogenetic tree of *Oryza sativa* diversity based on 169 nuclear SSRs (simple sequence repeats) and 2 chloroplast markers in 234 cultivars of rice. The color of the line relates to the chloroplast haplotype (adapted from Garris et al. 2005 and Van Driem 2011).

Finally, there is a wide range of variety within the species *Oryza sativa* and also within each subspecies. For example, temperate *japonica* is normally short and plump and tropical *japonicas* (also known as *javanica*) are long, large and awned. Most sticky rices are *japonicas* though there are some to be found in the *indicas* as well. Even if domesticated rices have a white pericarp, some varieties are light brown, red and even black or dark purple (Fuller and Castillo in press) [see Table 9.1].

9.3 DIFFERENTIATING WILD FROM DOMESTICATED RICE

Table 9.2 lists some of the most commonly used criteria to differentiate wild from domesticated rice. These are the examination of the abscission scar in the rachilla, grain size, presence of awns & the examination of the lemma apex, husk cell shape, arrangement and width, presence of trichomes and phytolith measurements; some of which are discussed below.

Using rice chaff or impressions as a method can result in misleading interpretations due to the limited amount of information derived from their study. Thompson (1997) reviewed some of the methodologies including the examination of husk patterns as defined by Chang and applied in her work at Khok Phanom Di. She concluded that the examination of the abscission scar found in rice spikelet bases and the lack of awns in the lemma apex were more useful in segregating wild from domesticated rice than the appraisal of morphometrics on rice grains, the tubercule pattern and the cell sizes of husk. The leading constraint according to Thompson was the relatively low amount of spikelet bases and lemma apices found in the archaeological record compared to caryopses and husk. Harvey (2006) also cites the lack of rice spikelet bases in the archaeobotanical record in her sites in India to be a limitation in using this methodology. However, this is no longer a constraint as shown in this dissertation if flotation is used using 250 μm mesh sizes which capture both the lemma fragments and spikelet bases; as well as sorting and identifying fine fraction to 500 μm. Both rice fragments are generally found in the 0.5-1 mm fine sort [56 domesticated and 4 wild rice spikelet bases from KSK were measured and had a mean length of 681.14 μm and mean width of 607.69 μm (Appendix 9.1); 1 lemma apex measured 680 μm at the base and 444 μm at the apiculus where the awn would have been attached]. Careful sorting with spikelet bases in mind is important, as rechecking of the fine fraction of some Indian sites has revealed spikelet bases that had previously been missed (Fuller et al. 2010). Similarly in

China, spikelet bases are often missed by beginner students until they are specifically taught to look for them (Fuller pers. comm.).

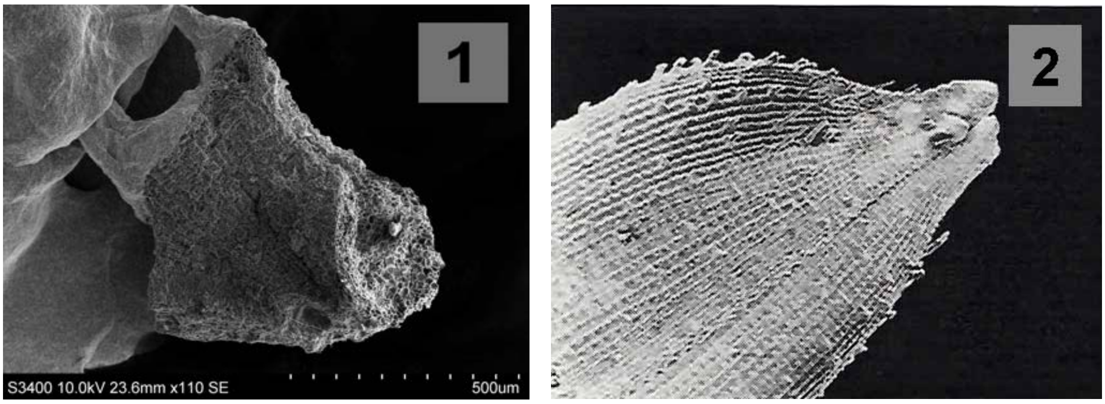


Figure 9.3: SEM images of 1) archaeological lemma apex from rice at Khao Sam Kaeo TP130 US6; 2) rounded distal end of modern *Oryza sativa*, scale 1mm. [1) Image by author, 2) Image by Thompson 1996].

Figure 9.3 (1) is a rice lemma apex from KSK demonstrating an angled or square fracture where the awn would have been attached whereas (2) is a lemma apex from domesticated rice which is rounded and smoothed out. Awnless rice is definitely domesticated rice [Figure 9.3 (2)], and although as mentioned, generally wild rice has awns there are some domesticated types with awns (see Table 9.1). Therefore, one should use caution in determining awned rice as wild. If the archaeobotanical assemblage provides evidence of both rice spikelet bases and lemma apices, it is best to study both their morphologies and consider the information jointly. For example, the rice awns found at Hemudu dating to *ca.* 5000-4500 BC were considered to be from wild rice. The wild status of much of the rice in Hemudu was further established by the rice spikelet evidence from the Lower Yangtze of the same period which is predominantly of wild morphology (Fuller and Allaby 2009). At KSK and PKT, the rice spikelet base analysis confirms predominantly domesticated rice though all the lemma apices recovered show the rice was awned. One could assume the rice to contain some wild stands but it may also signify an awned variety of domesticated rice, namely tropical *japonica* (*javanica* or bulu). Table 9.1 is a list of the different varieties of rice including information on awns.

Evaluating the status of domestication using phytoliths remains problematic (Harvey 2006; Fuller and Qin 2009; Fuller et al. 2010), though there are several scholars who believe it is possible (Gu et al. 2013; Saxena et al. 2006; Zhao et al. 1998). Using the methodology proposed by Zhao et al. (1998), double-peaked husk phytoliths were used to identify wild and domesticated rice in the site of Qinpu in the Lower Yangtze (Itzein-Davey et al. 2007). The results show that the rice assemblage was composed of predominantly wild-type phytoliths from 6000 to 2400 BP (Atahan et al. 2008; Itzein-Davey et al. 2007). These results conflict with the macroremains analysis for sites belonging to the Liangzhu period (*ca*. 2500 BC) on the Lower Yangtze when morphological domesticated rice spikelet bases comprised 68% of the assemblage (Fuller et al. 2010). As discussed above and summarised in Table 9.2, several methodologies are available to assess the domestication status of rice, and the most reliable method is the examination of the abscission scars found in rice spikelet bases (Thompson 1997; Fuller et al. 2009a). This can only be done with macroremains.

criteria	wild	domesticated	comment	Ref
abscission scar	smooth and round	rough and gouged out	most reliable criteria for domestication stat	Fuller et al 2007 Thompson 1996
awns	present	absent	only absence determines domestication as some cultivars are awned	Thompson 1997
grain size	smaller and thinner	larger and thicker	this should be used as a relative ratio comparing changes over time; requires examination of a large number of specimens	Fuller et al. 2010 Thompson 1997
husk cell shape & arrangement	irregular pattern	regular pattern	wild progenitors *O. rufipogon* and *O. nivara* have similar cell arrangements to *O. sativa*	Chang 1976, Harvey 2006, Savithri 1976, Sharma 19883
husk cell width	> variation in cell width	< variation in cell width	wide variation witihin one spikelet, several spikelets from same population	Thompson 1997 Yen 1982
lemma apex	angled fracture	rounded end	only absence determines domestication as some cultivars are awned	Thompson 1996 1997
phytoliths: double-peaked husk cell	Prediction of wild rice =-4.275 - 0.098(TW) + 0.356(MW) + 0.035(H1) - 0.074(H2)	Prediction of *O. sativa* =-9.403 - 0.066(TW) + 0.457(MW) - 0.248(HI) + 0.389(H2)	large variation within species, cannot be used to identify domestic rice; measurements top width (TW),width at the point where glume projection attaches to base (MW), height if each hair (H)	Gu et al. 2013 Harvey 2006 Pearsall et al. 1995 Zhao et al. 1998 Zhao 1996
phytoliths: keystone bulliform		*japonica:* fan handle length is long; *indica:* fan handle length is short	metric ratios on fan handle length separates *indica* vs. *japonica* using discriminant function multivariate analysis, although both types are found in wild *Oryza*	Fujiwara 1993
phytoliths: keystone bulliform	< 9 scales	8-14 scales	No. of scales on fan edge: Oryza genus identified when > 6 scales; distinction is between *indica/nivara* and *japonica/ rufipogon*	Harvey 2006 Lu et al 2001 Saxena et al. 2006
trichomes	present	present sometimes	preservation issues; trichomes present in some cultivars	Harvey 2006 Thompson 1996 Yen 1982

Table 9.2: Summary of the most cited and used criteria in the literature to identify domesticated from wild rice and comments on their usage.

Figure 9.4 shows the difference in shape between a wild and domesticated rice spikelet base. The abscission scar found in wild rice is circular with a shallow depression whereas domesticated rice displays irregular, sometimes squat, and deeply gouged out depressions. As mentioned previously, larger grain size is also a domestication trait especially increases in the width of the grain. However, this is not a reliable method to establish domestication since there is a wide range of size variation in modern cultivars and wild rice, and rice grain size is not only linked to human agricultural activities but also to climatic and ecological variations (Fuller et al. 2010).

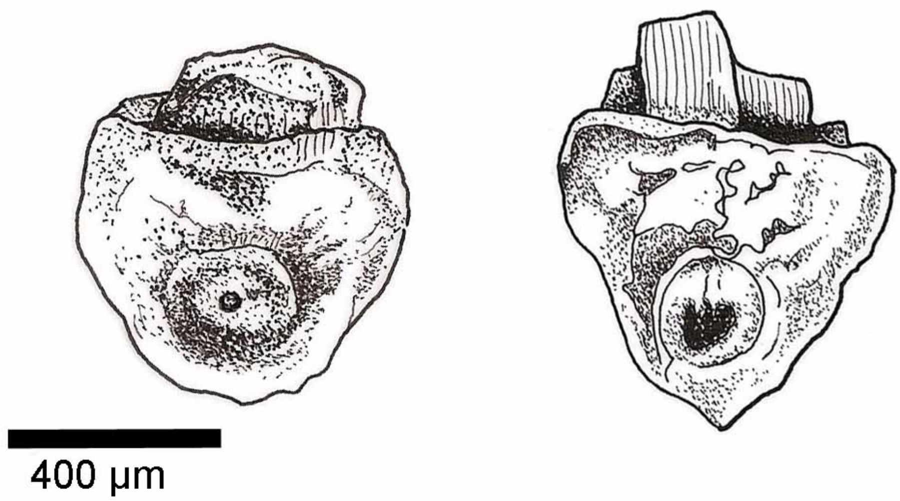


Figure 9.4: Domesticated (Left) and wild (Right) rice spikelet bases from Khao Sam Kaeo (Drawing by author).

Chang suggested, and applied by Zhang (2002), that there is a distinction in the density, regularity and alignment of the tubercule patterns in the husk between domesticated *Oryza sativa* and the wild *Oryza rufipogon* but Thompson's (1997) work shows that this method is not reliable due to the difficulty in tracking down the exact location in the spikelet from which the husk fragment originated, making variations in cell sizes difficult to interpret. In her PhD dissertation, Harvey (2006) reviews the different methods used in determining the domestication status of rice and she also dismisses the examination of the double peaked tubercules based on cell arrangement. This method using double peaked tubercules can only be applied when differentiating between species complexes in the Genus *Oryza* but it does not help in intra-species differentiation within the *Sativa* complex. Other methods used in determining the domestication status of rice include morphometrics of naked grains and double peaked phytolith husks. Rice caryopses measurements also do not allow archaeobotanists to establish the domestication status of rice because of variations, even of grains coming from the same plant (*ibid.*). However, Fuller et al. (2007) found that L/W ratios provide a tendency towards a subspecies (*indica - japonica*) if the rice remains have been

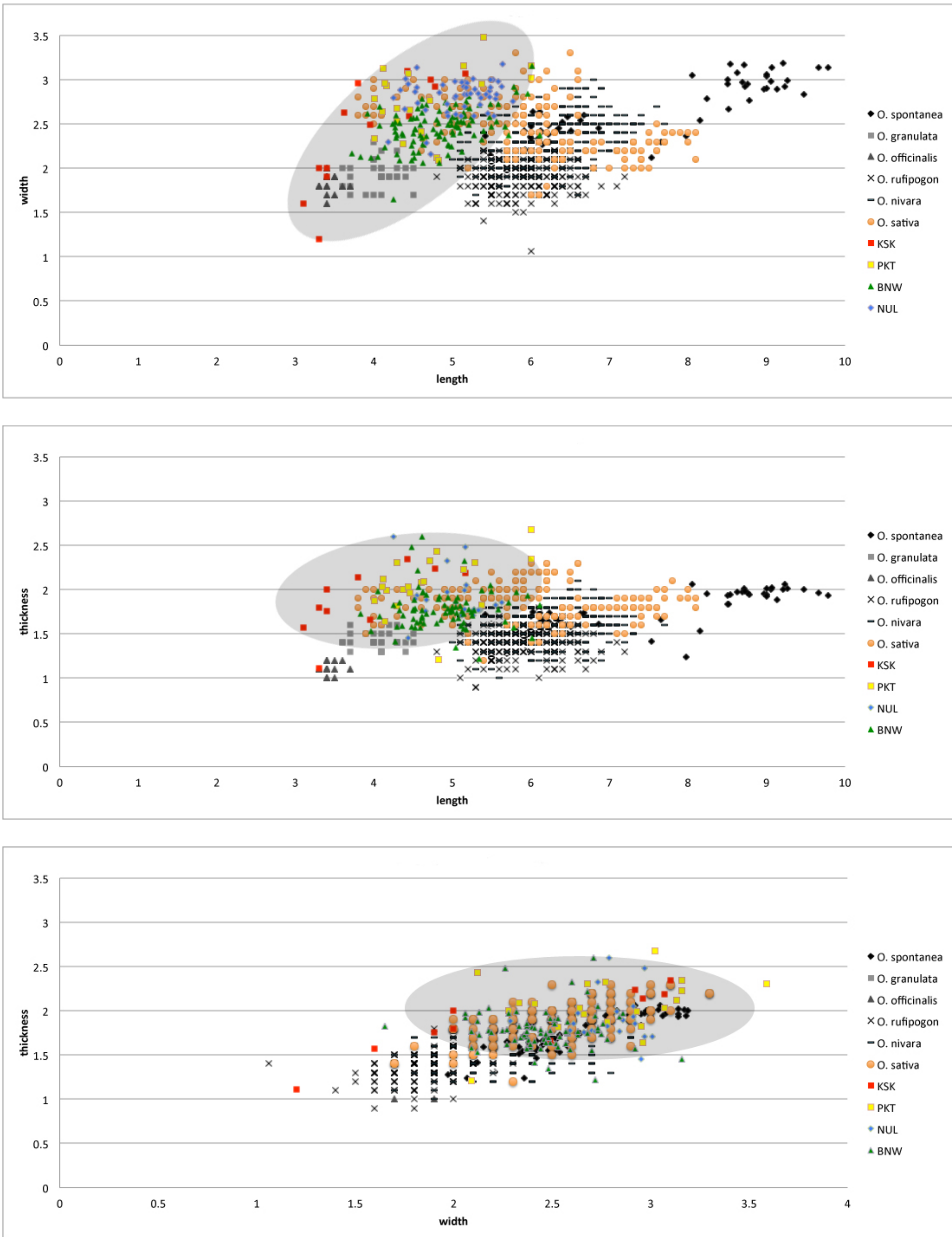


Figure 9.5: Three scatter plots of measurement ratios of wild, domesticated and archaeological grains. The top graph shows the length and width (L/W), middle is the length and thickness (L/Th) and bottom the width and thickness (W/Th). The measurements of modern populations (*O. spontanea, O. granulata, O. officinalis, O. rufipogon*, *O. nivara* and *O. sativa*) are from Harvey 2006. Harvey used 72 populations, 15 grains of each.

identified as domesticated. A study by Zhang in 2002 provided a framework for measuring the rice husk tubercules. However, Harvey found inadequacies in the Zhang study including the possible conflation of *Oryza nivara* into *Oryza rufipogon,* the limited number of wild rice species studied and the under-representation of rice populations studied. Harvey applied both the measurement of caryopses and Zhang's technique measuring the double-peaked phytoliths to her own study and so Harvey concluded that it is difficult to identify rice to species level using either of these two techniques. However, Fuller et al. (2007) consider plotting measurements in scatterplots helpful in distinguishing species on an assemblage level. A morphometric analysis was applied to four sites from Thailand namely KSK, PKT, Noen U-Loke (NUL) and Ban Non Wat (BNW). The results of the length-width (L/W), length-thickness (L/Th) and the width-thickness (W/Th) ratios were plotted against modern wild rices and *Oryza sativa.* Figure 9.5 shows the results. Similar to Harvey, it was found that the archaeological rice cannot be determined as domesticated through grain measurements but clustering does occur in all three scatterplots, in particular the W/Th ratio. The archaeological rice samples are consistently shorter and plumper than the majority of the wild rices. Wild rice is normally thin. Length is so variable in modern samples that it does not differentiate wild and domesticated types very well (Fuller et al. 2010; Harvey 2006).

9.4 RICE IN THAILAND

In this section, I examine the current evidence of rice in Thailand from archaeological research in order to try and piece together the history and spread of rice in Thai prehistory. During the course of my research, I identified twenty-eight sites in Thailand (Figure 9.6) which report rice finds dating from the Hoabinhian to the Late Prehistoric period (Fuller et al. 2011 on-line supplement). There are differences in the data quality dependent on the accuracy of interpretation and these were taken into account. Table 9.3 is the list of sites, the estimated dates, the rice parts found and their location. From these sites, only twelve have evidence of rice resulting from either flotation or phytolith analysis. The majority of the rice finds are chaff or impressions in pottery (Table 9.4). This is the same as that of the rest of mainland Southeast Asia where 66% of the 67 sites/phases that had evidence for rice come from rice temper finds (Fuller et al. 2010). Nonetheless, Thailand fares better than its neighbours in Southeast Asia since it has the highest number of systematically sampled sites for archaeobotanical research.

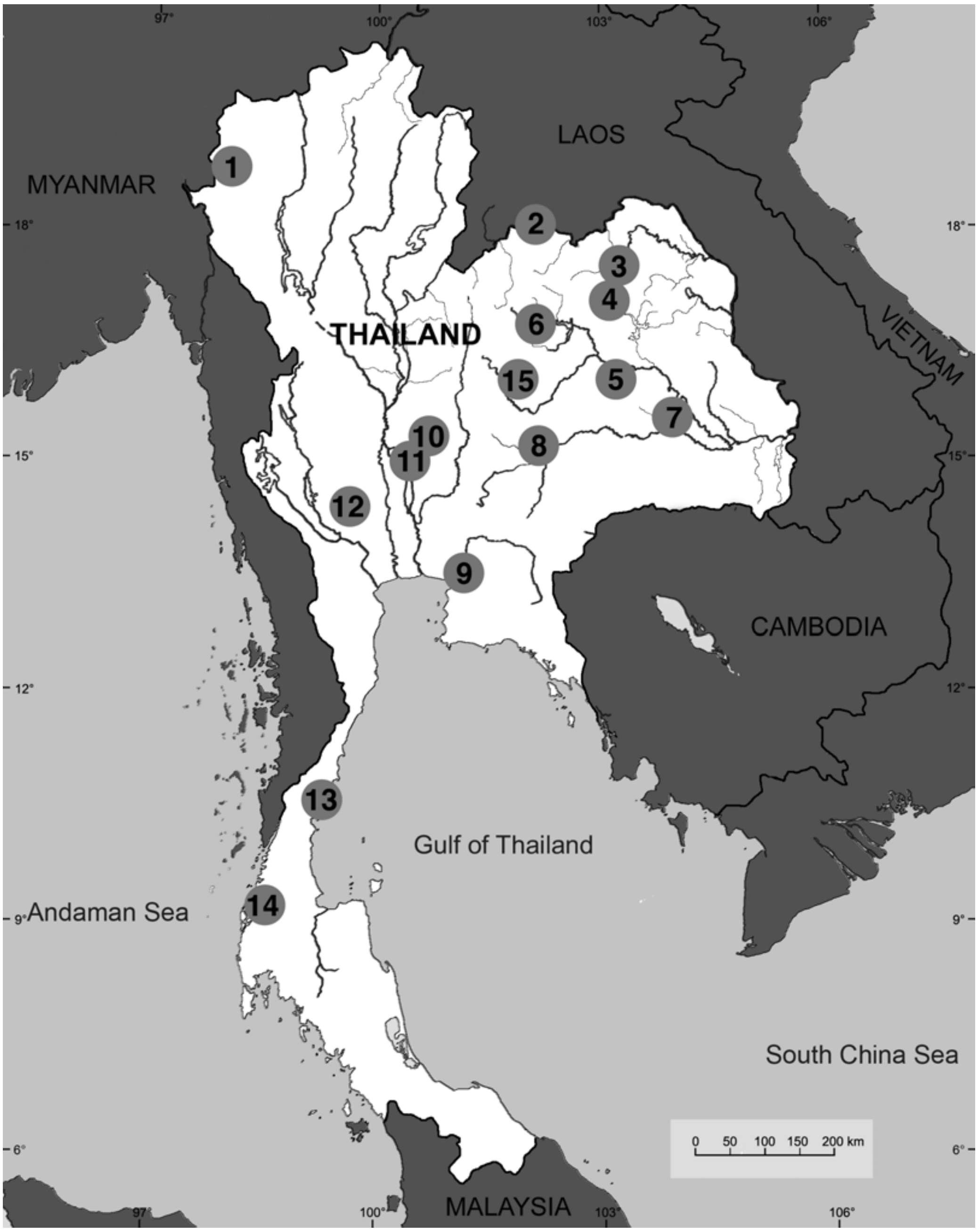


Figure 9.6: Map showing sites with evidence of rice. 1-Banyan Valley Cave; 2- Phu Lon; 3- Ban Chiang; 4- Nong Han Lake Kumphawapi, Ban Na Di; 5- Ban Chiang Hian, Non Noi, Ban Kho Noi; 6- Non Nok Tha; 7- Non Dua, Don Taphan; 8- Ban Non Wat, Phimai, Noen U-Loke, Non Muang Kao, Ban Tamyae; 9- Khok Phanom Di, Nong Nor; 10- Khok Charoen; 11- Non Pa Wai, Nil Kham Haeng, Non Mak La, Lopburi, Ban Tha Kae; 12-Ban Don Ta Phet; 13- Khao Sam Kaeo; 14- Phu Khao Thong; 15- Non Khao Wong (Map by author).

Province	Site	Period	Est. Date Range for rice*	Rice details	Other	References	Co-ordinates
Udon Thani	**Nong Han Lake Kumphawapi**	hunter-gatherer to Neolithic	>7000 BC	phytoliths		Bowdery 1999; Kealhofer 2002	103.030514° 17.157478°
Chonburi	**Khok Phanom Di**	hunter gatherers	7000-8000 BP	phytoliths		Kealhofer & Piperno 1994, 1996	101.140839° 13.584656°
Lopburi	**Lopburi area**	Neolithic	6000-3800 BC	phytoliths		Kealhofer 1997	100.593397° 14.898480°
Mae Hongson	**Banyan Valley Cave**	Hoabinhian	3500 BC - 700 AD	uncarbonised rice husk	*Canarium, Prunus,* bamboo, *Calamus, Cucumis, Lagenaria, Momordica, Trichosanthes,* bean, dog?, macaque, bear, langur, badger, pig, cattle, deer, porcupine, squirrel, rhinoceros	Higham & Thosarat 1998a; Mijares 2007; Oliveira 2008; Yen 1977, 1982	97.873903° 18.735405°
Lopburi	**Ban Tha Kae**	Neolithic	2200-1700 BC	impressions phytoliths chaff	bamboo	Higham 2002; Higham & Thosarat 1998a; Kealhofer 1997; Vincent 2003b	100.615777° 14.843418°
Nakhon Ratchasima	**Ban Non Wat**	Neolithic	2200 - 1300 BC	grains	pigs	Higham 2004; Higham & Higham 2009	102.277358° 15.267686°
Udon Thani	**Ban Chiang**	Neolithic (Early Period lower)	2100-1500 BC	grains impressions husk	domesticated cattle, dog, domesticated pig, deer, domesticated chicken	Chang 1989; Bronson & White 1992; Vincent 2003a; White 1982a White 1997; White et al. 2004; Yen 1982	103.255905° 17.502621°
Lopburi	**Non Mak La**	Neolithic	1800/1700-1100 BC	phytoliths	foxtail millet	Pigott et al 2006; Pigott pers. comm. (on date)	100.6748584° 14.963948°
Chonburi	**Khok Phanom Di**	hunter gatherers - Neolithic	2000-1500 BC	grains spikelet bases impressions chaff	*Sandoricum?, Amaranthus, Eleocharis, Cyperus, Cocos nucifera, Coix, Paspalum, Eragrostis,* fish, turtle, shellfish, deer, wild pig, macaque, domesticated dog, rhinoceros, water buffalo, pelicans, crocodile, pygmy cormorants	Higham 1995, 2002, 2004; Higham & Maloney 1989; Higham & Thosarat 1998b; Maloney & Brown 1990; Thompson 1996, 1997; Vincent 2003a, 2003b	101.140839° 13.584656°
Nong Khai	**Phu Lon**	Bronze Age - Iron Age	1st m BC	impressions		Higham 1996b, 2002; Pigott & Weisgerber 1998; Vernon 1997; Vincent 2002	102.0704498° 18.198715°

Province	Site	Period	Est. Date Range for rice*	Rice details	Other	References	Co-ordinates
Udon Thani	**Ban Chiang**	Bronze Age (Early Period upper)	1700-800 BC	grains impressions husk	domesticated water buffalo, domesticated pig, domesticated cattle, tiger, deer, turtles	Bronson & White 1992; Glover & Higham 1996; Higham 2002; Higham & Kijngam 1984; Thompson 1996; Vincent 2002; White 1982a; White 1997	103.255905° 17.502621°
Khon Kaen	**Non Nok Tha**	Neolithic - Bronze Age	1500-500 BC	impressions chaff	pig, domesticated cattle, dog	Bacus 2006; Glover & Higham 1996; Higham 1996b, 2002, 2004, 2005; Higham & Thosarat 1998a; Oliveira 2008; Thompson 1996; Vanna 2002; Vincent 2002, 2003b; Yen 1982	102.3116396° 16.800908°
Lopburi	**Khok Charoen**	Neolithic	1400-800 BC	husk		Vincent 2002, 2003b; Watson 1979	100.822450° 15.382662°
Udon Thani	**Ban Na Di**	Bronze Age	1400-400 BC	grains phytoliths impressions	domesticated cattle, dog, domesticated pig, crocodile, frogs, turtles, domesticated chicken	Chang 1989; Chang & Loresto 1984; Higham 2002, 2004; Higham & Kijngam 1984; Higham & Thosarat 1998a; Solheim 1966; Vincent 2002, 2003b	103.1339877° 17.256121°
Chonburi	**Nong Nor**	Bronze Age	1100-600 BC	impressions husk	dogs, pigs, bull, chicken	Higham 1996a, 2002; Higham & Thosarat 1998a; Higham et al 1997; Vincent 2002, 2003a, 2003b	101.222530° 13.486191°
Nakhon Ratchasima	**Ban Non Wat**	Bronze Age	1000 BC - 500 BC	husk impressions spikelet bases grains		Chang report unpublished; Higham 2004; Higham & Higham 2009	102.277358° 15.267686°
Maha Sarakham	**Ban Chiang Hian**	Bronze Age	900-600 BC	impressions	water buffalo (after 800 BC), cattle, pig, sambar deer, Eld's deer	Higham and Kijnjam 1984; Vincent 2003b; Vincent 2002	103.382778° 16.197222°
Maha Sarakham	**Ban Kho Noi**	Bronze Age	900-600 BC	impressions		Vincent 2002	103.281068° 16.172887°
Maha Sarakham	**Non Noi**	Bronze Age	900-600 BC	impressions		Vincent 2002	103.278585° 16.048372°
Mae Hongson	**Banyan Valley Cave**	Neolithic - Metal Age	900 BC - 1000 AD	carbonised grains	*Canarium*, bamboo, *Calamus*, deer, rat, rhinoceros	Reynolds 1992	97.873903° 18.735405°

Province	Site	Period	Est. Date Range for rice*	Rice details	Other	References	Co-ordinates
Lopburi	**Non Pa Wai**	Bronze- Iron Age	780-410 BC	grains	foxtail millet, *Panicum*, domesticated water buffalo, domesticated cattle, dog, pig, deer, fowl, pheasant, peacocks	Pigott et al. 2006; Weber et al. 2010	100.678000° 14.971100°
Nakhon Ratchasima	**Ban Tamyae**	Iron Age	600 BC	impressions chaff		Vincent 2003b; Welch & McNeill 1988	102.456911° 15.235668°
Nakhon Ratchasima	**Phimai**	Iron Age	600-200 BC	impressions		Vincent 2002	102.406338° 15.182755°
Lopburi	**Nil Kham Haeng**	Iron Age	500/450 BC - 300 AD	grains phytoliths	foxtail millet, bambusoid, panicoid grasses, turtles	Kealhofer 1997; Pigott et al. 2006; Pigott et al. 1997; Weber et al.2010	100.6559318° 14.956752°
Rot Et	**Non Dua / Don Taphan**	Iron Age	500-1 BC	impressions		Bronson & White 1992; Higham 1977; Higham & Thosarat 1998a; Vincent 2002	103.9216358° 15.563894°
Chumphon	**Khao Sam Kaeo**	Metal Age	300-100 BC	grains spikelet bases impressions	foxtail millet, mungbean, horsegram, long pepper, cotton	Bellina-Pryce 2008; Bellina-Pryce & Silapanth 2008; Castillo 2011; Castillo & Fuller 2010; Srisuchat 2003	99.18499511° 10.5282973°
Ranong	**Phu Khao Thong**	Metal Age	300-100 BC	grains spikelet bases	mungbean, horsegram, long pepper, sesame	Castillo 2011	98.422100° 9.380660°
Kanchanaburi	**Ban Don Ta Phet**	Iron Age	300-100 BC	grains impressions spikelet bases	hemp, silk, cotton	Glover 1990; Higham 2002; Higham & Thosarat 1998a; Thompson 1996, 1997; Vincent 2002	99.726222° 14.187403°
Nakhon Ratchasima	**Noen U-Loke**	Iron Age	300 BC - 500 AD	grains	water buffalo, domesticated pig, domesticated cattle, dog, deer, turtle	Higham 2004; Higham and Thosarat 1998a, 2007	102.256066° 15.260249°
Khon Kaen	**Non Khao Wong**	Iron Age	200-0 BC	chaff		Penny 1986	101.807013° 16.659669°
Roi Et	**Don Thapan**	Iron Age	5 BC - 20 AD	chaff		Gorman 1977; Higham 1972; Higham & Parker 1970	103.728917° 15.903293°
Nakhon Ratchasima	**Non Muang Kao**	Iron Age	1st c AD - Early Historic period	grains		Higham 2002; Higham and Thosarat 1998a; O'Reilly 2007	102.2862736° 15.215384°

* estimated date ranges using current evidence at time of writing; subject to changes (eg. Nil Kham Haeng, Non Pa Wai & Non Mak La are under review).

Table 9.3: Published sites in Thailand with evidence of rice, their location, chronology and other floral and faunal finds.

site	flotation	phytoliths	dry-sieving	impressions / chaff	hand-picked
Ban Chiang	x		x	x	
Ban Chiang Hian				x	
Ban Don Ta Phet				x	x
Ban Kho Noi				x	
Ban Na Di	x			x	
Ban Non Wat	x			x	
Ban Tamyae				x	
Ban Tha Kae		x		x	
Banyan Valley Cave			x		
Don Tha Pan				x	
Khao Sam Kheo	x			x	
Khok Charoen				x	
Khok Phanom Di	x	x		x	
Lopburi area		x			
Nil Kham Haeng	x	x			
Noen U-Loke					x
Non Dua				x	
Non Khao Wong				x	
Non Mak La	x	x			
Non Muang Kao					x
Non Noi				x	
Non Nok Tha				x	
Non Pa Wai	x				
Lake Kumphawapi		x			
Nong Nor				x	
Phimai				x	
Phu Khao Thong	x				
Phu Lon				x	
Total	9	6	2	19	3

Table 9.4: Rice finds in Thailand from published reports. The methodologies included are those with which the rice parts were retrieved (see Table 9.3 and Appendix 3.1 for references).

The earliest sites where rice has been found in Thailand show that rice may have possibly been cultivated as early as the mid-Holocene in the northeast and the central plains (Kealhofer 2002; Kealhofer and Piperno 1994). Periodic burning episodes also suggest human disturbance and food production. These inferences are based on phytolith studies conducted in Lake Kumphawapi, the Lopburi area and around Khok Phanom Di. The phytoliths from these sites were taken from sediment sequences in lake cores and alluvial deposits and the rice cannot be considered domesticated. As discussed above, methodologies based on phytolith analysis used to differentiate wild vs. domesticated rice have been proved to be deficient.

If one were to strictly adhere to the examination of rice spikelet bases, there would only be a handful of sites in all of Southeast Asia that would positively yield evidence for domesticated rice namely Ban Don Ta Phet (BDTP), BNW, KSK, Khok Phanom Di, and PKT. Most rice reports come from rice temper or impressions in pottery consisting mainly of husks and, like phytoliths, these data do not provide information on the domesticated status of the cereal.

The first evidence of domesticated rice in Thailand identified using macroremains dates to 2000-1500 BC from the Neolithic period in the coastal site of Khok Phanom Di (Thompson 1996). Khok Phanom Di provides rice finds in the form of domesticated-type rice spikelet bases and weeds of cultivation. Ban Chiang in the northeast yielded rice remains from the Neolithic Period predating Khok Phanom Di (Bellwood 2005) but this is almost certainly not domesticated rice. Yen (1982) studied the rice husk and husk impressions of Ban Chiang pottery and although the use of rice husk has already been shown to be a poor indicator of the domestication status, even Yen concluded that the rice in Ban Chiang contained wild features. Later, the rice evidence from Bronze Age Ban Chiang has been presumed domesticated and to have been grown under permanent inundated conditions though this is based on ethnoecological studies (White 1995) rather than archaeobotanical studies. Even though ethnoecology helps archaeobotanists understand the different cultivation systems that are in place, interpretations are more robust when actual plant remains from the site including weeds are studied. Unfortunately, no such study was undertaken in Ban Chiang. The majority of Neolithic rice finds in Mainland Southeast Asia (see Table 9.3) are situated in low-lying coastal areas, interior river valleys and floodplains possibly indicating rain-fed lowland cultivation systems. Although ethnoarchaeological studies have provided a basis for this hypothesis (White 1995), cultivation practices could be better interpreted by identifying the weed assemblages in archaeological sites. Also, the rice remains from the Neolithic were either from phytoliths or rice impressions and chaff in pottery, and as mentioned in section 9.2 both criteria are poor evaluators of domestication status.

Higham (2002b) originally proposed that rice agricultural expansion followed major riverine routes and would be archaeologically visible in interior sites, an idea previously put forth for Austroasiatic language expansion by Blust (1996). However Ban Tha Kae and Ban Chiang are the earliest interior sites dating to the Neolithic and are reported to have rice cultivation, but the evidence is based on rice-tempered pottery, so it may be open to doubt. The first inland sites that provide reliable domesticated rice finds are

Non Pa Wai, Nil Kam Haeng and Non Mak La in the Khao Wong Prachan Valley (henceforth KWPV). The rice finds at these sites date to the first millennium BC and not earlier. Two rice grains from Nil Kham Haeng yielded calibrated accelerator mass spectrometry (AMS) dates of 780-410 BC and 690-540 BC (Weber et al. 2010). All three sites from the KWPV also provide evidence of millets but interestingly, these are all found in earlier levels than rice suggesting millet cultivation before rice farming. A single grain of *Setaria* from Non Pa Wai yielded an AMS date of 2470-2200 cal. BC. The principal millet in all three sites in the second millennium BC was foxtail millet (*Setaria italica*) (*ibid*.). Non Pa Wai's evidence of *Setaria* during the third millennium BC signifies the introduction of millet cultivation at least a thousand years before rice at this site. This cereal originates from the north of China, though in the third millennium BC it was also evident in south China bordering Vietnam together with rice remains (Fuller et al. 2010). Lastly, the weeds associated with the KWPV millets indicate dryland cultivation whereas such weeds are inconclusive in the case of rice (Weber et al. 2010). However, it could be possible that the mode of cultivation for rice was dryland and was a technological continuum from the previous millet farming regimes. Furthermore, Mudar and Pigott (2002) have argued in favour of dryland crops prior to the late first millennium BC. At present, dryland cultivation is practiced in the KWPV including dry rice, maize, cotton, beans and millet. This agricultural regime is defined by environmental and climatic limitations of the area, such as porous soils causing poor water retention, which would have also been the case in prehistory. It is hypothesised that the subsistence strategy in the KWPV relied on the exchange of foodstuff for copper because of an insecure subsistence base dependent on dryland crops (*ibid*.). Dating also to the Bronze Age, five samples from BNW yielded sixty-nine rice spikelet bases of which 96% were domesticated (Table 9.5). More layers and samples from different periods need to be analysed to plot any changes in the domestication rates; n=69 is still a small sample.

It is not until the Late Prehistoric period that more rice macroremains are reported, though this over-representation is due to the amount of flotation conducted in Metal Age sites by the author. The spikelet bases from BDTP, BNW, KSK and PKT were examined and revealed that during the Late Prehistoric period, domesticated rice dominates the assemblage (Table 9.5). In the future, the author hopes to find more rice spikelet bases in other sites to plot the domestication rate in Thailand (cf. Fuller et al. 2010 for Chinese sites) and also see if there is any spatial correlation. Figure 9.7 is the data from KSK and PKT plotted against some of the Chinese sites where rice spikelet bases have been analysed. Unsurprisingly, the graph clearly shows the trend over time towards a higher percentage of domesticated rice spikelet bases and a decrease in the wild spikelet bases.

	domesticated	wild	immature	indeterminate	total
Ban Don Ta Phet	7 (100%)	0 (0%)	0 (0%)	2	9
Ban Non Wat	53 (96%)	1 (2%)	1 (2%)	14	69
Khao Sam Kaeo	836 (86%)	115 (12%)	23 (2%)	241	1215
Phu Khao Thong	493 (91%)	35 (6%)	9 (2%)	98	637

Table 9.5: Tally of rice spikelet bases and their status from Prehistoric sites. All studied by the author.

rice species	optimum daily mean temperatures	effect of light & temperature on grain filling
indica (IR20)	19-25°C	both ↓ = 65% filled spikelets ↓light/↑temp. = 62% filled spikelets ↑light/↓temp = 87% filled spikelets both ↑ = 86% filled spikelets
japonica (Fujisaka 5)	16-22°C	both ↓ = 86% filled spikelets ↓light/↑temp. =82% filled spikelets ↑light/↓temp = 91% filled spikelets both ↑ = 92% filled spikelets

Table 9.6: The optimum temperatures and effects of light and temperature on grain filling (Source: Yoshida 1981).

Figure 9.7 also shows that the two Sushui survey sites in the Yellow River, North China have a high percentage of immature rice spikelet bases even when compared to the earlier Tianluoshan site from the Lower Yangtze. Tianluoshan shows a decrease in immature rice spikelet bases over time as one would expect. This trend is the same with respect to larger grain sizes over time in the Lower Yangtze whilst the grains from the Yellow River in North China are comparatively smaller than in the Yangtze (Fuller et al. 2010, Liu et al. 2007). As mentioned earlier, increases in grain size can be attributed to not only better soil management but also better soil, and better grain filling conditions. Thus less water and too low or too high temperatures may also contribute to less complete grain filling or grain weight (Yoshida 1981 - Table 9.6). Low immaturity levels might also suggest better growing conditions. The two Thai sites, KSK and PKT have very low immaturity levels probably suggesting better growing conditions and grain filling in Southern Thailand than in the Yellow River.

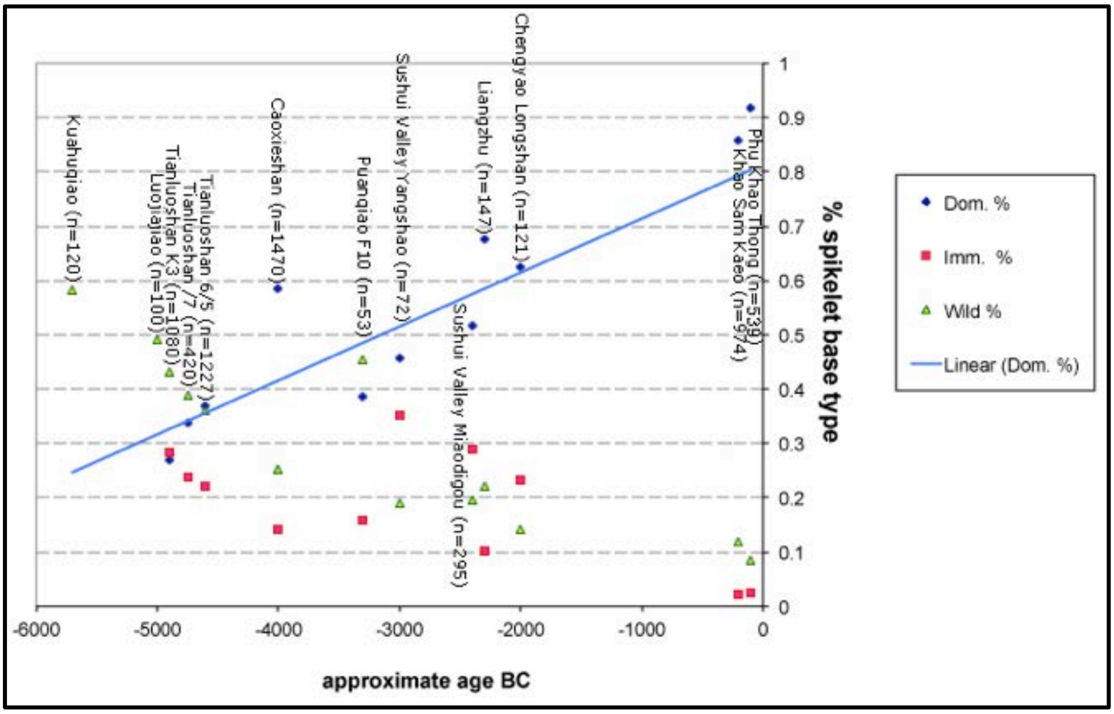


Figure 9.7: Data from China and Thailand showing increasing domesticated and decreasing wild spikelet base ratios over time. In parentheses are the number of spikelet bases of each site. Data for Kuahuqiao and Luojiajiao indicate only the wild fraction as immature and domesticated forms were not separated (after Zheng et al. 2007). (Adapted from Fuller et al. 2010).

The samples from BDTP were the contents of a bronze bowl and although there were more whole spikelets with the base still attached, they were silicified and encrusted in the metal making it hard to examine. Figure 9.8 is a scanning electron micrograph of a domestic rice spikelet base from BDTP showing the irregular and deep abscission scar. At BNW, flotation samples taken by the author from seven contexts were sorted and identified and all of them had rice grains and spikelet bases and some samples had weeds of cultivation. The Metal Age sites KSK (*ca.* 400-200 BC) and PKT (*ca.* 200 BC -100 AD) in the southern Peninsula have also yielded a large number of rice remains and associated weeds, as well as the Indian pulses *Vigna radiata* and *Macrotyloma uniflorum*. A sub-sample of the rice grains (n=53) from burial #105 at NUL was found by the author and Pattayaraj Thamwongsa at the Rice Research Institute in Phimai. There were no associated weeds or other plant parts and this is probably because they were pre-sorted and donated to the institute for their display. Information from this sample is therefore limited but morphometric analysis was used as a guide to differentiate between *Oryza sativa japonica* and *Oryza sativa indica.* The results discussed below show *japonica*-type rice at NUL. Similarly, BNW, KSK, and PKT have domesticated *japonica*-type rice based on morphometrics and possibly dryland and rainfed rice cultivation systems based on the weeds associated with the rice remains.

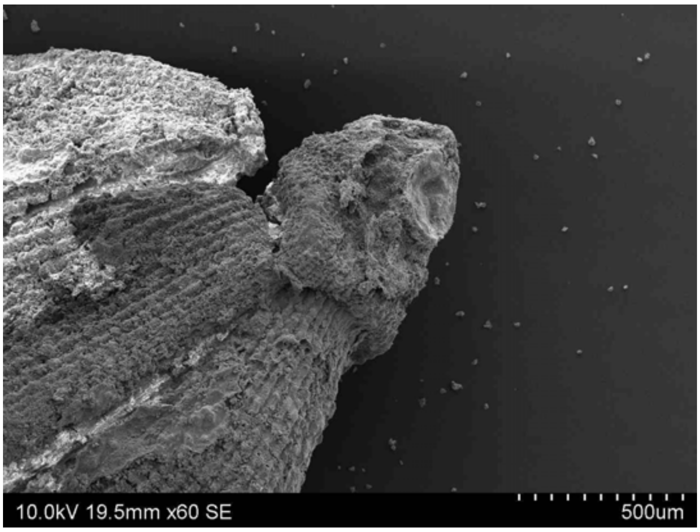


Figure 9.8: SEM image of a domesticated rice spikelet base found in a bronze bowl at Ban Don Ta Phet.

9.5 ORIGINS and SPREAD OF RICE

The widely held view is that rice in Southeast Asia came from China and that it was *Oryza sativa* spp. *japonica.* The linguistic evidence indicates that the original domesticators of rice, depending on the author of the hypothesis, were the Miao-Yao coming from south and central China (Blench 2005) or 'Austric' speakers (Blust 1996, Higham 1996) from the Yangtze Valley. The movement of Tibeto-Burman agriculturalists into northern China has also been proposed (van Driem 1998). Van Driem (2005) suggests that the Tibeto-Burman homeland was Sichuan, from which Tibeto-Burman speakers spread to the Himalayas, northern India and eventually north to the Yellow River Valley. Austroasiatic speakers, a subset of Austric, might also have been responsible for the early spread of rice from Southwest China (Sagart 2005; Higham 2002b). The Austric-farming-dispersal hypothesis proposes the dispersal of rice from Yunnan to Assam and eventually the Ganges (Bellwood 1996, Higham 2002b). Fuller (2011) points out that there is a lack of archaeological evidence, including archaeobotany, in northeastern India to substantiate any of these hypotheses. Bellwood

(1996, 2007) proposed that the Austronesians, another subset of the Austric, were responsible for the spread of rice from Taiwan to the Philippines and further south. However, evidence for archaeological rice along the southward path, from Taiwan to the Philippines, is scarce.

Unlike the lack of a single robust hypothesis in linguistics, the archaeological evidence consistently points to the Yangtze valley as the area where rice was first domesticated (Fuller et al. 2007b; Fuller et al. 2010; Nakamura 2010; Zhao 2010). However, which group of people brought rice cultivation to Thailand remains a matter of debate. Unfortunately, archaeological work in the region does not assist due to the paucity of archaeobotanical sampling (Castillo and Fuller 2010). There are not enough rice finds to permit geographic and chronological resolution for a clear picture of the diffusion of rice cultivation to emerge.

Evidence for both wild and domesticated rice is found along the Yangtze River and to the east along the Hangzhou Bay. These areas are suited for rice production as they are wetter and have floodplain lakes. The earliest evidence of presumed use of wild rice and therefore incipient cultivation comes from phytolith analysis performed on samples found at Diaotonghuan cave originally dated to *ca.* 12000 BP (Zhao 1998) and in the sites of Xianrendong (15000-12000 cal. BP) and Yuchanyan (18500-14000 cal. BP) located in the Middle Yangtze, where it has been postulated rice was exploited *ca.* 12000 years ago (Lu 2006). These dates have been recently revised using C14 dating. The new dates based on charcoal and bone collagen for Yuchanyan Cave range from 21000-13800 cal. BP (Boaretto et al. 2009). At Xianrendong Cave, the dates for the site have been pushed back to 20000-19000 BP (Wu et al. 2012). The new dates would necessarily also push back the dates for the hypothesis of rice domestication, that had been inferred from husk phytoliths (Zhao 1998). The interpretation of rice so early is difficult to accept, because of the lack of any other evidence of rice farmers, or the expected population growth of the Neolithic revolution, for 6000-10000 years, when evidence from substantial quantities of rice (of unclear domestication status) comes from Bashidang (7000-6000 BC). More rice phytoliths show up in a sediment core from the East China Sea dating to as early as 13900 BP though these are interpreted as wild by Fuller et al. (2010) as there is no anthropogenic association with the phytoliths, and the rice phytoliths disappear from the record during the colder spell known as the

Younger Dryas between 13000-10000 BP (Lu et al. 2002). The rice phytoliths from the East China Sea core and Diatonghuan cave are claimed to be the earliest domesticated rice by Lu et al. (2002) and Zhao (1998) respectively. These two claims are derived using distinct phytolith methodologies to determine domestication. Lu et al. use the keystone bulliforms' edge facets whereas Zhao uses the double peaked husk phytoliths. However, as mentioned above, both these methodologies are problematic and depend on whether one accepts that wild and domesticated rices can be distinguished through a typological change in phytoliths. There is, as yet, no explanatory mechanism of how such phytolith changes would have been selected for as part of a domestication syndrome. Fuller et al. (2010) believe that the changes in cell husk morphology are caused by climatic adaptations making the husk phytoliths appear more like those of Holocene domesticated rices.

The sites of Shangshan (10000-8000 BC), Pengtoushan (8000-7000 BC) and Bashidang (7000-6000 BC) show more evidence of rice use though again there is not enough evidence to confirm domestication (Fuller et al. 2007a, 2010; Sweeney and McCouch 2007; Zhao 2010). In the middle Yangtze, Pengtoushan produced rice husk tempered ceramics, while Bashidang produced large quantities of rice grains alongside a very diverse seed and nut assemblage. Bashidang rice grain measurements appear consistent with wild rice (Fulller et al. 2007a). In the Lower Yangtze, at Shangshan, rice cultivation was possible, but evidence consists mainly of rice chaff used as temper in a clay artefact. From this two rice spikelet bases, one wild and one immature, were extracted. It is more likely that the rice was wild and was preserved as a result of foraging activity or very early cultigen rather than domestication suggested by Liu et al. (2007) [Fuller et al. 2007a].

Incipient domestication was underway by around 6000 BC in the Lower Yangtze. A pre-domestication phase is also evident in the sites of Hemudu (5000-4000 BC), Majiabang (4800-4000 BC) and Kuahuqiao (6000 BC) (Fuller et al. 2007a, 2010). It follows that a period of pre-domestication cultivation must take place before the plants show physical signs of domestication. Wild and immature rice spikelet bases dominate the assemblage in the pre-domestication phase in the Lower Yangtze, although there is clear evidence of cultivation. Majiabang culture shows manipulation of the water table, at least from the Late Majiabang period as well as fully domesticated rice by the end of the sequence (Fuller pers. comm.), as sites such as Caoxieshan and Chuodun (Fuller and Qin 2009). Hemudu has hoes, bone and wooden spades suggesting soil tillage. Tianluoshan (5000-4500 BC), another site in the Lower Yangtze illustrates the domestication syndrome as the proportion of domesticated rice spikelet bases are increasingly represented in the assemblage over time. Unfortunately, the later levels at Tianluoshan dating to the Songze period *ca.* 3500 BC lack comparable archaeobotanical evidence to determine full domestication. Examination of all the characteristics found in the domestication syndrome such as seed shattering and grain size brings the date of rice domestication in China to *ca.* 4000 BC (Fuller et al. 2007a).

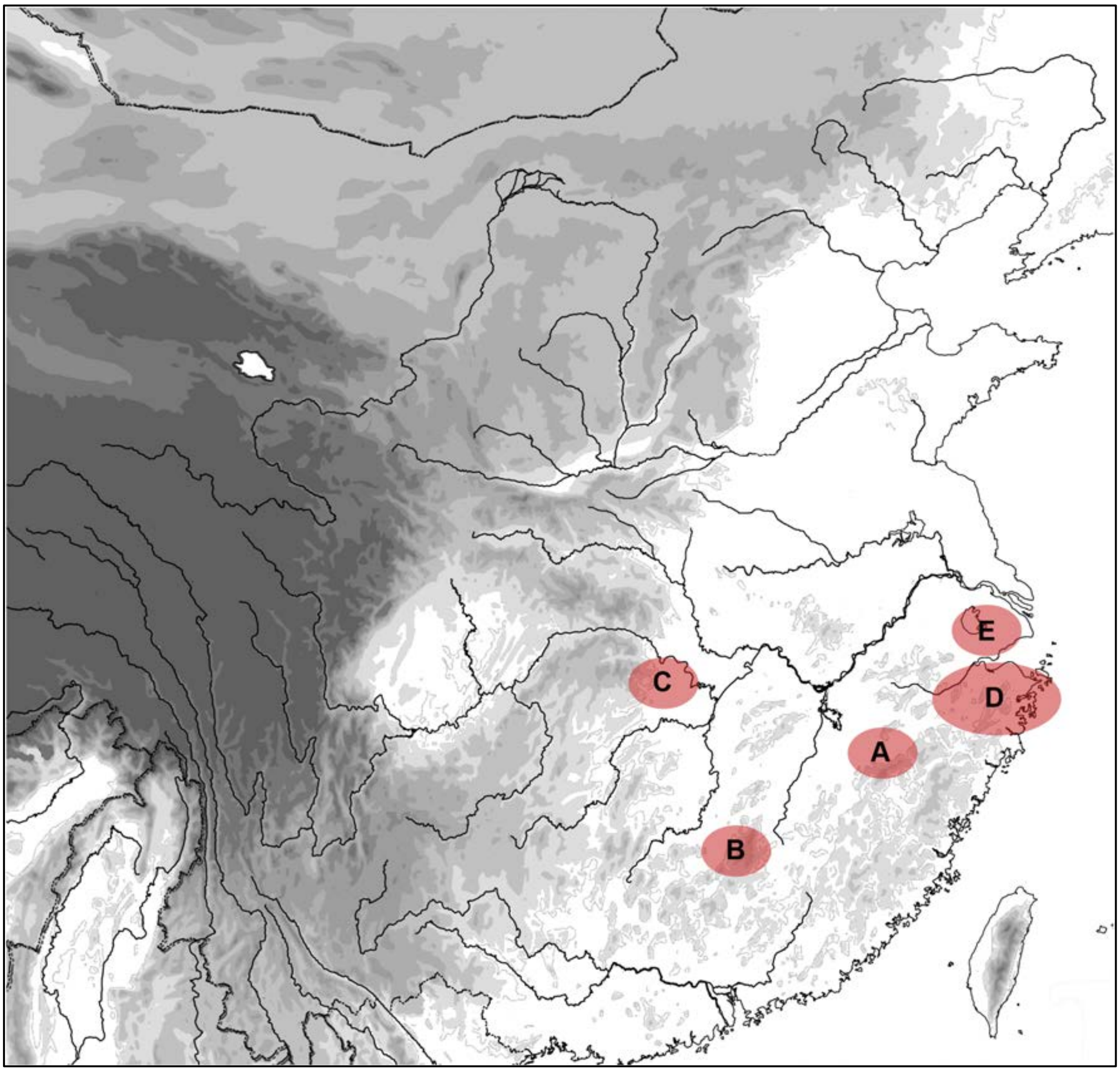


Figure 9.9: Chinese archaeological sites mentioned in the text. A: Diaotonghuan, Xianrendong; B: Yuchanyan; C: Bashidang, Pengtoushan; D: Shangshan, Hemudu, Kuahuqiao, Tianluoshan; E: Majiabang, Caoxieshan, Chuodun (Base map courtesy of Fuller).

In India, one finds early evidence of rice use in the middle Ganges at Lahuradewa with an AMS date of 6442-6376 cal. BC (ERL-6442: 7532±58 BP). Though Tewari et al. (2008) consider the rice in Lahuradewa domesticated based on grain morphometrics and the morphological characteristics of the husk fragments and the spikelet bases, Fuller et al. (2010) and Fuller (2011b) argue that the morphometric analysis was misinterpreted and instead shows the presence of wild rice or at best cultivated but undomesticated rice. The first real evidence of domesticated rice in India dates to 2000 BC with a presumed pre-domestication phase dating to at least *ca.* 2500 BC (Fuller et al. 2011). It is also during this period that other Chinese crops move into Northwest India (Boivin et al. 2012; Fuller and Boivin 2009). The later appearance of domesticated rice in India can be understood by considering the genetic data available to support either the single origins or multiple origins model. This is discussed briefly in the next section.

9.6 GENETIC and MORPHOMETRIC STUDIES

In this section, the background on the genetics of modern rice and some of the genes responsible for domestication is provided. An ancient DNA (aDNA) study and a morphometric analysis of prehistoric rice from Thailand are then presented. The morphometric analysis shows *japonica*-type rice in prehistoric Thailand and this is confirmed by the aDNA study. There is no indication that early rice in Thailand was *indica* which means that *indica* might have been brought into Thailand after the initial period of Indian contact. KSK and PKT belong to the early period of Indian contact and both sites have *japonica*-type rice veering toward the temperate *japonica* end of the spectrum as established by the morphometric analysis. Although mentioned earlier, the presence of awns signifies a tropical *japonica*-type.

There are two main cultivated subspecies of *Oryza sativa* namely *indica* and *japonica.* These two subspecies have different mitochondrial genomes and therefore point towards a multiple origins model. It has now been established by geneticists that *indica* is derived from an extinct *O. nivara*-like ancestor and *japonica's* wild progenitor is from a subset of *O. rufipogon (sensu stricto)* also extinct. Some geneticists refer to *O. nivara* as annual *O. rufipogon* and therefore the literature often refers to only *O. rufipogon (sensu lato)* but with two ecotypes (Cheng et al. 2003). The genetic study by Garris et al. (2005) maintains distinct and separate domestication events for *indica* and *japonica* (temperate), with the divergence between the groups from the ancestral *O.*

rufipogon ca. 440,000 years ago. Other studies indicate the divergence from the last common ancestor to have taken place 45,000-250,000 years ago (Tian et al. 2006). However, there are other genetic studies that conclude rice domestication had a single origin (Molina et al. 2011; cf. He et al. 2011; Sang and Ge 2007; Vaughan et al. 2008).

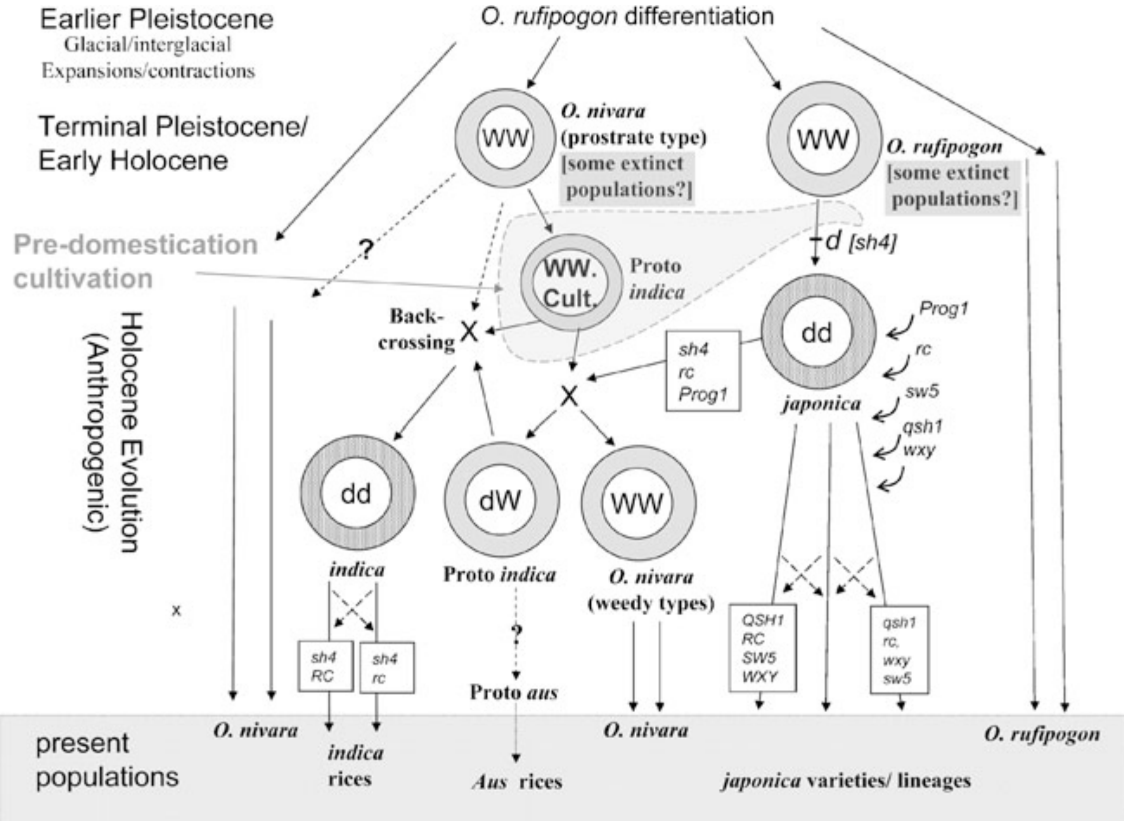


Figure 9.10: Diagram showing the multiple origins hypothesis on the evolution of *Oryza sativa*. Genetic mutations: *sh4* non-shattering, *Prog1* erect growth, *rc* white grain pericarp, *sw5* wider grains, *qsh1* further non-shattering, *wxy* waxy/glutinous rice (low amylase), WW wild genepool, dd domesticated genepool, cult. cultivated, X major hybridisation event; crossed arrows indicate continued gene flow or introgression. (Source: Fuller et al. 2010).

Figure 9.10 is a diagram (from Fuller et al. 2010) that expresses the multiple origins hypothesis starting with the divergence of the extinct wild progenitors *O. nivara* and *O. rufipogon* and ending with the different varieties of *O. sativa.* The *japonica* varieties/lineages include temperate *japonica,* tropical *japonica* and aromatic rice. The diagram illustrates that the evolution of domesticated rice was not straightforward, often affected by introgression and back-crossing. Introgression has been cited as an additional source of increased diversity in rice by single and multiple origins proponents alike (Fuller et al. 2010; Kovach et al. 2007; Molina et al. 2011; Vaughan et al. 2008).

The multiple-origins model proposes two centres of domestication, one in China *ca.* 4000 BC and the other in South Asia *ca.* 2000 BC (Fuller 2007a; Purugganan 2010). The single-origin model considers *indica* to be a hybrid of *japonica* rice and therefore, the origin lies in China even though its development or expansion occurred in India (Molina et al. 2011). The archaeobotanical evidence in Thailand does not corroborate either of the two 'centre/s of origins' models. It does however, point towards a largely *japonica*-type variety in prehistory and using either model ultimately shows that rice in prehistoric Thailand until at least the Iron Age has its origins in China.

Plant domestication has already been defined as the process whereby a plant is genetically modified from its ancestral wild predecessors and adapted to cultivation as a result of human manipulation. The increase in grain size, loss of seed dispersal, lack of awns, synchronous tillering and white pericarp of domesticated rice are the phenotypic expressions of these genetic mutations some of which are traits actively sought by farmers. Genes responsible for domestication traits have been identified for many plants and contribute to our understanding of the trajectory of domestication (Fuller and Allaby 2009; Schlumbaum et al. 2008) though this is often not a clear-cut path. For example, there are at least two main genes responsible for non-dehiscence, *sh4* and *qSH1*. Although it has now been established that seed shattering is caused by an interaction of these major genes with other genes associated with the formation of the abscission layer (Fuller 2011a; Ishikawa et al. 2010). Of the two major genes, *sh4* is found in both *indica* and *japonica* rice and has a single origin whereas this is not the case with *qSH1* (Purugganan 2010; Zhang et al. 2009). Zhang et al. (2009) posit that the non-shattering gene *sh4* was subsequently fixed by artificial selection into rice cultivars via introgression either 1) from an early partially domesticated cultivar that contained the *sh4* allele to the wild progenitors *nivara* and *rufipogon* and then back again to form the domesticates *indica* and *japonica* or 2) from distinct wild progenitors leading to distinct cultivars which subsequently introgress with each other allowing for the *sh4* gene flow. Sang and Ge (2007) also believe that introgression played an important role in the domestication of rice including *sh4* though the domestication alleles would have been fixed in the founding cultivars prior to hybridisation. Other possibilities for the genetic flow of *sh4* between *japonica* and *indica* is that the gene found in both modern cultivars was fixed in *japonica* prior to the development of *indica* in the single-origin model or alternatively, it was fixed in a proto-*indica* cultivar via introgression with *japonica* in the multiple-origins model resulting in *indica* (Fuller and Qin 2009; Fuller et al. 2010).

Introgression has played an important role in the history of rice and shows the close contact between *indica* and *japonica.* A gene found in both *japonica* and *indica* suggesting allelic flow between species is the *Rc* gene responsible for the white pericarp, another single origin mutation originating from *japonica* and flowing to *indica* (Purugganan 2010; Sweeney et al. 2007). That this intraspecific introgression took place with the intent of the farmers cannot be discounted because it is often the case that certain traits are desired by groups of people. This is the case of genes selected for diversification traits as a result of cultural preferences. For example, the main genetic determinant responsible for fragrance *BADH2* (*frg)* is found only in some rices (the aromatic group including basmati and jasmine) and was actively selected for independently by ancestral farmers on multiple occasions in different geographic regions (Kovach et al. 2009; Prathepha 2009). The *waxy* gene is responsible for sticky rice varieties in *japonica* rice though the degree of stickiness is variable. The origins of sticky rice probably lie in China along with sticky millets and travelled south into Southeast Asia (Fuller and Castillo in press) although Purugganan (2010) has argued in favour of peninsular Southeast Asia as the origin. Sticky or glutinous rices are popular in East and Southeast Asia but are not found beyond the Assam region (Sharma et al. 1971). The sticky/non-sticky rice geographical division is clearly caused by cultural food preference, which is argued to correlate with a broader set of deep historical differences in cooking (Fuller and Rowlands 2011). The same areas where one finds sticky rice, one will also find other sticky crops such as sticky maize and millets (Sakamoto 1996). We still do not know when rice was made sticky. The aDNA study presented below attempted to find the *Wx* gene in prehistoric rice but unfortunately it yielded no results.

Another issue on rice widely discussed by geneticists is whether the wild progenitor was *Oryza nivara* or *Oryza rufipogon* (Sang and Ge 2007; Sweeney and McCouch 2007). Domesticated rice exhibits qualities derived from both wild species. *O. nivara* is an annual species preferring dryland habitats, is photo insensitive and self-fertilising. Whereas *O. rufipogon* is a perennial species better adapted to wetlands, is photo sensitive and cross-fertilising. *O. sativa* is annual and self-fertilising like *O. nivara* though domesticated rice varieties also grow in deep water and are mainly photo-sensitive (Sang and Ge 2007). Examples of photo-insensitive *O. sativa* rices are mostly *aus* and tropical *japonica* rices (Fuller and Castillo in press, Table 1). Cheng et al. (2003) propose that there are two distinct maternal lineages for *indica* and *japonica*; in other words, the two rice cultivars are derived from different wild rice strains namely perennial *O. rufipogon* and annual *O. rufipogon*. Annual *O. rufipogon* is synonymous with what other geneticists refer to as *O. nivara* (Sharma and Shastry 1965). It is proposed by Fuller (2011) that a proto-*indica* evolved from the continuous exploitation of the wild progenitor *O. nivara* whereas *japonica* was derived from *O. rufipogon* (see Figure 9.10). The development of *indica* took place through the hybridisation of proto-*indica* with *japonica*. It is due to introgression events that the *O. sativa* varieties demonstrate such a large degree of variability in their characteristics but also have shared genes of single origin. As mentioned above, many genes such as *rc* (white pericarp) and *badh2.1* (fragrance) that have been demonstrated to have a single origin can be found in both *japonica* and *indica* because of introgressive hybridisation (Kovach et al. 2009).

In my view, the studies concluding two centres of domestication as well as two distinct wild progenitors are to be preferred. Although, there might be more than two since the domestication of *aus* rice is yet to be determined.

Ancient DNA / Archaeogenetics

DNA amplification remains an issue for ancient DNA studies due largely to preservation issues. DNA degradation is especially high in hot and wet climates. Also, sunlight, water in the soil and acidic pH levels can damage DNA. DNA survives best under cool, dry, dark, anaerobic and slightly alkaline conditions which is why caves make good locations to sample aDNA (Bollongino et al. 2008; Schlumbaum et al. 2007). Desiccated plant material also make good samples (Bunning et al. 2012). On the other hand, it has been observed that charred remains to not make the best samples for archaeogenetic studies and their success rate is dependent on the extent of the charring (Palmer et al. 2011).

To date, there have been no published aDNA studies on rice from prehistoric sites in Thailand. However, in 2012, Dr. Katsunori Tanaka from the Faculty of Humanities in

Hirosaki University conducted the first genetic study of rice from two prehistoric sites in Thailand. The following section is a summary of the results sent to me by Dr. Tanaka on the 141 archaeological grains and fragments of rice I sent him for this study. The working hypothesis was that the rice remains from the prehistoric sites used in the aDNA study were *O. sativa japonica* and not *indica.* The preliminary results based on electrophoresis show that the chloroplast genotypes in the samples are *japonica.* This is ground-breaking work as it provides further proof to my working hypothesis of the late arrival of *indica* rice in Thailand, probably during the historic period.

Rice caryopses and fragments from Northeast Thailand, BNW and NUL, and Southern Thailand, KSK and PKT, were sent for aDNA analysis. Sample sizes are found in Table 9.7. The samples from KSK and PKT are from the Iron Age period dating to *ca.* 400-100 BC and *ca.* 200 BC to the first centuries AD, respectively. The two samples from Ban Non Wat are from the Late Bronze to Early Iron Ages based on AMS dates (Table 9.7). The samples from the other Thai site, NUL, were handpicked by the excavators during fieldwork and also came from a secure context. The site has been dated and belongs to the Iron Age, from *ca.* 200-300 BC up to the middle of the first millennium AD (Higham et al. 2007) and the NUL samples comes from a pit in layer 4 which was full of carbonised rice and a rice grain was AMS dated to 1650±70 BP Wk-562 (cf. Higham et al. 2007).

Sample	Laboratory Reference No.	Radiocarbon Age BP	Calibrated Age (2σ)	δ13C (‰)	Period*
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					

Table 9.7: AMS dates of rice grains from Ban Non Wat.

Extraction of aDNA from the samples was variable and the samples from sites located in the south of Thailand had much lower success rates than those from the Northeast, BNW and NUL (Table 9.8). This could reflect different charring conditions, in particular temperatures of less than 200°C under anaerobic conditions (Threadgold and Brown 2003). The lower success rate of aDNA extraction at KSK and PKT could also reflect the much higher humidity levels which deteriorate DNA, where these sites are located.

sample	no. of grains	success rate
bnw k500 4:2 GEN	20	80%
bnw k500 4:5 GEN	18	94%
bnw v200 7:3 Δ2	20	85%
bnw v200 7:4 Δ27	30*	80%
ksk07 tp57 us16	18*	61%
nul 105	20	100%
pkt09 s7 us5	15*	40%

Table 9.8: Number of grains from the sites Ban Non Wat, Khao Sam Kaeo, Noen U-Loke and Phu Khao Thong sent for aDNA fingerprinting together with the extraction success rate. The symbol * signifies rice grain fragments were sent.

Modern rice accessions were analysed for comparative material (20 *O. indica* and 15 *O. japonica*). The chloroplast sequences of both *indica* and *japonica* subspecies and the nuclear sequences of chromosomes 6 and 7 (Ch6 and Ch7), the waxy gene and *Rc* gene (responsible for white pericarp) which are registered in the National Center for Biotechnology Information (NCBI) in the US were also used to compare with the prehistoric rice samples. The aDNA extraction and amplification methodology followed was Tanaka et al. (2010). Four primer sets in the chloroplast genome to determine whether prehistoric rice was either *indica* or *japonica* were amplified and sequenced in the following regions: *Orf100, PetN-TrnC, Rp114-Rp116* and *Rp116*. Figures 9.11 to 9.13 show the PCR amplifications and sequence analyses done in these regions demonstrating that the samples from Noen U-Loke and Ban Non Wat have the same sequence as modern *japonica*. Out of the 108 samples from these two sites, eighty-six shared the same chloroplast genome as modern *japonica*, the others did not produce results either way. Out of the thirty-three samples from KSK and PKT, seventeen shared the same chloroplast genome as modern *japonica*, the others did not produce results either way.

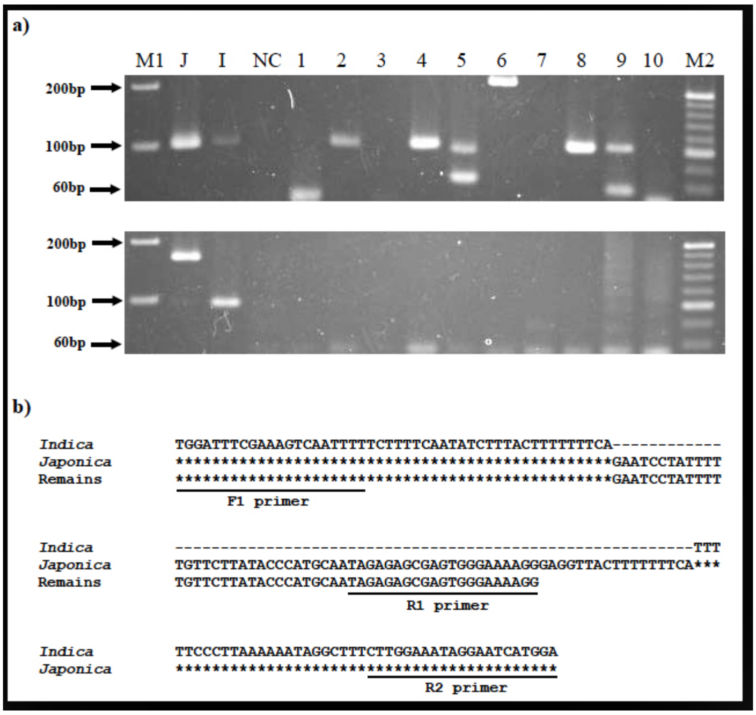


Figure 9.11: PCR amplification for the chloroplast genome region *Orf100* and the sequence analysis.

a) M1: 100bp DNA Ladder, M2: 20bp DNA Ladder, J: modern *japonica,* I: modern *indica,* NC: negative control, numbers 1-10 represent remains from Noen U-Loke.
b) Sequence detected in *indica, japonica* and archaeological remains from Noen U-Loke. Remains represent 2,4,5,8 and 9. "-" symbolises a gap whereas "*" shows identical sequencing to *indica.*

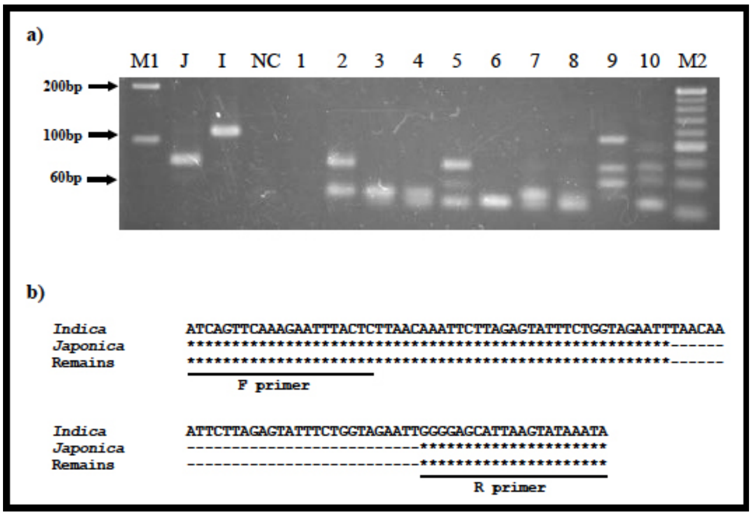


Figure 9.12: PCR amplification for the chloroplast genome region *PetN-TrnC* and the sequence analysis.

a) M1: 100bp DNA Ladder, M2: 20bp DNA Ladder, J: modern *japonica,* I: modern *indica,* NC: negative control, numbers 1-10 represent remains from Noen U-Loke.
b) Sequence detected in *indica, japonica* and archaeological remains from Noen U-Loke. Remains represent 2,5,9 and 10. "-" symbolises a gap whereas "*" shows identical sequencing to *indica.*

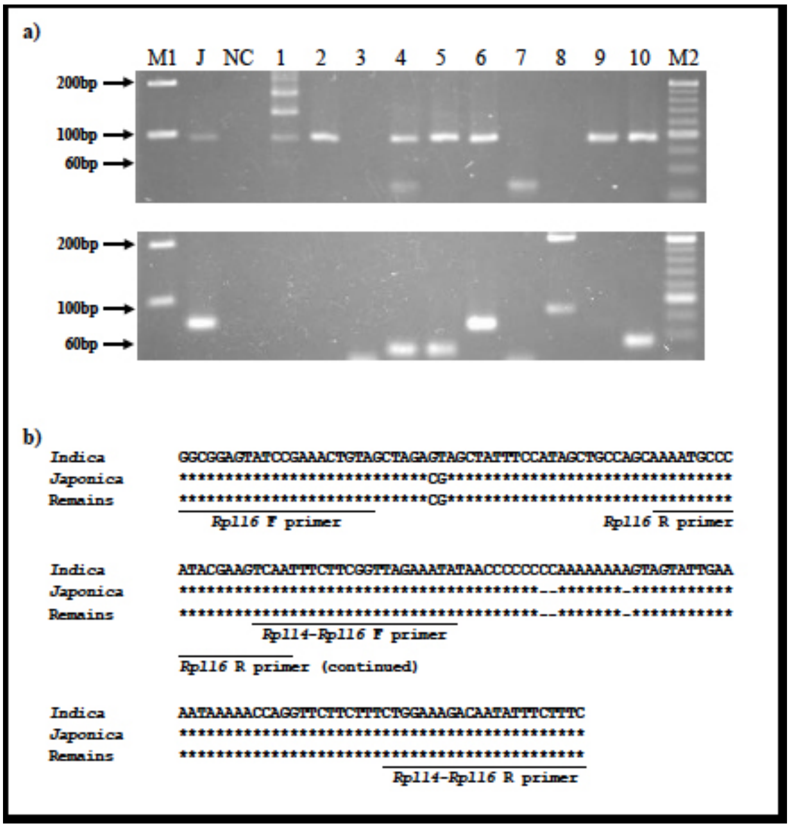


Figure 9.13: PCR amplification for the chloroplast genome region *Rp114-Rp116* and *Rp116;* and the sequence analysis.

a) M1: 100bp DNA Ladder, M2: 20bp DNA Ladder, J: modern *japonica,* NC: negative control, numbers 1-10 represent remains from Ban Non Wat K500.
b) Sequence detected in *indica, japonica* and archaeological remains from Ban Non Wat. Remains represent 1,2,4,5,6,9 and 10. "-" symbolises a gap whereas "*" shows identical sequencing to *indica.*

The six markers used in the nuclear genome sequencing were *qSh1, Sh4, Waxy,* Ch6, *Rc* and *Acp1.* The nuclear genome sequence analysis conducted on the archaeological samples in the Ch6 region showed that eighty-six grains shared the same genetic background as temperate *japonica,* tropical *japonica* and inter-mixed type of tropical, temperate *japonica* and *indica.* Out of the eighty-six archaeological samples, twenty-three were both temperate and tropical *japonica* shared sequences or heterozygous. The results derived from the sequencing of the *Waxy* and *Rc* gene were not as conclusive and therefore, the study was not able to characterise the samples as either sticky or non-sticky, white or red. Further analysis was conducted by Tanaka on the genes responsible for non-shattering, *qSh1* and *Sh4.* Only five of the samples (one from NUL and PKT each and three from BNW V200 7:3 Δ2) were successfully sequenced using SNP polymorphism but the results showed that the *Sh4* gene is the same as the modern rice cultivars suggesting domesticated rice.

This aDNA study by Tanaka is an important body of work as it allows both archaeologists and geneticists working on modern material to prove or disprove their theories on origins. It also demonstrates that given good preservation of plant remains enough aDNA can be extracted and analysed. In the case of NUL, the preservation of the rice grains may have been good because they were concentrated in a pit and when the burning occurred, the grains smouldered. NUL#105 belongs to the Iron Age 3 (IA3) period dating to *ca.* 200-400 AD (Higham 2011b). Graves and pits of this period at NUL were sometimes lined and sealed in clay (*ibid.*). It is not clear how these rice grains were preserved and although unconfirmed, perhaps the pit they came from was similarly lined with clay keeping the prehistoric rice grains cool, dry and dark. At BNW, it is possible that the archaeological rice remains were preserved by the hard floors and annexed burials. BNW V200 7:3 Δ2 lies in trench V200 where very hard floors often described as industrial by Dr. Nigel Chang (unpublished excavation report) were found. Trench K500 where sample BNW K500 4:2 GEN comes from has water features though there were also burials found.

The above results were based on chloroplast and nuclear genome sequencing. It was found that the genetic make-up of most of the archaeological samples (58 of n=60) shared a similar background as modern rice. The chloroplast genome sequence of the archaeological samples indicated *japonica*-type rice whereas the nuclear genome sequence revealed both temperate and tropical *japonica.* In the following section, morphometric analysis of archaeological rice from NUL and BNW provide similar results as the aDNA study and show predominantly *japonica*-type L/W ratios.

Morphometric analysis in relation to the aDNA study

The morphometric analyses of rice grains from four Thai archaeological sites dating to the Bronze and Iron Ages (Ban Non Wat, Khao Sam Kaeo, Noen U-Loke and Phu Khao Thong) suggest that rice in prehistoric Thailand was *Oryza sativa japonica* (Figure 9.14). As discussed earlier, once the domestication status of rice is established through the analysis of the spikelet bases, morphometrics can be used to indicate to which domesticated subspecies the archaeological rice approximates.

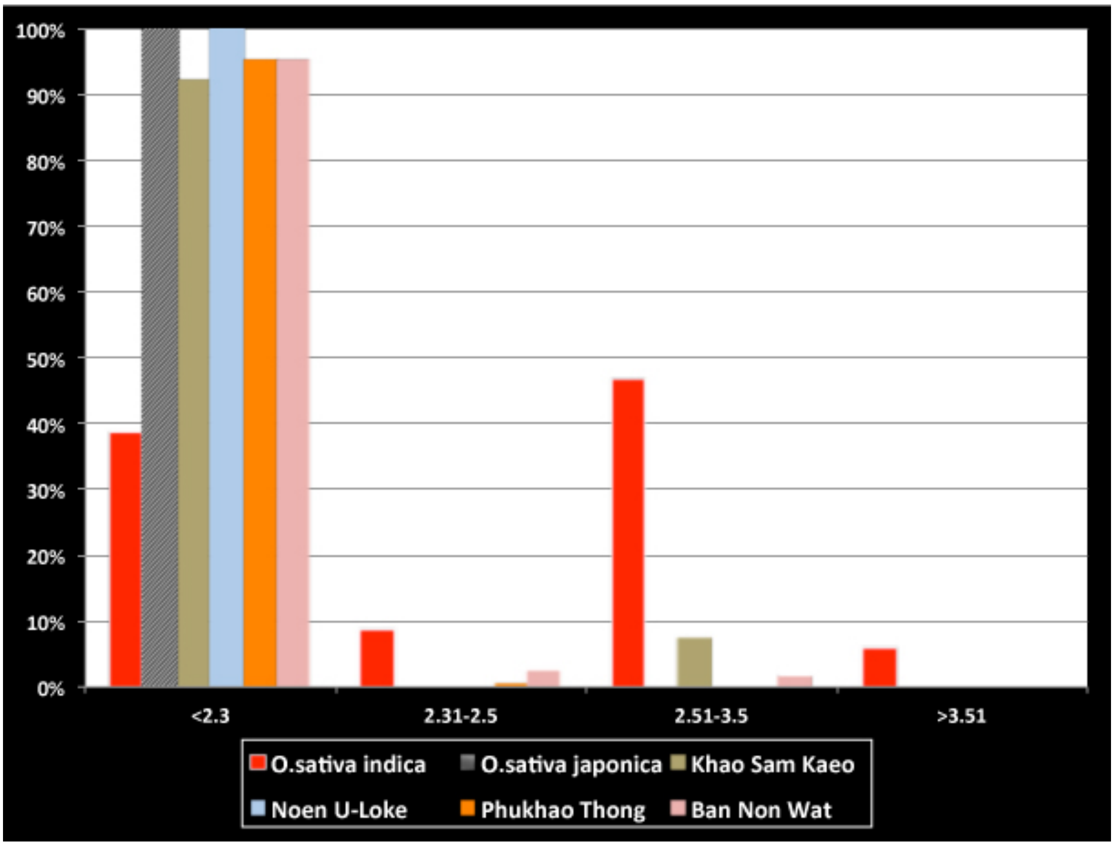


Figure 9.14: Comparison of L/W ratios of rice from four prehistoric sites in Thailand to modern populations of domesticated and wild rice. (Modern population measurements after Fuller et al. 2007; Harvey 2006).

Because of the wide variation in the size and proportions of wild rice, Fuller et al. (2007) believe that the use of morphometrics as an identification ratio does not work if the result sought is whether rice is domesticated or wild. However, if the domestication status of rice is already established, then morphometric studies can provide some useful indications to what subspecies the rice belongs. In this study, the length-width (L/W) ratios of the archaeological rice grains were compared with those of modern populations of domesticated and wild rice. According to Ahn (1993), L/W ratios are not affected by charring so ancient and modern rice should therefore be comparable. *Indica* rice normally has a L/W ratio above 2.5 whereas *japonica* rice is below 2.3 (Fuller et al. 2007b), although some tropical japonica long-grained rices are an exception and would be more *indica*-like. This morphometric analysis together with the aDNA study presented above provide a strong case that the Chinese rice subspecies *japonica* was being consumed and cultivated by at least *ca.* 1050-420 BC and up to *ca.* 200-400 AD in Northeast Thailand and *ca.* 400-100 BC in the southern Peninsula. One can further infer that rice found in Thailand in earlier periods if domesticated would also have been *japonica*. Also, the morphometric analysis above indicates that during the Late Prehistoric period *japonica* was the type of rice found across Thailand. But several questions arise: When did *indica* become the dominant rice variety; what agricultural regime was practiced in prehistory (wetland vs. dryland cultivation); was the cultivation technique also brought in with the introduction of rice or was it a local innovation? Some of these questions will be addressed later in this dissertation.

9.7 NEW VIEWS ON THE SPREAD OF RICE

I use my work in three sites (KSK, PKT and BNW) and the published data from four other sites (Khok Phanom Di, Non Pa Wai, Non Mak La and Nil Kham Haeng) to interpret the evolution of rice in prehistoric Thailand through cultivation systems and the type of rice cultivated. Furthermore, a summary of the results from the charring experiments of cereals is provided to show that preservation biases exist and should be considered in discussions. The full analysis of the charring experiments including pulses is found in Chapters 5 and 8.

Cultivation systems and weeds of cultivation

Today *indica* is the dominant rice type and rainfed cultivation is the main agricultural system practiced in Thailand. Table 9.9 shows the different cultivation practices in Thailand, India and China in 1987, with 62% of the land used for rice cultivation in Thailand being rainfed compared to only 5% in China. Cultivation today is mostly in the lowlands with bunded fields that retain rainwater and allowed to dry naturally. The fields are inundated during part of the growing season. Together with irrigation, this cultivation system falls under wetland agriculture and the rice is planted either by broadcasting or transplanting.

	irrigated	rainfed	deepwater	upland
China	93	5	*	2
India	44	35	6	15
Thailand	27	62	8	3

Table 9.9: Different cultivations systems in percentages in 1987 (Source: IRRI World Rice Statistics 1991).

Rainfed systems of cultivation were most likely also practiced during prehistoric times though probably not in bunded fields. This system of cultivation is dryland though if found in elevated areas such as hills it is called upland. Upland rice cultivation can be found in low-lying valley bottoms as well as steep sloping lands and transplanting is never used. Dibbling with a stick or broadcasting are normally the planting methods used. As discussed in Chapters 6 and 7, the rice found at both KSK and PKT were from dryland and not wetland cultivation (i.e. irrigated or rain-fed lowland bunded). However, White (1995) proposes that in Thailand both wetland and dryland rice cultivation evolved from inundated rice cultivation (décrue), a less labour-demanding technique than irrigated cultivation. Though this appears to be the case of the low-lying coastal site Khok Phanom Di during the Neolithic where rice cultivation at a nearby swamp is believed to have been dependent on natural flooding (Thompson 1996), this does not seem to be the case for KSK or PKT since one would expect a suite of wetland weed species to be present in the archaeobotanical assemblage (Weisskopf et al. 2013) and this is clearly not evident. That different cultivation systems existed in prehistoric Thailand is plausible and reasonable.

Weeds in an archaeological assemblage can serve several functions (Bogaard et al. 1999; Colledge 1994; Colledge et al. 2005; Fuller and Qin 2009; Jones 2002; Kealhofer and Piperno 1994): 1). Weed flora has been used by archaeobotanists to define systems of land use and cultivation practices. To investigate the type of cultivation systems in place, modern agricultural fields have been examined for weeds that occur together with crops. In particular, the weeds of rice have been reported in several publications specifically identifying the ecosystem to which they belong (Galinato et al. 1999; Moody 1989; Soerjani et al. 1987). More recently, phytolith studies have proven useful in identifying cultivation systems through the study of weed flora associated with rice (Weisskopf et al. 2013). For example, wetland rice agriculture is generally dominated by phytoliths from hydrophilic species (*ibid.*). The occurrence of specific morphotypes in an archaeological assemblage helps infer cultivation practices in the past. 2) Weeds are also important determinants of habitats because some species occur in certain ecological zones. However, weed assemblages are affected by many factors including forming part of habitats that may seem like natural primary habitats at present but in reality occur due to human disturbance (Colledge 1994). This sometimes makes it difficult to determine with certainty if the weed flora in a certain area were indigenous or introduced by humans. 3) Weeds are also translocated with particular crop packages and this could help signify a point of origin. 4) The presence of certain weeds with crops also helps identify the crop processing stages.

The examination of weed flora in the archaeobotanical assemblage has been applied mainly in Europe though there are some Southeast Asian sites where it has also been used such as in the KWPV sites. Unfortunately, macroremains from the KWPV sites (Nil Kham Haeng, Non Pa Wai and Non Mak La) dating to the Bronze Age do not contain sufficient numbers of weed seeds to define the rice agricultural regime and such weed seeds as are found provide ambiguous results. Sedges normally associated with wetland rice as well as dryland weeds such as chenopods are found in the samples with rice (Weber et al. 2010). Although prior to rice cultivation, millets were being cultivated in dryland conditions potentially signifying a continuum in the cultivation practice for rice in the area.

The site KSK in Peninsular Thailand (*ca.* 400–100 BC) is strategically located between the Indian Ocean and the South China Sea and provides evidence of Indian, Han Chinese and locally produced cultural material (Bellina et al. in preparation; see Chapter 6). The archaeobotanical assemblage also attests to South Asian and East Asian influence: the mungbean and horsegram of Indian origin and the northern Chinese cereal foxtail millet. But the site has also yielded the greatest amount of rice yet from a Thai archaeological site and provides information on the domestication of rice and the cultivation practices during this Late Prehistoric period. At KSK, the majority of the weed assemblage comes from dryland habitats. This is discussed at length in Chapter 6. The predominant weed is *Acmella paniculata* belonging to the Asteraceae family. It is significant in that 93% of the samples with rice contained this weed representing a high level of co-occurrence. Furthermore, *Acmella paniculata* is reported to be a weed of rice throughout Indonesia, Bangladesh, India, Philippines, Sri Lanka and Thailand (Moody 1989) found in rainfed and upland fields (Soerjani et al. 1987). The other crops found at KSK, such as foxtail millet and the mungbean, are also indicative of dryland cultivation systems, are drought resistant and found mainly in upland cultivation systems. Accordingly, it is clear from the weeds and other cultivars that the rice cultivation system at KSK was dryland.

A similar assemblage of pulses and weeds associated with rice at KSK is also found at PKT, also belonging to the Metal Age. Again, the predominant weed species occurring with rice in PKT is *Acmella paniculata.* This is fully discussed in Chapter 7. Preliminary identifications of the weed assemblage from the Bronze Age period at BNW in northeast Thailand also indicate dryland cultivation. The weed *Acmella paniculata* is found in 73% of the samples with rice. It appears that rice cultivation in Thailand during the Bronze Age and Metal Age was rainfed and dryland. As a point of comparison, a geomorphological study in Kedah situated in the Thai-Malay Peninsula hypothesises communities in the first millennium AD being dependent on dryland cereal cultivation and not irrigated rice agriculture (Allen 1991).

The cultivation practices inferred from prehistoric sites in Thailand and one in the Thai-Malay Peninsula discussed above differ from the lowland paddy field agricultural system that was in place at the centre of origin in the Lower Yangtze when rice spread outwards to other regions *ca.* 4000 BC (Fuller and Qin 2009; Fuller and Weisskopf 2011; Weisskopf et al. 2013). This difference may be because wetland paddy field agriculture in Thailand developed later. Although the earliest paddy field agriculture is found in China, it is during the first millenium AD that *Oryza indica* together with wetland systems of cultivation may have been introduced into Southeast Asia from India as a result of exchange networks. In the Neolithic, dryland weeds dominate the archaeobotanical assemblages in north India (Weisskopf et al. 2013). However, the expansion of rice agriculture in India occurs during the Iron Age and is linked to labour-intensive irrigated rice cultivation (Castillo and Fuller 2010; Fuller and Qin 2009; Shaw et al. 2007). It seems likely that during the early contact period with South Asia (*ca.* 400 BC), Thailand already had an established rice agricultural regime primarily focused on dry cropping in low lying areas and hills and the rice grown as has been shown through morphometric and aDNA studies was *japonica*. This accords well with ethnographic traditions for the importance of upland tropical *japonica* throughout Southeast Asia (Nozawa et al. 2008; Roder et al. 1996). Whereas the archaeobotanical studies in the Middle Yangtze show that wet rice farming was in place since the Neolithic, in the Yellow River Valley, northern China the evidence points towards dryland cultivation with foxtail and broomcorn millets being the dominant crops (Weisskopf et al. 2013). However, once rice agriculture becomes widespread in the Yellow River *ca.* 3000 BC, wetland rice is reported (Fuller et al. 2010). In Thailand, specifically in the KWPV, millets together with dryland farming techniques may have been brought in from a northern route though exactly when and what route was followed remains to be found. It is also likely that domesticated rice was a late addition to an already established dryland system of cultivation and it was this system of cultivation that continued to expand to more southern parts of Thailand, including KSK and PKT. The data assembled as part of the present study support the conclusion that dryland rice cultivation was practiced. This implies that it was after continuous contact with India that wetland systems of agriculture were developed.

Caveats: preservation bias

Rice is the most commonly reported archaeobotanical find in Thailand. This is not surprising because unlike other macroremains, rice is easy to recognise. The grains are large enough to be found with the naked eye, whereas the retrieval of finer fraction (e.g. millets) requires the use of flotation. Rice also has distinctive phytoliths (e.g. bulliforms). Also being now the most important economic crop in Southeast Asia, scholars have dedicated more effort in the search of prehistoric rice to clarify its history and that of the people that consumed and produced it and have therefore reported more finds than for other cereals.

At several excavations in Thailand where I have worked as the on-site archaeobotanist, I have found that rice is the most common crop in the samples floated. This pattern leads one to presume that rice was the most important economic crop in prehistory, just as it is today. However, preservation biases must be considered. The lack of substantial evidence of millets in Southeast Asia has been attributed to preservation issues, for example (Weber et al. 2010; Weber and Fuller 2008). The charring experiments using real fire instead of a muffle furnace suggest that hulled rice grain does preserve better than some of the small millets, foxtail and broomcorn. Rice also has even greater visibility than the two small millets when the husk is taken into account. In comparison to *Panicum miliaceum* (broomcorn millet) and *Setaria italica* (foxtail millet), hulled rice is easier to recognize than each of the millets in charring experiments.

ratios	1A	1B	1C	1D	2A	2B	2C	2D	4A	4B	4C
hulled rice: hulled foxtail millet	100:7	100:92	100:83	no rice no foxtail	8:100	100:70	100:29	100:25	-	-	-
hulled rice: hulled broomcorn millet	100:50	100:87	100:17	no rice 1 broomcorn	100:100	100:63	100:23	100:19	-	-	-
rice husk: foxtail millet husk	12 rice husk fragments no foxtail husk	100:15	100:33	8 rice husk fragments no foxtail husk	100:9	100:14	100:14	100:8	-	-	-
rice husk: broomcorn millet husk	100:8	100:26	100:11	8 rice husk no broomcorn husk	-	100:58	100:21	100:18	-	-	-
naked rice: naked foxtail millet	-	-	-	no rice 6 foxtail	-	-	-	-	no rice 3 foxtail	no rice 1 foxtail	no rice no foxtail
naked rice: naked broomcorn millet	-	-	-	no rice 15 broomcorn	-	-	-	-	no rice 14 broomcorn	no rice 1 broomcorn	no rice 2 broomcorn

Table 9.10: Twenty-five grains of each cereal were used in all the experiments. Fires were fed for 3 hours with the highest temperature reaching 900ºC. All cereals were hulled in Ex1, Ex2 and Ex3. In Ex1, the cereals were in the fire for an hour longer than Ex2 and Ex3. All cereals were naked in Ex4.

Although details of these charring experiments are discussed in Chapters 5 and 8 (summarised on Table 9.10), the main conclusions are as follows: all three cereals preserve better when hulled; and rice disintegrates to an unidentifiable state when naked grains are charred (experiments 4A, 4B and 4C). In at least 6 out of eight experiments, the preservation of rice (excluding husk but including spikelet bases) compared to the millets was higher. In all the experiments where hulled cereal was used (experiments 1A to 2D), rice husks preserved better than the husks from the millets. These experiments lead me to believe that if hulled rice or the waste products after dehusking happened to come into contact with fire in prehistory, they would have a higher chance of preserving than remains of the two millets referred to above. The archaeological record shows that *ca.* 67% of reported rice in Thailand are rice husks or rice impressions (Fuller et al. 2010 on-line supplement). Though these are mostly found in pottery and not necessarily from floated material. In my own work at KSK, rice spikelet bases comprise 76% of the rice assemblage and 11% of the entire assemblage.

It appears that at least in the Bronze Age in the KWPV, millets were the dominant cereals and were cultivated before rice (Weber et al. 2010). Perhaps the reason why millets in this area are archaeologically visible is because flotation was used. In order to verify this conclusion what is needed is to continue gathering samples for flotation from more sites spanning hunter-gatherer sites to the proto-historic periods across the whole of Thailand.

9.8 CONCLUSION

There is no doubt that more archaeological and archaeobotanical work needs to be carried out across Thailand as well as in the neighbouring countries in order to refine the history of rice agriculture in the region. More aDNA studies are also needed in order to confirm hypotheses postulated and analyses limited in scope, such as morphometrics. In this chapter, I have outlined what is known so far about prehistoric rice in Thailand and used an archaeobotanical approach to qualify what information can actually be inferred from these data. I have also presented the results from the first aDNA study conducted on prehistoric rice in Thailand and this supports the morphometric analysis confirming the existence of *japonica* rice but not *indica* from the Bronze Age to the Iron Age in the northeast and southern Thailand.

I have also presented a new hypothesis of rice dispersion which indicates the Indian subspecies *indica* to arrive in Thailand at a later period in the first centuries AD than during the first contacts between India and Thailand. So it is not always the case that the spread of domesticated crops happens at the same time as the migration or movements of people, especially when the people traveling, as is the case in Khao Sam Kaeo, are craftsmen or traders. Perhaps the transient status of the craftsmen and traders from India in this early period did not allow for a whole new cultivation system to take place and maybe this occurs once there are permanent settlers. It also follows that perhaps there was no need for a different variety of rice to be brought in because local cultivation of *japonica* was already in place. However, the craftsmen did take with them Indian pulses and perhaps this demonstrates a preference for certain foods (see discussion in Chapters 6 and 7).

The presence of rice, its domestication status, varieties and cultivation practices all contribute to the understanding of the origins and movements of rice. However, we should also take into consideration that other domesticates, including millets, may have been the precursors to rice and how this contributes to our understanding of the people that settled or migrated to Thailand.

CHAPTER 10
Conclusion

10.1 SUMMARISING THE LATE PREHISTORIC SUBSISTENCE REGIME IN PENINSULAR THAILAND

It took five years to excavate Khao Sam Kaeo and a further four years to complete the analysis and interpretations of the site. During the last years of fieldwork, it was difficult to find viable undisturbed locations to excavate. However, those excavations which were viable, yielded a large corpus of material that permitted an understanding of the social, cultural and economic elements that constituted an early urban centre involved in an exchange network that spanned the Bay of Bengal and the South China Sea. Phu Khao Thong, on the other hand, was studied from survey material collected during two field seasons and the archaeobotanical analysis presented in this study. The archaeobotanical remains from PKT were surprisingly rich and, as at KSK, has provided information on the social and economic character of an entrepôt during the Late Prehistoric Period in the Thai-Malay Peninsula. In combination, these two sites provide information for a period during which intensified foreign contact with South Asia, China and other Southeast Asian areas took place. The evidence suggests that contact was primarily through trade. However, initial contacts were probably a result of explorations and embassies such as those recorded in the Chinese annal *Ch'ien Han Shu* (Wheatley 1961). Chinese explorations were in all likelihood politically motivated as is evidenced by the eventual absorption of Yunnan, Guangxi and Guangdong provinces, and parts of Vietnam (the Red River Delta), into the Han Empire (Higham and Thosarat 2012).

The archaeobotanical studies conducted in the sites Khao Sam Kaeo and Phu Khao Thong have contributed to the understanding of subsistence, agricultural practices, exchange and evolution of agriculture in Peninsular Thailand during the Late Prehistoric Period. The local population was engaged in craft production, trade and agriculture. Foreign populations also engaged in craft and/or trade, making the Thai-Malay Peninsula their permanent or temporary home. The agricultural base that supported the populations at KSK and PKT was rice. However, other cultivars such as pulses formed part of the subsistence regime. The present study dedicated a chapter to rice as it was the staple cereal. As was demonstrated at both sites through morphometric studies rice was the Chinese domesticate *Oryza japonica.* The first genetic study on ancient Thai rice was conducted in relation to this study confirming *japonica* rice in both sites. Furthermore, the lemma apices recovered from both sites showed that they would have been awned, a morphological trait normally associated with wild rice and with some domesticated rices, such as tropical *japonica* rices. Since the domestication status for rice was established using the largest dataset so far available in Southeast Asia of rice spikelet bases, it was considered that rice in KSK and PKT was domesticated tropical *japonica.*

Arable farming at KSK and PKT was dryland cultivation. Because tropical *japonica* is normally cultivated in dryland regimes, the possible identification of tropical *japonica* accords with the inferred cultivation system of KSK and PKT. The main indicator of a dryland cultivation system in KSK and PKT was the weed assemblage. It contained predominantly dryland species that are known to co-occur with rice. It is a possibility that swidden cultivation took place in KSK and PKT since the weed *Acmella paniculata* (para-cress), which is found in both archaeobotanical assemblages, is normally found in modern swidden agricultural fields but not in wetland systems. However, *Acmella paniculata* is still widely consumed throughout Thailand and other Southeast Asian countries as a vegetable and may also have formed part of the local diet in prehistory. Another cultivar found in both sites, *Vigna radiata* (mungbean) is a pulse also commonly grown in dryland cultivation systems. In fact, most of the pulses found in KSK and PKT grow in dryland cultivation systems.

There were several species of cultivars found that demonstrated links with foreign groups, predominantly with South Asia. As has been demonstrated, mungbeans formed part of a crop package introduced from South Asia which included other pulses, such as horsegram and black gram. These pulses have also been hypothesised to represent particular social groups in South Asia and have been used to infer that different social groups from South Asia were represented in KSK and PKT. Furthermore, social and cultural meanings ascribed to food may have affected the adoption or lack of adoption of certain foreign crops. For example, horsegram which was not adopted by the local populations in the Thai-Malay Peninsula, is considered a poor man's pulse and it does not make good bean sprouts. Bean sprouts are an important and preferred Southeast Asian way of eating beans nowadays. If certain eating and cooking habits were important to local populations, this would have influenced decisions on which crops to adopt.

Trade was best seen in both sites by the existence of cash crops, particularly the spice long pepper, cotton and sesame. Several spheres of influence and contact from South Asia, East Asia and Insular Southeast Asia helped shape the identity of the sites KSK and PKT into areas where cross-cultural interactions took place and ideas, technologies and goods were transmitted. From the archaeobotany, KSK and PKT had very similar subsistence resource bases although the location of PKT on the west coast results in more foreign crops, including the African crops finger millet and hyacinth bean. Whilst these were introduced into Thailand at this early period they did not necessarily become part of the local diet. Indigenous crops were also found in both sites such as rice bean and citrus which are native to Southeast Asia. Rice bean may have been domesticated in Thailand and further research will verify this. The presence of citrus rind demonstrates that arboriculture was also part of the cultivation regime in both sites.

From the examination of the archaeobotany of these two sites, we now know that wetland rice agriculture was not introduced to the Thai-Malay Peninsula in the Metal Age. It is posited, in this dissertation, that wetland rice agriculture (of *indica* rice) was introduced with sustained Indian contact possibly in the middle of the first millennium AD. Furthermore, there were probably other factors, including demographic pressure, religious and political changes that also caused a change of agricultural regime. Wetland rice agriculture is more labour demanding, but also yields higher returns. The development of city-states in the middle of the first millennium AD may signal such a shift.

10. 2 INDIANISATION and WORLD SYSTEMS

More than three decades ago, discussions on Indian contact and influence in Southeast Asia focused on highly visible Indianised evidence such as Hindu and Buddhist architectural monuments and icons. The evidence of this Indian contact dated to the middle of the first millennium AD when 'Indianisation' was well established. As archaeologists sought an explanation for the transfer of elements of Indian culture to Southeast Asia, the origin of 'Indianisation' became a line of enquiry (Glover 1996; Manguin 2011). More recently, archaeologists discuss the flow of technologies, information and products taking into account local population agency and not just foreign agency, whether Indian or Chinese (Bellina et al. in preparation; Dzung 2011). It is now generally accepted that the formative or 'pre-Indianisation' period dates from the fifth century BC to the fifth century AD (Manguin 2011). The earliest dates were largely determined through work done at sites in the Thai-Malay Peninsula including Khao Sam Kaeo and Phu Khao Thong, and the central Thai site Ban Don Ta Phet, where the first traces of Indian contact and trade can be documented. However, the early exchange networks which also include China and Southeast Asia, demonstrate the extent and complex nature of trade taking place in the region, with production from all three regions (India, China and Southeast Asia) supplying prestige and symbolic items, but also common ware.

Trading centres were established along the coast of the Thai-Malay Peninsula, such as the entrepôts KSK on the east and PKT on the west coast. KSK was a substantial urban settlement of approximately thirty-four hectares and PKT formed part of a complex of trading sites. In this study, both are believed to have played a role in the management of distribution networks, especially along trans-peninsular routes. Furthermore, these locations on either side of the Peninsula were strategic since they were main points of entry and/or exit of goods flowing from the Bay of Bengal and the South China Sea. Sites engaged in trade must have benefited from the accumulation and flow of these goods (Higham and Thosarat 2012). According to Jacq-Hergoulac'h (2012) *'the main feature of their* (the chiefdoms in the Malay Peninsula that evolved to become city-states) *prosperity lay almost exclusively in their ability to receive commercial ships from every corner of Asia, in several different entrepôt ports*.'

As presented in the Introduction, 'world-systems' was used as the theoretical framework to examine the two sites, KSK and PKT, in relation to Asian trade networks. In the period that concerns us, the last half of the first millennium BC, a unified political and economic presence in the Indian Ocean did not exist and both the Eurasian and African 'world-systems' only appear in the first centuries AD (Beaujard 2005). Although 'world-systems' is normally applied to large-scale, long-distance contact, it can be argued that regional networks can also be viewed using a similar approach. In fact Chase-Dunn and Hall (1997) consider West Africa and Southeast Asia smaller world-systems that were later on incorporated into the Afroeurasian 'world-system.' 'World-systems' analysis emphasises that interaction is central to cultural and social change (Denemark et al. 2000). In Southeast Asia, the early interactions between India and the coastal polities, KSK and PKT, created the avenue for a lasting flow and exchange of economic and cultural elements which some have interpreted as 'Indianisation.' Furthermore, economic and social analysis using 'world-systems' should be considered within differing scales, and not be based on any predetermined scale such as modern political boundaries (Bevan 2007; Chase-Dunn and Hall 1997; Feinman 1999; Hall et al. 2011). Chase-Dunn and Hall (1997) contend that *'small stateless and classless systems also can be studied meaningfully with world-systems concepts*.'

KSK and PKT were neither stateless nor classless. They were polities with an organised trade network. Whilst it is considered that KSK and PKT were of significant regional importance in the control and administration of trade, they were not the 'cores' in a 'world-system,' (although Chase-Dunn and Hall would call them smaller 'world-systems') but regional cores with dependent peripheries. Core dominance largely depends on the existence of division of labour, political hegemony and production of surplus goods. At KSK and PKT, evidence exists of a division of labour into craftsmen, farmers and traders. There was local fine quality goods production, such as of glass and stone beads which can also be referred to as 'luxury items,' a fixed-field agricultural base which would have played an important role in keeping the social network in operation, and a flow of foreign goods (North Vietnamese Dong Son drums, Chinese Han ceramics, Taiwanese jadeite, Indian raw materials and crops). Moreover, there was also division of labour between the core sites, KSK and PKT, and the peripheries found in the interior of the Peninsula and probably along the trans-peninsular routes. KSK and PKT produced and supplied luxury items to the peripheries, whereas the peripheries supplied raw materials and services to the cores. A current ethnographic example of what a periphery could represent in the Late Prehistoric Period is the Semang, a tribe settled in the Southern Peninsula, who exchange wild tubers for luxury items such as tobacco, rice and flour, honey for sugar, and bark cloth for cloth (Bisht and Bankoti 2004). In Wallerstein's original 'world-systems' model, this relationship would be considered asymmetric. Chase-Dunn and Hall (1997) propose that not all relationships are asymmetric in favour of the cores. In fact, Bellina et al. (in preparation) have described the relationships between KSK, PKT and interior sites as symbiotic. Finally, the political importance of KSK and PKT on a regional scale is discerned from literary sources, in particular the Chinese annal *Liang Shu,* which mentions the maritime campaign by the ruler of the Funan kingdom, Fan-shih-man, to secure the Isthmus of Kra in order to control trade in the Thai-Malay Peninsula in the third century AD. It is also the case that the Isthmus of Kra became less important when trade routes shifted from portage to circumpeninsular routes (Mudar 1999). With intensification of trade in the region, India and China emerged as the dominant cores and Southeast Asia assumed the role of periphery at least in a 'world-system' as defined by Beaujard (2005).

'World-systems' explains social interactions which transform social structures. In the case of KSK and PKT that explanation does not provide a framework to understand all aspects. 'World-systems' gives a generalised view of trade relations and how these brought about wealth accumulation and control of the Kra Isthmus by coastal polities. But 'world-systems' does not explain other important results that arose in this study. Some of these results are presented above including the development and evolution of local agriculture, and adoption of or resistance to the cultivation by local populations of certain crops, in addition to those necessary for subsistence.

10. 3 FUTURE WORK

This study has looked at the macroremains from the two sites, KSK and PKT. The original intention was also to undertake the phytolith analysis, in order to compare methodologies and to obtain information which phytolith analysis is better equipped to provide. Phytoliths might for example provide evidence of banana consumption and palm use. Phytoliths may corroborate the macroremains analysis regarding the rice processing stages. It is the intention of the researcher to complete the phytolith analysis in the near future.

Another field of future endeavour to be pursued is archaeogenetics. Chloroplast sequencing was used to determine that prehistoric rice in KSK and PKT was *japonica.* It is now hoped that aDNA applied to more archaeological rice remains from other sites from Thailand belonging to different time periods may provide a better understanding of when *indica* rice was introduced to Thailand. It is also hoped that nuclear sequencing more archaeological rice remains from KSK, PKT and other Thai sites will determine the presence of certain domestication genes such as non-shattering genes, and also genes selected for as a result of cultural preferences such as fragrance and sticky genes.

In the case of the non-shattering genes, the findings may corroborate the archaeobotanical research done with spikelet bases.

Finally, the Thai-French Mission is currently investigating sites in the interior of the Peninsula. These sites would form what are presently called 'peripheries' in this study. Part of the investigations involve the analysis of what finished goods arrived at these peripheries, possibly as status or luxury times, and what raw materials might have been supplied to the coastal sites KSK and PKT. The interactions and relationships of what has been termed in this dissertation as core-peripheries will benefit from these new archaeological discoveries.

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www.agritech.tnau.ac.in - TNAU Agritech Portal

- www.agritech.tnau.ac.in/seed_certification /seed_pul_greengram.html accessed 18/02/2013
- www.agritech.tnau.ac.in/seed_certification/seed_pul_horsegram. html accessed 18/02/2013

www.ars-grin.gov/cgi-bin/npgs/html/index.pl - GRIN Taxonomy for plants

www.data.gbif.org/welcome.htm - Global Biodiversity Information

www.database.prota.org - PROTA

www.d-maps.com - base maps

www.ecocrop.fao.org - Ecocrop

- www.ecocrop.fao.org accessed on 16/02/2013

www. econ.eldoc.ub.rug.nl - Digital Atlas of Economic Plants

www.efloras.org - eFloras

www.fao.org - Food and Agriculture Organization of the United Nations (including FAO LADA Land Use Systems Maps 2010)

- www.fao.org/ag/AGP/AGPC/doc/GBASE/Safricadata/eleucor.htm accessed on 16/02/2013
- www.fao.org/rice2004/en/p17

www.faostat.fao.org - Food and Agriculture Organization of the United Nations

www.flora.huh.harvard.edu/china -Flora of China

www.forestryimages.com - Forestry Images

www.idtools.org/id/citrus/citrusid - Citrus ID

www.irri.org - International Rice Research Institute

www.issg.org - Global Invasive Species Database

www.kew.org/herbarium/keys/fm/key.html - Interactive Key to Seed Plants of Malesia and Indo-China

www.mansfeld.ipk-gatersleben.de/pls/htmldb_pgrc - Mansfeld's World Database of Agricultural and Horticultural Crops www.maps.com - base maps

www.nationaalherbarium.nl - Nationaal Herbarium Nederland

www.ngfl-cymru.org.uk - base maps

www.plants.usda.gov/wetland.html - USDA Wetland Indicator Status

www.plantsystematics.org - Plant Systematics

www.proseanet.org/prosea/eprosea.php - Plant Resources of South East Asia

www.seeds.eldoc.ub.rug.nl - Digital Seed Atlas of the Netherlands

www.tmd.go.th - Thai Meteorological Department

www.theplantlist.org - working list for all known plants

www.web3.dnp.go.th/botany/Botany_Eng/index.aspx - Office of the Forest Herbarium

www.worldagroforestry.org - World Agroforestry Centre