Plant-related subsistence in the Pearl River Delta, Southern China, from 6,000 BP to 3,000 BP

A thesis submitted for the degree of Doctor of Philosophy

at the University of Leicester

By

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April 2020

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Thesis abstract

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In South China, there is limited evidence for prehistoric plant-related subsistence practices, due to poor macrofossils preservation in the acid soils and humid climate and the limitation of phytoliths analysis. The Pearl River Delta has an important sea-land transition position in South China, where the native Neolithic cultures had weak cultural continuity but easily adopted external features from other regions. To understand prehistoric plant-related subsistence, especially starch plant use, in the Pearl River Delta, the analysis of archaeological starch grains recovered from plant processing tools is selected as the main research approach of this thesis.

A total of 61 grinding and pounding tools were selected as archaeological samples from two sites from around 6,000 to 5,000 BP (Guye site and Haogang site (the second phase)) and five settlements during 4,500 to 3,000 BP (Haogang site (the third phase), Yuanzhou site, Cuntou site, Yinzhou site, and Hengling site) in the Pearl River Delta.

The results show that from 6,000 to 3,000 BP, acorns and geophytes were important food sources in the Pearl River Delta. In the early phase (from 6,000 BP to 5,000 BP), the proportion of acorn/oak-chestnut starch was higher than that of geophytes (in this thesis, it refers to the plants with starch-rich underground storage organs), but that after 4,500 BP the role of geophytes in the diet appears to have increased. The starch granule data from grinding and pounding tools combined with other archaeological site data strongly suggest that during the mid-Holocene small, sedentary, village settlements were heavily dependent on hunting and gathering, with only limited impact from cereal cultivation (e.g. rice and millets).

Acknowledgments

I would like to acknowledge many people who support and assist in this thesis.

Firstly, I especially thank my supervisor at the University of Leicester, Dr. Huw Barton. He provides continuous supports throughout my studies, involving the training and advice in the lab, and guidance of sample collection and stone tool descriptions. I am strongly grateful to him for patiently answering every question, detailed editing every draft, and giving lots of encouragement, all of which help to complete this thesis.

I also express my thanks to Prof. Xiaoyan Yang, at the Institute of Tibetan Plateau Research, Chinese Academy of Sciences. She arranged access to samples in China and shared her modern reference database and knowledge of starch residue identification.

For sample collecting, I thank Lu Li at Southwest Forestry University and Fuchuan Wu at Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, for their help of modern reference collection in Yunnan; Jun Wei at Guangdong Museum, Xiaoling Chen and Haicheng Zhang at Dongguan Museum, Xiaobin Wu and Bin Luo at Dongguan Haogang site Museum, Lei Zhang at Sanshui Museum; Jie Shang and Yuliang Bai at Guangdong Provincial Institute of Cultural Relics and Archaeology; Qianglu Zhang and Liangbo Lu at Guangzhou Municipal Institute of Cultural Heritage and Archaeology, for their permission and help of archaeological sample collection.

I would like to acknowledge the financial support of China Scholarship Council, providing tuition fees and living fees for my study (No. 201604910602), and the project (International Partnership and Mobility awarded by the British Academy), led by Dr. Huw Barton and Prof. Xiaoyan Yang, for supporting the sample collecting.

More personal, I also appreciate my family and friends for giving me a lot of patience, understanding, and encouragement over the years.

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Chapter 1: Introduction

The aim of this thesis is to investigate plant-related subsistence and its changes in the Pearl River Delta in southern Guandong during the Neolithic period and early Bronze Age (c. 6,000-3,000 BP). It is argued that the communities that begin to emerge in the forested and coastal landscapes of this region from c.7,000 BP onwards were those of sedentary hunter-gatherers and sedentary hunter-gatherer-fishers until around 3,000 BP (e.g. Hung and Zhang 2019; Yang et al. 2015). Hundreds of sites, mostly recorded by type as either shell midden sites or sand dune sites, were found in the Pearl River Delta in the Neolithic period and early Bronze Age (Figure 1.1) (Li 2019; Yang et al. 2015). What we know of these communities derives from archaeological excavations that have recovered traces of settlements (postholes, burials, and other features), pottery and stone tools (e.g. Guangdong Museum and Foshan Museum 2006; Li 2000; Li and Cui 2018; Li, Z. and Li, Y. 1997; Mo 2003; Yang et al. 2015).

The Pearl River Delta was an important eco-zone for early human settlement, offering hunter-gatherers and alter farmers, access to range of habitat types from low hills covered in oak forests, open grasslands, swamps, as well as freshwater and estuarine habitats.. Early settlements are include remains of terrestrial as well as marine remains including shellfish, fish bones, pointed tools for oyster working, and net weights for fishing (e.g. Huang and Zhang 2019; Li 2019; Yang et al. 2015; Zhang and Huang 2016). Pollen analysis shows that during the Holocene, the vegetation of the delta was dominated by subtropical forest until around 2,500 BP. After this date there is an increase of open grass landscapes and associated decline of the oak forests (Huang et al. 2016; Li 2019; Ma et al. 2018; Peng et al. 2015; Wang et al. 2009; Yang et al. 2015; Zheng et al. 2004). The pollen cores also show increases in charcoal that has been interpreted as widening disturbance activities from human settlements engaged in rice and millet farming (Ma et al. 2018).

Although current evidence does not reveal whether the forest was under deliberate management by hunter-gatherers or by later sedentary farmers, forest exploitation would have been a significant part of any subsistence and economic activities (e.g. Barker et al. 2017; Barton 2005; Marinova and Ntinou 2018). For example, within Neolithic sites archaeological excavation has recovered wood working tools, wooden tools for food processing, evidence of complicated housing construction, canoes, trackways, barkcloth and some decorative objects (e.g. Cui 2007; Fang 2006; Tegel et al. 2012; Xu et al. 2017; Yang, H. and Yang, Y. 1983). However, the preservation of these wooden artifacts is limited, recovered in waterlogged conditions (Out et al. 2020; Sun et al. 2013; Yang, H. and Yang, Y. 1983). But inferred from the presence of stone tools with thin parallel grooves that are analogous with ethnographic parallels (Deng 2007), evidence of bark cloth manufacture occurs from the Neolithic period.

Another critical resource provided by the forested delta are carbohydrate resources. Both ethnological and archaeological evidence points to the importance of perennial plants, such as acorns from oaks, palm and possibly cycad sago, as well as a range of terrestrial and riparian or swampy geophytes, as key carbohydrate resources for foragers and farmers (e.g. Barker et al. 2017; Barton 2005; Barton and Denham 2018; Denham 2008; Denham et al. 2018; Higham 2014; Li and Lu 1987;Yang et al. 2013). The archaeobotanical records recovered in Southeast Asia provide good analogies for understanding pre-agricultural forest exploitation strategies. A range of plant remains were recovered at Niah cave site in the late Pleistocene, including palms (Aracaceae), aroids (Araceae), yams (Dioscoreaceae), edible nuts and olive fruits (*Canarium*), that are considered representative of a wider Island Southeast Asian forest adaptation (Barton et al. 2016). Several of these plants though are either toxic or contain irritating and unpleasant chemicals such as tannins, alkaloids, and physical irritants (calcium oxalates) that require treatment before safe consumption (Barker et al. 2011; 2017; Barton et al. 2016; Barton and Denham 2016). In mainland southeast Asia, limited archaeobotanical evidence also points to the importance of nuts as a rich source of calories (mainly as unsaturated fats but also from starch granules), in both hunter-gatherer and early farmer diets. Remains of oak-chestnut (*Castanopsis*) and walnut (*Juglans*), have been recovered at Hoabinian culture sites (hunter-gatherers), such as Spirit Cave in northwest Thailand from 9,000-5,500 BC (Higham 2014; Yen 1977). While nut exploitation has received some attention, it was clearly an important component of many forager diets across China, Europe , and North America (Basgall 1987; Fuller and Qin 2010; Liu et al. 2010; Marinova and Ntinou 2018; Tushingham and Bettinger 2013). The management of plants capable of vegetative propagation has been proposed in this region (Yang et al. 2013) within a system broader referred to as 'vegeculture'. While discussion of vegeculture has mostly focused on tuberous plants, it can extend to the management of tree crops, or 'aboriculture' (Barton and Denham 2018).

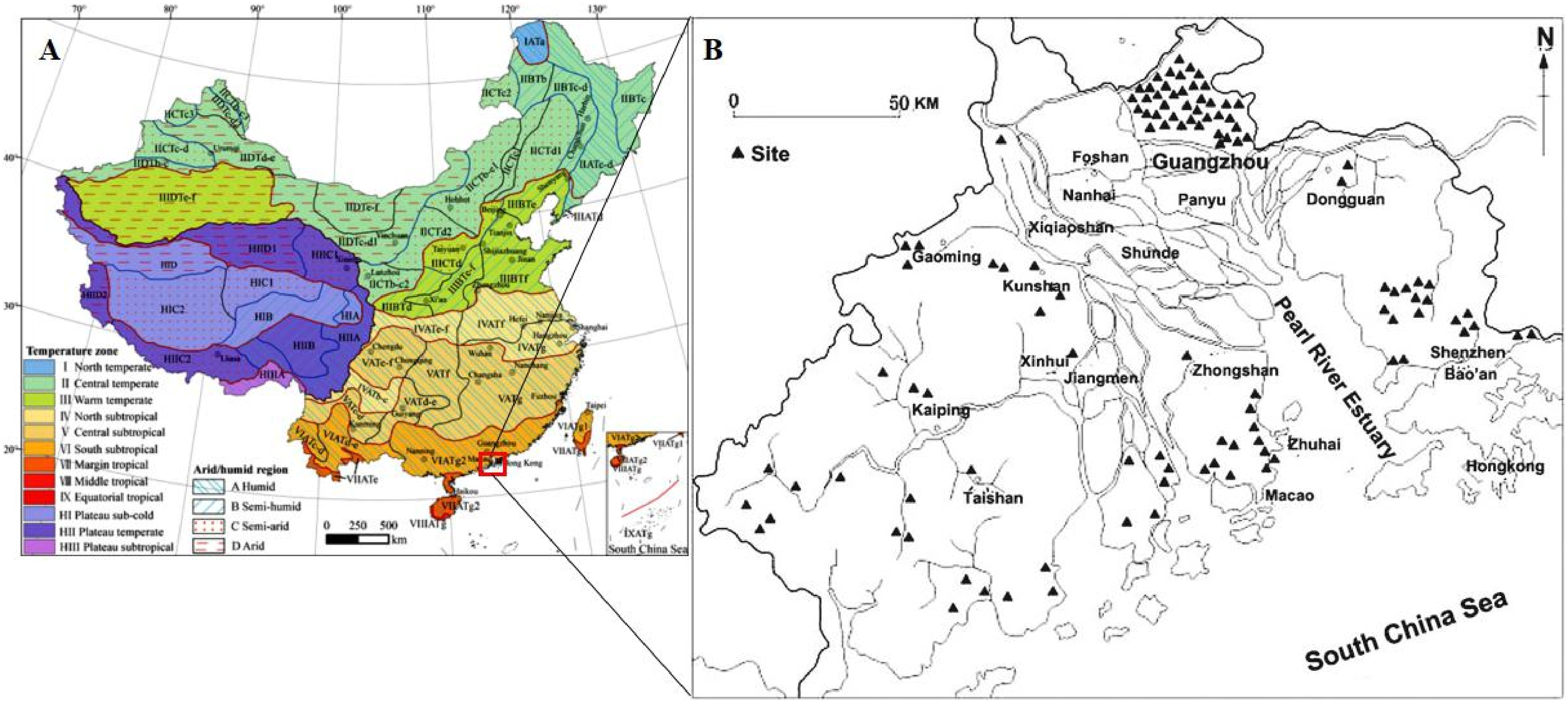


Figure 1. 1 Site distribution in the Pearl River Delta: A. Map of Chinese climate zones: VI South subtropical climate zone in China (Figure 1.7 in Qin et al. 2015); B. Site distribution in the Pearl Pearl River Delta during Neolithic period and Early Bronze Age (Figure 6.5 in Li 2019).

1.1 Research problem

There is a major gap in our knowledge about the role of plants in the diet, particularly of what we would refer to as staple foods (those foods consumed on a regular basis), in the Pearl River Delta before 2,500 BP. Although little direct archaeobotanical evidence has been recovered, the plant-related subsistence prior to the induction of rice farming is widely said to rely on geophytes, especially yams and taros, mainly based on ethnological results (Lu and Li 1987; Tong 1984; Yan 2005; Zhao 2005). After 2,500 BP, pollen cores indicate significant landscape transformation including widespread forest clearance and anthropogenic burning that is interpreted as resulting from practices of slash and burn dryland agriculture (e.g. Ma et al. 2018; Peng et al. 2015).

In spite of this, there are some clues about woody plant use in the prehistoric period. Large numbers of nut remains have been recovered from the village site of Guye site (5,900-5,000 BP) from waterlogged middens, and the sago starch residues were recovered from stone tools at Xincun site (5,300-4,400 BP) (Yang et al. 2013; 2018). Until now, edible and spiritual values of woody plants are preserved in small scale in modern southern China, for example, guanglang palm (a kind of sago-type palm) consumption in Longzhou, Guangxi, and the tree worship of some ethnic minorities in southwest China, such as Hani people to palm trees and Buyi people to oak trees, a suggestive of how important the woody plants were (Ge 2015; Gu 2002; Guan 2017).

In this thesis, I have undertaken a study of starch granules recovered from grinding and pounding tools in order to identify the range of carbohydrate-rich plant foods consumed during the Neolithic period and early Bronze Age of the study region. To address the main study aim, the following research questions will be pursued:

1. What types of plant foods can be identified by the analysis of starch granules recovered from pounding and grinding tools from the study region? Were the arboreal resources included in the diet of Neolithic populations in the Pearl River Delta?

2. Can an analysis of starch granules from food processing tools reveal details of plant subsistence strategies, including regional and temporal trends in diet between 6,000 to 3,000 BP?

Beyond simply plugging a gap in this area of our knowledge, a better understanding of the regional subsistence economy will also help contextualise the nature of human occupation at this time - i.e. how did hunter-gatherers and hunter-gatherer-fishers maintain sedentary occupation patterns? – and, to better understand what is now viewed as a delayed uptake of domesticated rice and other grain crops over this time (e.g. Deng et al. 2018; Wu 2018; Yang et al. 2018; Zhang and Hung 2012).

1.2 Study approaches

Starch is a substance contained in all plants and is stored in the cytoplasm of parenchyma cells of plant organs in the form of microscopic granules. Starch grains in different species have typical morphological characteristics and could be left for millions of years, which makes it possible to be applied in the identification of plants and research on subsistence strategies (Torrence and Barton 2006). Because of the advantages of this methods, it began to be attempted in archaeological researches, as a supplement to macro-remains analysis and phytoliths analysis, providing direct evidence on subsistence patterns and adaption of the environment of ancient people and functions of stone tools (see Barton and Torrence 2015; Copeland and Hardy 2018).

Throughout China, this approach has expanded the traditional understanding of plant use strategies in the Palaeolithic period, which are centered on grass seeds, including the tribe Triticeae and the tribe Paniceae, and supplemented by acorns (*Quercus* spp.), edible legumes, and some unidentified roots and tubers (e.g. Liu et al. 2011; 2013; Wan et al. 2012). It has also been important in debates about diet (e.g. Liu et al. 2010; 2014; Tao et al. 2015; Wan 2012; Wu 2011; Yang and Jiang 2010; Yang and Perry 2013; Yang et al. 2013; Zhang et al. 2011) and the domestication process of some seed crops during the Neolithic period (e.g. Ma 2014; Yang et al. 2012; 2015). Starch evidence reveals that millets (especially the genera *Setaria* and *Panicum*) began to be collected intensively and domesticated gradually in northern China in the early Holocene (e.g. Liu et al. 2010; Ma 2014; Yang et al. 2012). And some wild plant resources, such as geophytes, the tribe Triticeae and *Quercus* spp., were still components in the indigenous diet at late Neolithic sites in north China (e.g. Li et al. 2010; Liu et al. 2010; Lu et al. 2005; Yang et al. 2012; Zhang et al. 2011). Through this approach, it is also argued that domesticated wheat and barley had been introduced in North China at c. 4000 BP (Li et al. 2010; Wang et al. 2015). Along lower Yangtze River during early and middle Holocene, such as at Shangshan site (11,000 to 8,600 BP), Xiaohuangshan site (c. 9000 to 7000 BP), and Kuahuqiao site (8,000 to 7,000 BP), starch residues recovered showed that acorns (*Quercus/ Lithocarpus/ Cycloblanopsis* spp.) were exploited widely, alongside a minor use of a diverse range of wild plants, like job's tears, edible legume, and barnyard grasses (Liu et al. 2010; Yang and Jiang 2010; Yang et al. 2015; Yao et al. 2016). These starch residues recovered from grinding tools and potsherds in lower Yangtze River revealed that the other plant resources gathered and managed during the initial phase of rice cultivation, suggesting a broad wetland grass management and the importance of tree nuts in the early stages of rice cultivation (Liu et al. 2010; Yang and Jiang 2010; Yang et al. 2015; Yao et al. 2016).

Except for a few waterlogged environments, for example, at Guye site (Cui 2007), the macro plant remains are not well-preserved in the humid climate and acid soil. Some edible parts of possible major crops in prehistoric subtropical and tropical regions do not produce phytoliths as well, such as Araceae, Dioscoreaceae, and Liliaceae (Wang and Lu 1993). Therefore, in this context, starch grain analysis is likely to be the most effective method to identify the major plants that were consumed in local diets.

Currently, starch grain analysis has become an important method for exploring prehistoric plant-related subsistence practice in tropical and sub-tropical regions (e.g. Barton and Torrence 2015; Dickau et al. 2007; Field et al. 2016; Fullagar et al. 2006; Owen et al. 2019; Torrence and Barton 2006; Yang et al. 2013). In south subtropical China, limited starch residues recovered provide some clues of prehistoric starch plant consumption. For example, at Niulandong cave site in Guangdong (c. 12,000 BP), besides Panicoideae, some roots and tubers and possible cycad pith, were processed by grinding tools (Wan 2012). The analysis of pebble tools, including pounders and grinders, from the coastal site of Xincun (5,300-4,400 BP) in Southern Guandong, revealed a sago-dominant subsistence pattern, as well as the use of roots including fern, arrowhead, and freshwater chestnut (Yang et al. 2013).

1.3 Study Region

The study region, the Pearl River Delta, is located in the sub-tropical landscape of Southern Guangdong, China, which is comprised of two sub-deltaic plains, the North and West Rivers deltaic plain and the East River deltaic plain, with an estuary, and several rocky islands (Huang et al. 1982; Wei and Wu 2014; Zeng 2012; Zong et al. 2009; 2012). It is a transitional zone between the catchment basin of the Pearl River and the South China Sea, which contains several major cities, such as Guangzhou, Foshan, Dongguan, Hong Kong, and Macao (Figure 1.2). The climate in this region has both humid subtropical monsoonal and maritime features (An 2000; Hu et al. 2013). The landscape is covered by various vegetation types, including pine (*Pinus massoniana*) forest, evergreen broad-leaved forests, mixed coniferous forest, and mangroves (Yang and Guan 2006).

During the early Holocene, this region exhibited the rapid rise of sea-level (Li et al. 1991). At the peak of sea-level transgression around 7,000 BP, the modern delta plain was a broad, shallow estuary with complex borders and many isolated bedrock islands (e.g. Li et al. 1991; Wei et al. 2011; 2016; Zong et al. 2009; 2012; Zong 2004). Over several millennia, this estuary was filled with river sediments creating the modern estuary (Huang et al. 1982; Wei and Wu 2014; Wei et al. 2011). The Holocene vegetation was dominated by evergreen oak forest as well, such as *Castanopsis* and *Quercus* (e.g. Huang et al. 2012; Ma et al. 2018; Peng et al. 2015; Zhao et al. 2014).

The earliest archaeological findings in the Pearl River Delta, such as Tung Wan site in Hong Kong and Xiantouling site in Shenzhen, could date back to the middle Neolithic period, at around c. 7,000 BP (Deng 1997; Shenzhen Cultural Relics and Archeology Institute 2013). The chronological sequences and the features of archaeological cultures in the Neolithic period and early Bronze Age are initially summarized in Table 1.1.

Between 7,000 and 6,000 BP, the culture in this region is named after Xiantouling site, which is an independent regional culture developed in the Pearl River Delta, influenced by the cultures from the northwest on this regions, such as Gaomiao culture (c. 7,800-6,700 BP) in west Hunan and Tangjiagang culture (c. 6,800-6,300 BP) in middle Yangtze River (Shenzhen Cultural Relics and Archeology Institute 2013). Painted pottery and white pottery, involving ring-foot plate, round-bottom *fu* cauldrons, and *guan* jars, decorated by cording marking, incisions, and shell impressions (Table 1.1), are highly typical at that time (Institute of Archaeology, Chinese Academy of Social Sciences 2010; Shenzhen Cultural Relics and Archeology Institute 2013).

The later culture in the middle Neolithic period has been preliminarily named as Guye culture, according to the recent research at Guye site (c. 5,900-5,000 BP) and some related sites, such as Xincun site (c. 5,300-4,400 BP), in the Pearl River Delta (Li and Cui 2018). Besides those inherited from Xiantouling culture, the pottery sequence at Guye site indicated that the cultural influence from the lower Yangtze River strengthened, such as Songze culture (c. 6,000-5,300 BP) and Liangzhu culture (c. 5,300-4,300 BP) (Li and Cui 2018). For example, the new decoration patterns on ceramic vessels were introduced, like the blank strips on the vessel shoulders, which seemed to be influenced by Duiziling culture (c. 6,800-5,300 BP) in Hunan (Li and Cui 2018). On the aspect of stone tools, the shouldered tools emerged and the microlithic tools flowed from Southwest China (Fu 1988; Li and Cui 2018).

Cultural changes in the delta during the late Neolithic period are mainly characterized by the emergence and development of geometric stamped pottery and stepped tools with shoulders, introduction of concave-bottom ceramic vessels, and the increases of stone axes/adzes (Table 1.1) (e.g. Lu 2007; Wu and Ye 1993; Xiao 2004; Yang et al. 2015). According to the development level of geometric stamped patterns on pottery, the cultures of the late Neolithic period could be classified as two phases. The Yonglang type (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 710) or Yuanzhou type (Li and Cui 2018), dating from 5,000 to 4,200 BP, is the initial emergence phase of geometric stamped patterns (Table 1.1) (e.g. Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li 2000; Wu 2000). In this phase, the microlithic tools accepted by Guye culture vanished (e.g. Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li and Cui 2018; Wu 2000). The following culture (4,200-3,500 BP) is named after the Hedang site, which typical feature was the elaborate geometric stamped decoration patterns (e.g. Chen 2012; Guangdong Museum and Foshan Museum 2006; Li 1992; Zhu 1989). Cultural interactions with other regions were also frequent in the late Neolithic period. The new stone tool design, the stepped tool with shoulders, combined the features of stepped tools introduced from the lower Yangtze River with the indigenous shouldered tools in the Pearl River Delta (Fu 1988). The finding of tripods was an indicator of the southward spread of Shixia culture (c.5,000-4,100 BP) in northern Guangdong (e.g. Li 2000; Wu 2000), and the concave-bottom ceramic vessels should be introduced from eastern Guangdong (e.g. Bu 2002; Chen 2012).

The new cultural features in the Pearl River Delta in the early Bronze Age include some new forms of ceramic vessels, like *zun* goblets, narrow-collar *fu* cauldrons, and narrow-collar *guan* jars with saggy belly and concave bottom, and the emergence of stone dagger-axes and *yazhang* serrated-edged tablet (Table 1.1) (Excavation report of Cuntou site, in press; Li 2019; Yang et al. 2015). Such typical sites involve the second and third phases of Cuntou site, the third phase of Yinzhou site, Maogang site, and Tangxiahuan site (Table 1.1). During this period, the cultures in the Pearl River Delta were continuously influenced by those from east Guangdong and lower Yangtze River (Li 2019).

Table 1. 1 Summary of archaeological culture in the Pearl River Delta (*Besides Xiantouling culture, other culture names are still under discussions)

Period	**Date (/BP)**	**Culture Name***	**Some key sites**	**Features**	**Reference**
Middle Neolithic period	7,000-6,000	Xiantouling culture	Xiantouling site; Dahuangsha site; Xiaomeisha site; Longxue site; F layer of Sham Wan site; Xiankezhou site; Wanfoan site; Lower layer of Jinlansi site	1. The toolkit contained axes, adzes, stone beaters, disc-shaped handstones, pitted stone cobbles, pestles, and pointed tools for shellfish processing 2. Painted pottery and white pottery are popular at this time. 3. The main forms of ceramic vessels are ring foot plate, round bottom *fu* cauldrons and *guan* jars, decorated by fine cording markings, incisions, shell impressions, or embossed lines.	Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li 2019; Shenzhen Cultural Relics and Archeology Institute 2013
	5,900-5,000	Guye culture	Guye site; Xincun site; The first phase of Caotangwan site	1. The pottery is characterized by round-bottom *fu* cauldrons, *dou* pedestals, round-bottom *guan* jars with straight neck, ring-foot plates, and some new forms developed, like those with folded shoulders. 2. The painted pottery is absence, and some new decoration emerged, such as continuous dots, convex ridge, and blank strip on shoulders. 3. The double-shouldered tools, especially adzes, were prevalent. 4. Microlithic tools were coexist with double-shouldered tools in the later phase.	He and Li 2015; Li and Cui 2018; Li 2019

Late Neolithic period	5,000-4,200 Youyugang type	The first phase of Yuanzhou site; The first phase of Youyugang site; The first phase of Yinzhou site; The second phase of Yonglang site	1. The shouldered stone tools were still popular, but the microlithic tools disappeared. 2. The pottery forms includes *guan* jars, *fu* cauldrons, *bo* bowls, stands, and spinning wheels, in which the round-bottom vessels with low ring foot are popular. 3. The pottery decoration is characterized by cord marking, and geometric stamped decoration emerged, including stripe pattern, leaf vein pattern, checkered pattern and zigzag pattern. But incision on ceramic vessels vanished.	Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li and Cui 2018; Wu 2000
	4,200-3,500 Hedang type	The second phase of Yinzhou site; The second phase of Youyugang site; The second phase of Yinzhou site; The first phase of Cuntou site; Zaogang site; Baojingwan site; Lujingcun site	1. The middle and small size shouldered tools and stepped tools with shoulders were common, and the number of perforated stone tools increased. 2. The pottery forms are similar as those from the previous period, with some new forms like the *guan* jars with a wide shoulder, round belly and low ring foot. 2. Geometric stamped pottery becomes more elaborate. 3. The concave-bottom ceramic vessels are introduced into the traditional assemblage, including round-bottom type and ring-foot type, but the three-foot or flat-bottom ones are infrequent. 4. Tooth-extraction is common among young people	Chen 2012; Guangdong Museum and Foshan Museum 2006; Li 2019; Yang 2007; Zhu 1989
Early Bronze Age	3,500-3,000 Cuntou type	The second and third phases of Cuntou site; The third phase of Yinzhou site; Maogang site; Tangxiahuan site	1.Most pottery forms shows inheritance relationship with these of the previous pottery, together with some new forms, like *zun* goblets, narrow-collar *fu* caldrons, and narrow-collar *guan* jars with saggy belly and concave bottom. 2. Stone dagger-axes and *yazhang* serrated-edged tablet are characteristic of this period.	Excavation report of Cuntou site, in press; Li 2019; Yang et al. 2015

1.3.1 Previous studies on plant-related subsistence in the Pearl River Delta

Abundant marine resources were argued to support the affluent foragers in coastal Neolithic China (Chang 2013). The Pearl River Delta should be one of these regions, where the local subsistence was based on hunting, fishing, and gathering, without or with a small amount of cereal cultivation (e.g. Liu and Chen 2014; Ma et al. 2018; Yang et al. 2017; Zhang and Hung 2012; Zheng et al. 2004; Zong et al. 2012).

The evidence in southern China revealed the similarity of plant-related subsistence based on vegetative propagation with the plant exploration records across Southeast Asia, Melanesia, and Northern Australia (see Denham et al. 2018). The starch plants mainly consumed in the Pearl River Delta probably includes palm trees, and geophytes during the prehistoric period (Lu 2013; Wan 2012; Wang 2017; Wen and Chen 1990; Yang et al. 2013). The phytoliths recovered at Xiantouling site (7,000-6,000 BP) indicate a large number of palm trees were accessible around the settlement, while sago recovered from these trees were confirmed to be largely consumed by Xincun people (5,300-4,400 BP) (Lu 2013; Yang et al. 2013). The geophyte starch grains were recovered at each site in this region where starch analysis has been performed (Wan 2012; Wang 2017; Yang et al. 2013). Charred plant remains, speculated to be the remains of tubers, were found in a *fu* cauldron from Dahuangsha site (6,500-6,000 BP) (Wen and Chen 1990). Besides, some tree nut remains, such as *Lithocarpus* spp. at Guye site (5,800-5,300 BP) and Longxue site (c. 6,000 BP) (Yang S. et al. 2015; Yang X. et al. 2018b) and other wild plant remains, like *Canarium* and *Diospyros* at Maogang site (c. 3,500 BP) (Yang, H. and Yang, Y. 1983) and Solanaceae, Leguminosae, and Amaranthaceae floated at the Chaling site (4,500-3,700 BP) (Xia et al. 2019), indicate the diverse range of prehistoric plant use in the Pearl River Delta.

Between 5,000 and 4,000 years ago, it appears that cultivation practices emerged in the Pearl River Delta. This is supported by the recovery of a range of plant remains from Sha Ha site (c.4,500 BP) in Hong Kong and Chaling site in Guangdong (4,500-3,700 BP) (Lu 2007; Xia et al. 2019; Yang et al. 2018). At Sha Ha site, the phytoliths of Cucurbitaceae from Neolithic layers were identified as a likely domesticated type (Lu

2007). And both domesticated charred rice seeds and *Oryza* phytoliths were recovered from the Chaling site (4,500-3,700 BP) (Xia et al. 2019; Yang et al. 2018). However, if there was cultivation at that time, it appears to have been limited temporally and spatially, because pollen analysis and charcoal records indicate that the region was heavily forested with no real evidence of anthropic burning (e.g. Ma et al. 2018; Peng et al. 2015).

1.3.2 Plant food processing technology

The combination of millstones and grinders was traditionally thought to be the significant plant food processing tool in China, no matter for crops or wild plants (e.g. Liu et al. 2010; Yao et al. 2016; Yang et al. 2012). It is argued that these grinding tools were more popular in northern China, but along the Yangtze River and in the south and southeast China, a small amount of these grinding tools were unearthed (Song 1997; Zhao 2005). This is not to deny the importance of such tools in southern China, but they may have other forms. The studies on disc-shaped handstones suggested that this kind of stone tools, which has one or two grinding surfaces, was used for grinding plants as well, together with netherstones (one of a pair of ground tools used for grinding plants in the lower place) with flat surfaces (Chen 2017; Shenzhen Cultural Relics and Archaeology Institute 2013). Besides grinding tools, pounding tools, such as pestles and mortars, were applied frequently in south China for plant processing (Song 1997; Zhao 2005; Zhang and Wang 1986). The orthodox view on the function of these pounding tools is that they are the tools for small seed processing, like rice or millets (Song 1997; Zhang and Wang 1986; Xu 2017). But the ethnological investigations and archaeobotanical evidence expand the understanding of these tools, suggesting that they may also be used for processing acorns and palm pith and roots (Chen 2019; Guangxi TV Official Channel 2018; Liu 2010; Yang et al. 2013). According to these previous studies, I selected the study stone tools of this thesis, involving both grinding tools and pounding tools.

1.3.3 Study samples

A total of six sites located on the Pearl River Delta were selected for starch analysis: Guye site, Haogang site, Yinzhou site, Yuanzhou site, Hengling site, and Cuntou site (Figure 1.2). Apart from the Hengling site (Figure 1.2: 3), which is located in the north of the Pearl River Delta, all other sites are distributed along the main tributaries of the Pearl River. Within them, Guye site (Figure 1.2: 1) and Yinzhou site (Figure 1.2: 2) are located along the West-North River, and Haogang site (Figure 1.2: 4), Yuanzhou site (Figure 1.2: 5), and Cuntou site (Figure 1.2: 6) are along the East River (Figure 1.2).

The research sample consists entirely of stone pounding and grinding tools. All tools are stored in local and regional museums with permission to access and sample given by Dongguan Museum, Haogang site Museum in Dongguan, Gaoming Museum, Sanshui Museum, and Guangzhou Municipal Institute of Cultural Heritage and Archaeology (Table 1.2). The study sample includes not only handstones, such as the disc-shape type with two ground surfaces, and netherstones, including fragments of milling stones and irregular grinding slabs, but also some informal pounding tools (normally recorded as hammerstones or ‘other’). These informal tools have largely been ignored in previous studies, with attention paid to formal or shaped types. However, according to ethnological records, these informal tools may also have been used for processing a range of plant foods, especially for the processing of nuts and palm pith (Chen 2019; Guangxi TV Official Channel 2018; Liu 2010; Stevens and McElreath 2015).

Table 1. 2 Sampled stone tools in the Pearl River Delta

Site Name	Date (/BP)	Tool type				
		Handstone	Netherstone	Pestle	Hammerstone	Others
Guye	5,900-5,000	1	6	0	3	0
Haogang	6,000-4,000	4	3	1	7	0
Yuanzhou	c.4,500	0	4	0	0	0
Yinzhou	c.4,500	0	6	0	0	0
Hengling	c.4,000	4	2	1	1	4
Cuntou	4,100-3,000	1	3	4	4	2
	Total	10	24	6	15	6

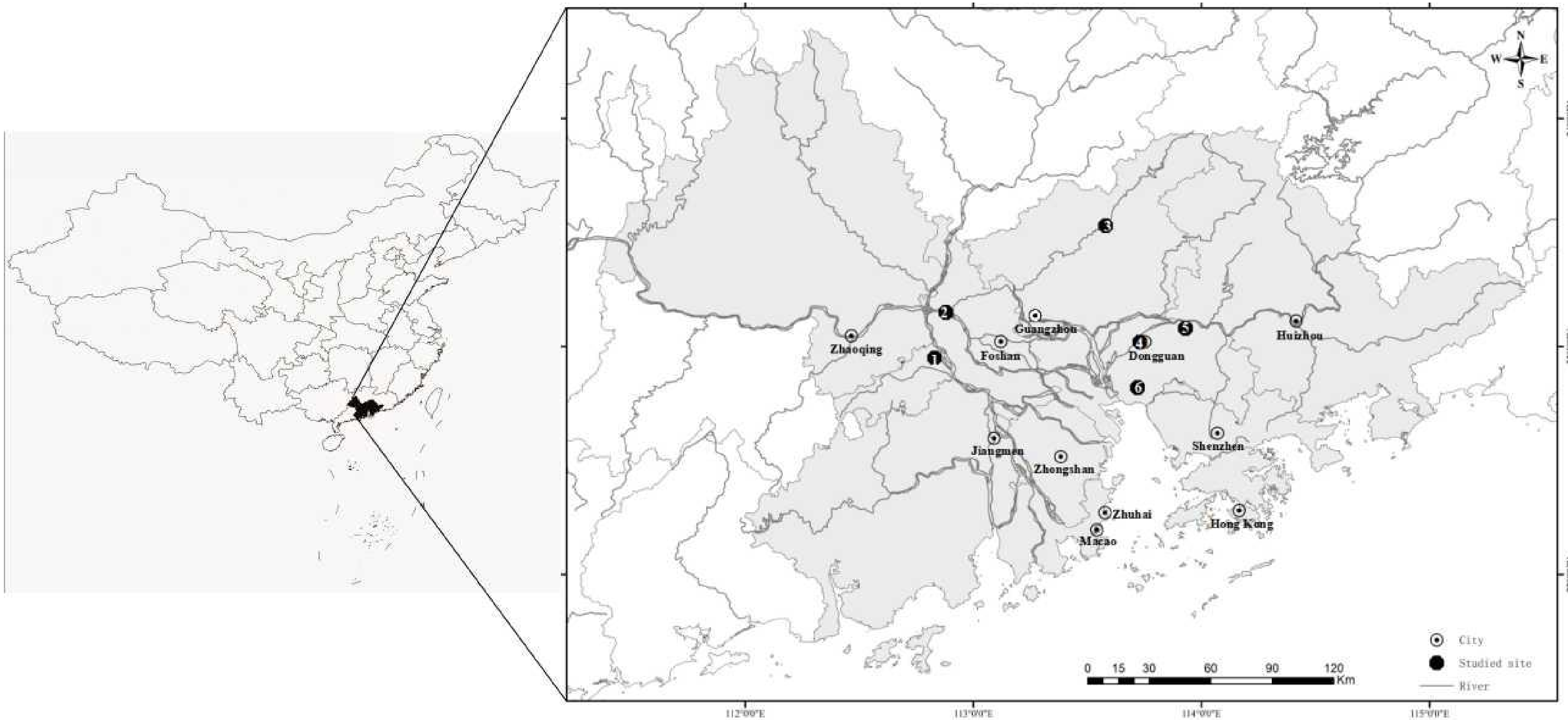


Figure 1. 2 Map of Pearl River Delta and the locations of studied sites. 1, Guye site; 2, Yinzhou site; 3, Hengling site; 4, Haogang site; 5, Yuanzhou site; 6, Cuntou site.

1.4 Thesis organization

Chapter 1 discuss the research problem and introduce the study region and study sample. Chapter 2 is a review of the paleoenvironment and archaeological contexts of the Pearl River Delta. Chapter 3 presents a review of the ethnological records and historic documents of plant use by ethnic minorities living in subtropical China. This section provides ethnographic data on plant use from Chinese sources that is made available to Western scholarship for the first time. Chapter 4 provides details of the sampled sites in which I describe the stone tools selected for starch analysis. Chapter 5 is a review of methodology employed to analyse the study sample.

Chapter 6 is a detailed description of the reference collection of starches. This collection consists of plants collected from southern China. The sample collection is provided by Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Kunming Institute of Botany, Chinese Academy of Sciences, Institute of Botany, Chinese Academy of Sciences and Institue of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences. Chapter 7 presents the results of the starch analysis of the archaeological sample.

In Chapter 8, I discuss the implications of the results with a focus on two main resources: tree nuts and geophytes. In Chapter 9, I develop an argument about subsistence practices in the region and important changes between 6,000 BP to 3,000 BP, along with wider archaeobotanical evidence, such as macro remains, phytoliths and pollen analysis from the wider region. I also introduce an argument about observed changes in food processing technology that I believe is related to a major shift in subsistence practices from systems of aboriculture and horticulture to seed-based agriculture. Finally, Chapter 10 provides a summary conclusion and suggestions for future work.

Chapter 2: The Pearl River Delta in the Holocene Period

In this chapter, I will first review the environmental background (section 2.1) of the Pearl River Delta in the Holocene Period, including the modern delta formation evolution of the delta, climate fluctuation and the vegetation evolution, giving a geographic position of the studied sites. And then, in section 2.2, I will list the cultural sequences in the Pearl River Delta in the middle and late Holocene.

The Pearl River Delta is the largest alluvial plain in South China. Current archaeological research has identified the earliest human activities in the region from 7,000 BP. At this time the delta was a shallow and broad estuary and many isolated bedrock islands (e.g. Cheng 2015; Li et al. 1991; Shenzhen Cultural Relics and Archeology Institute 2013; Wei et al. 2016). At that time, Xiantouling culture (7,000-6,000 BP) flourished, which mainly distributed in the dune sites in the estuary regions (Shenzhen Cultural Relics and Archeology Institute 2013). Then, the human activities became frequent and gradually produced the archaeological culture with local characteristics, such as double-shouldered ground and polished adzes and geometric stamped pottery (e.g. Bu 2005; Fu 1988; Yang et al. 2015).

2.1 Holocene evolution of the Pearl River Delta

This section reviews the modern geography and palaeogeography of the study area. This includes a discussion of the palaeoclimate, impacts of sea level change during the Holocene, including shoreline progradation during the late Holocene. The review concludes with a detailed review of palaeovegetation changes throughout the Holocene drawn from a number of pollen cores taken from within and nearby the Pearl River Delta.

2.1.1 The Pearl River Delta

The Pearl River Delta, in southern Guangdong province, South China (Figure 1.1), is a transitional zone between the catchment basin of the Pearl River and South China sea, covering an area of 9,750 km^2. This delta is comprised of two merged deltaic plains, the North and West Rivers deltaic plain and the East River deltaic plain (covering an area of about 5,650 km^2), with an estuary, and several rocky islands (Huang et al. 1982; Wei and Wu 2014; Zeng 2012; Zong et al. 2009; 2012). The upland landscape of the catchment basin frames the estuary creating a horseshoe-shaped bay and the bifurcations of main tributaries of the Pearl River, the East River, the North River and the West River, form a highly complex river network system in the modern delta (e.g. Hu et al. 2013; Huang et al. 1982; Li et al. 1991; Wei and Wu 2014; Zong et al. 2009; 2012). The region contains several major cities, including Guangzhou, Foshan, Dongguan, Jiangmen, Zhaoqing, Hong Kong and Macao.

The Pearl River Delta experiences a humid subtropical monsoonal climate, with characteristics of maritime climate (Hu et al. 2013). In general, the climate of the Pearl River Delta is warm and rainy, which annual average temperature is 21.4°C - 22.4°C (General Office of the Guangdong Province Government 2014). At present, the annual average precipitation is between 1,600 and 2,300 mm, but more than 80% of rainfall occurs during the wet season (April-September), forming a warm humid summer and a dry cool winter (Editorial board of Encyclopedia of Rivers and Lakes in China 2013).

In this subtropical region, the vegetation types are abundant, including *Pinus massoniana* forest, evergreen broad-leaved forests, mixed coniferous forest, and mangroves (Figure 2.1) (Yang and Guan 2006). The quantity of common plants is more than 500 species, most of them are subtropical species, belonging to 373 genera, such as banian (*Ficus microcarpa*), kapok (*Bombax ceiba*), fishtail palm (*Caryota ochlandra*) and poinciana (*Delonix regia*) (Chen 1983). However, modern vegetation in this region is highly fragmented by secondary forest, dominant by masson pine (*Pinus massoniana*), and rice farming fields (Cheng et al. 2018). In the reserved forest around some villages, some tropical plants can still be found, for example, eagle-wood (*Aquilaria sinensis*), indicating the existence of the tropical monsoon forest in the historical period (Yang et al. 2015).

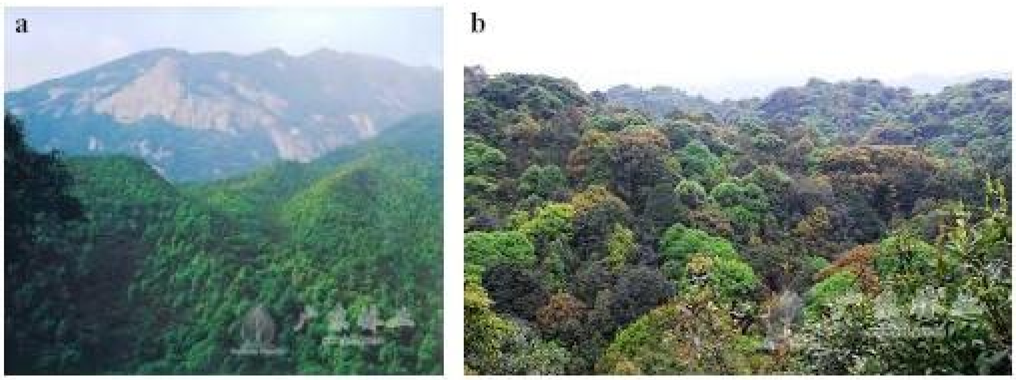


Figure 2. 1 Subtropical evergreen forest in the Pearl River Delta (Guangdong Forestry 2007). a, subtropical evergreen broad-leaved forest at Luofushan at Huizhou; b, subtropical monsoon evergreen broad-leaved forest at Xiangtoushan, Huizhou.

2.1.2 History of the delta

As a transitional zone of land and ocean and its particular geography, the Pearl River Delta is sensitive to the climatic and sea-level change (Huang et al. 1982). During Holocene, sea-level in the Pearl River Delta fluctuated (Figure 2.2) (Li et al. 1991). This geographical environment determined that the climate and sea level had important influence on the prehistoric culture of the Pearl River Delta.

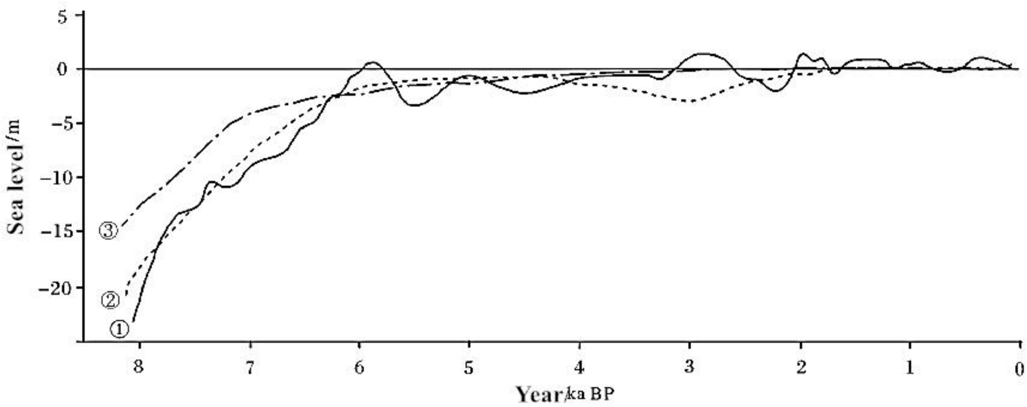


Figure 2. 2 Curve of sea level changes in Pearl River Delta from 8000 BP. (from Fig 5 of Wei et al. 2011): ① from Li et al.1991; ②from Long 1997; ③from Zong 2004

After the low sea level in glacial period, which has fallen by more than 100 m and the rapid transgression of the early Holocene, the sea level of the South China Sea gradually stabilized at around 6,000 BP, close to that at present (Figure 2.2) (Li et al. 1991; Zheng et al. 2016; Zong et al. 2010). Meanwhile, the paleo-estuary began to be filled in with the seaward movement of shorelines (Wei and Wu 2014; Zeng 2012; Zong et al. 2010; 2012). The filling up process of delta-plain and the paleo-shoreline change, based on archaeological evidence and historical records, is shown in Figure 2.3 (Huang et al. 1982; Li et al. 1991; Long 1997; Wei et al. 2016; Zheng et al. 2004; Zong 2004; Zong et al. 2009; 2010).

At the peak of transgression around 7,000 BP, the modern delta plain was still a broad, shallow estuary with complex border and many isolated bedrock islands, which could provide easily acquired aquatic resources (Li et al. 1991; Zong 2004; Zong et al. 2009; 2012; Wei et al. 2011; 2016). These abundant aquatic resources supported early human occupation (sand dunes and shell middens mainly) and maritime economy on the delta (Jiang 1997; Li et al. 1991; Xiao 1999; Yang 1999; Zhang and Hung 2008; Zheng et al. 2004). Then, the paleo-estuary exhibited the filling up process with a relatively slow deltaic progradation deposition rate at first (Huang et al. 1982; Wei and Wu 2014; Wei et al. 2011). With continuous growth of the deltaic plain, the Neolithic culture flourished, in terms of site density and quantity (Cheng 2015; Xiao 2004; Zheng et al. 2004)

After around 2,500 BP, the shoreline progradation accelerated, while the sedimentary processes became fluvial dominated (e.g. Huang et al. 1982; Wei and Wu 2014; Zong et al. 2012). As a result, the deltaic plain expanded rapidly at that time (Huang et al. 2016; Zong et al. 2012). Based on analyses of sedimentary sequences of grain and pollen, it is argued that the evolution of the delta plain was not a purely natural process, but one influenced by human activity increasing sediment runoff into the basin, especially after 2,500 cal BP when there is increased evidence of land clearance and burning(e.g. Hu et al. 2013; Huang et al. 1982; Li et al. 1991; Wei and Wu 2011; Wei et al. 2016; Zheng et al. 2004; Zong et al. 2010; 2012).

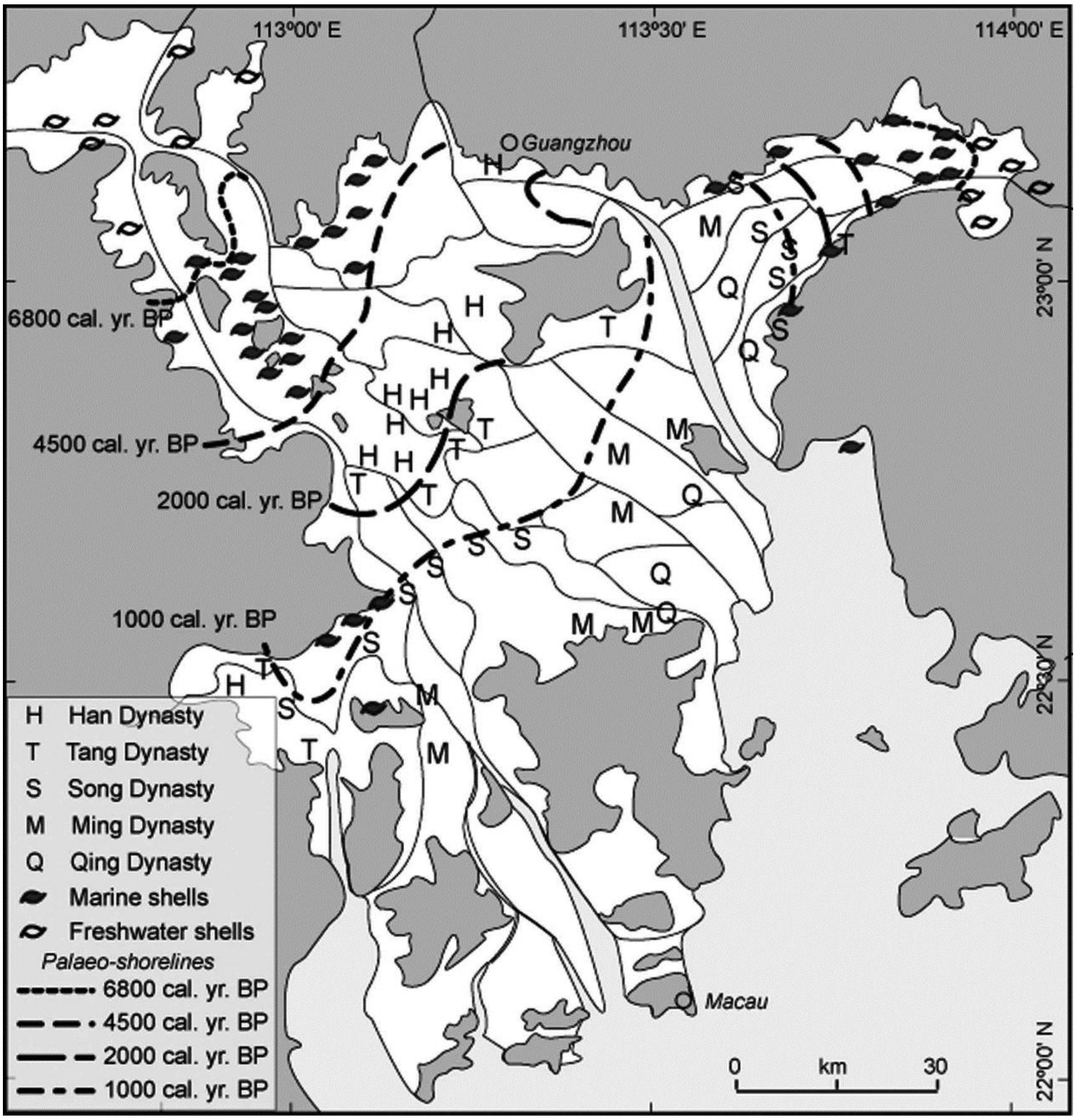


Figure 2. 3 Estimated palaeo-shorelines of the Pearl River Delta (from Zong et al. 2009).

2.1.3 Climate fluctuation during Holocene

The Holocene climate of the Pearl River Delta was predominantly warm and wet (e.g. Cao et al. 2012; Yang et al. 2012; Zhao et al. 2014; Zheng et al. 2004). The Holocene Megathermal Period in south subtropical China occurred in the early Holocene, about 9,500 to 8,000 cal. BP, according to the pollen sequence in Huguangyan Maar Lake (Wan et al. 2018; Wang et al. 2007). Different from other regions in China, where the Holocene Optimum appeared in the middle Holocene, the climate in south subtropical China became dryer due to a weakened monsoon (Cao et al. 2012; Wang et al. 2007;

Yancheva et al. 2007; Zhao et al. 2014). This tendency to dry weather was also reflected in the peat/mud sequences of Dahu (Jiangxi Province) (Zhou et al. 2004) and stalagmite calcite in Dongge Cave (Guizhou Province) (Dykoski et al. 2005). Meanwhile, the temperature became cooler than before, but was relatively warm (Wan et al. 2018; Zhao et al. 2014).

During c. 4,000 to 3,000 BP, climate in subtropical China experienced drastic fluctuations, similar to other regions affected by the eastern monsoon (Yao and Thompson 1992; Zheng et al. 2004; Zong et al. 2013). At that time, the temperature and humidity in south tropical China decreased and seasonal change was more pronounced (Cao et al. 2012; Wan et al. 2018; Wang et al. 2007; Yang et al. 2012; Zhao et al. 2014; Zheng et al. 2004), corresponding to the 4,200 BP climatic event at the middle and low altitudes of the northern hemisphere which may relate to increasing ENSO (El Niño-Southern Oscillation) (Bond et al. 2001; Shi et al. 1992; Zheng et al. 2003; 2004). Later, at around 2,000 BP, the climate became rather wet, while the temperature slightly rebounded (Cao et al. 2012; Wang et al. 2009; Yang et al. 2012).

2.1.4 Vegetation changes in the Pearl River Delta

The regional vegetation indicates the plant food availability and then influences the indigenous plant-related subsistence choices. Generally, during the middle and late Holocene, the delta was mainly covered in subtropical evergreen forest, dominated by Fagaceae, including *Castanopsis*, *Lithocarpus* and *Quercus*, before around 2,500 BP (Figure 2.4 and Figure 2.5) (e.g. Huang et al. 2016; Ma et al. 2018; Peng et al. 2015; Wang et al. 2009; Zheng and Wang 1998).

Pollen analyses in the delta reveals key vegetation changes. For example, the cores GY-1 (Figure 2.4) and SS0901 in the north part of the Pearl River Delta (Huang et al. 2016; Ma et al. 2015), located in Gaoyao plain and Sanshui Basin, separately reveal the wide coverage of subtropical evergreen forest, dominant by *Castanopsis* and *Lithocarpus* around 5,400 to 4,100 cal. BP. The pollen sequences also demonstrated a gradual change from subtropical evergreen forest to swamp forest in lowland areas as early as 4,900 cal. BP, when Chinese cypress (*Glyptostrobus pensilis*) thrived at around 4,000 BP (Huang et al. 2016; Peng et al. 2015). Increased burning at this time may relate to human activities, for example, small-scale cultivation activities based on slash and burn that extent beyond the basin to surrounding hill slopes (Huang et al. 2016; Ma et al. 2018; Peng et al. 2015). After around 2,500 BP, the sharp reduction of trees and the rapid growth of Poaceae and charcoal records are considered as suggestive of the beginning of large-scale rice farming (Ma et al. 2018; Peng et al. 2015).

In the coastal area, the Holocene vegetation was similar to that in the north area, supported by well-dated pollen sequences, such as Core GZ-2 (Figure 2.5), QZK6 and ZJK06 (e.g. Wang et al. 2009; Yang et al. 2012; Zhao et al. 2014). During the Holocene, fern was flourishing in the estuarine area of the Pearl River Delta, which is different from that in the north area (Wang et al. 2009; Yang et al. 2012). However, this does not mean the low forest cover. According to these cores, during the middle Holocene, the forest dominated by *Castanopsis* spp. and evergreen *Quercus* spp. (Wang et al. 2009; Yang et al. 2012; Zhao et al. 2014). From at least 3,500 BP, and perhaps as early as 4,300 BP, the vegetation began to shift to a more open landscape with the reduction in subtropical evergreen forest cover and increases in species that favour disturbance including grasses (Poaceae), ferns (*Dicranopteris*) and pine (Wang et al. 2009; Yang et al. 2012; Zhao et al. 2014).

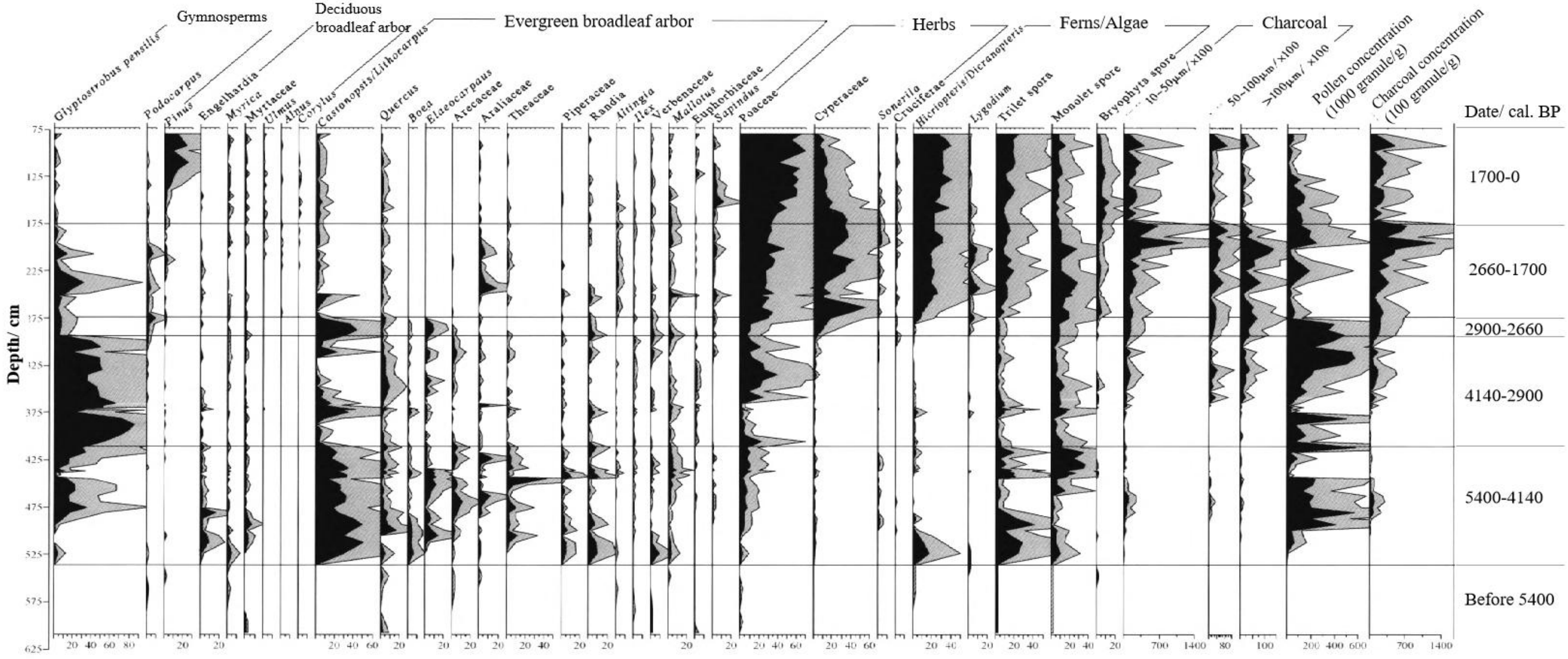


Figure 2. 4 Pollen diagram of core GY1. (after Figure 3 in Peng et al. 2015). (The gray shadows are amplified by three times in area of black. Due to the rare pollen occurrences in the section of 536-610cm, here, the authors use 1 to indicate the presence of of pollen and 0 for none)

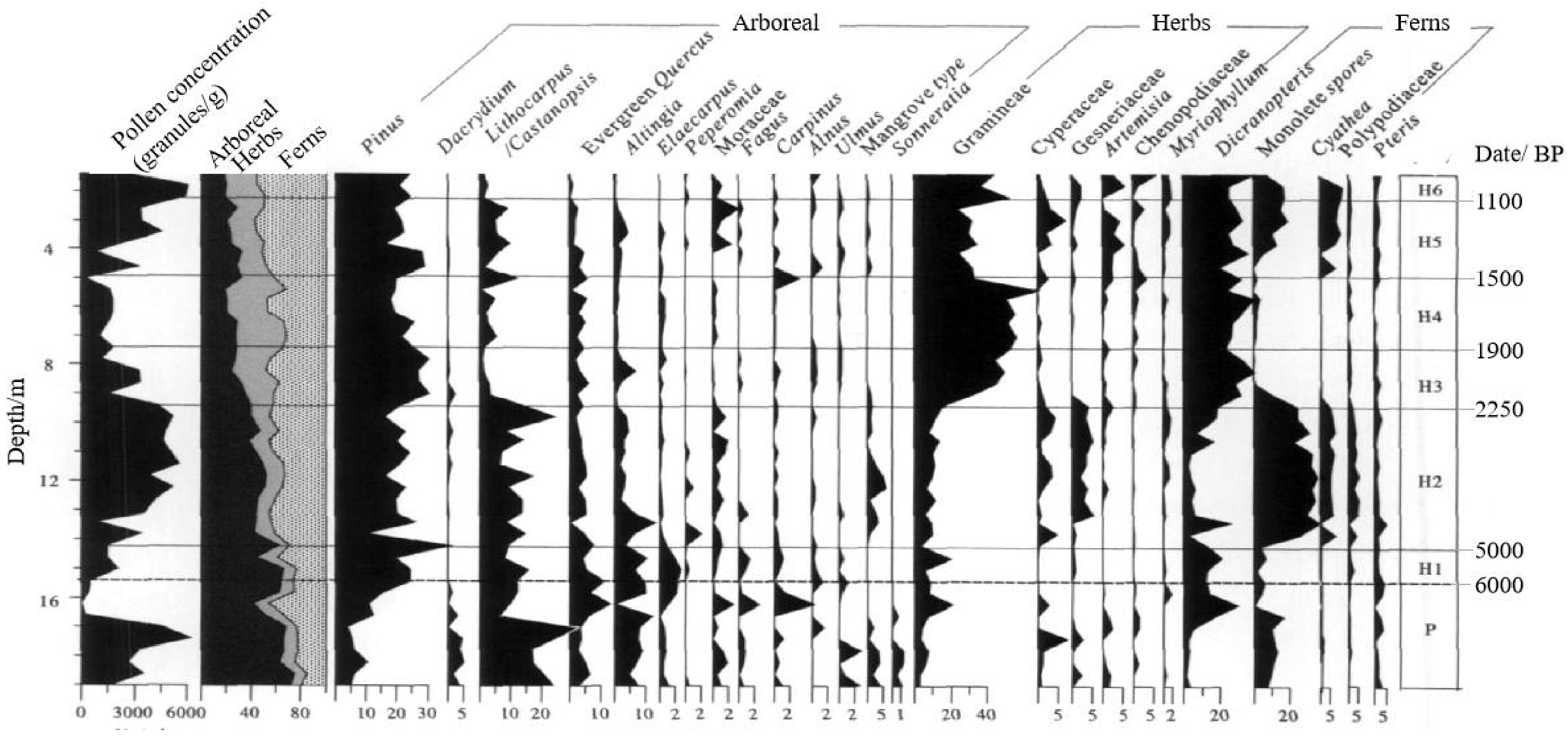


Figure 2. 5 Pollen percentage diagram of the Holocene in core GZ-2. (after figure 4 in Wang et al. 2009)

2.2 Archaeological context in the Pearl River Delta from Neolithic period to Early Bronze Age (c. 7,000-3,000 BP)

In the warm and humid Southern limit of China, South China offered a dense river network and lush vegetation, within which a series of relatively independent archaeological cultures developed during here from c. 12,000 BP to c. 3,500 BP, that were quite different character from those found along the Yangtze River and Yellow River at this time (e.g. Bu 2005; Su 1999; Zhang and Hung 2008). It has a developed early phase (around 10,000 BP) when the polished stone tools increase in frequency and early pottery emerged, such as Zengpiyan cave site (c. 12,000 to 7,000 BP) in Guangxi, and Niulandong cave site (c. 12,000 to 8,000 BP) in North Guangdong (Figure 2.6 B) (Bu 2005; Dai 1985; Institute of Archaeology, Chinese Academy of Social Sciences et al. 2003; Jin et al. 1998; Liu and Chen 2012; Wu and Ye 1993). A relatively long-term stable period followed with less change in pottery type, where round-bottom *fu* cauldrons, ring-foot plates and *wan* bowls decorated with cord-marking and incisions were always popular amongst affluent foraging economy (e.g. Bu 2005; Dai 1985; Liu and Chen 2012; Ma et al. 2018; Wu and Ye 1993; Zhang and Hung 2010; 2012).

The earliest archaeological evidence of Neolithic cultures in the Pearl River Delta is recorded from the middle Neolithic (7,000-5,000 BP) (Figure 2.6 C) (e.g. Bu 2005; Cheng 2015; Shenzhen Cultural Relics and Archeology Institute 2013; Zheng et al. 2004). These Neolithic communities in the Pearl River Delta have their own regional cultural characteristics, represented by shouldered stone tools, bark-cloth beaters, sand-tempered *fu* caldrons, cord-marking *guan* jars with a ring foot, and geometric stamped pottery decorations (Bu 2005; Fu 1988; Yang et al. 2015). The proximity of these groups to the open sea and at the termination of large rivers may have facilitated a high degree of culture contact from other regions and groups. Li and Cui (2018) argue that this is evidenced by typical white potsherds from the Gaomiao culture located along the middle Yangtze River that were recovered at Xiantouling site (c. 7,000 to 6,000 BP) (Shenzhen Cultural Relics and Archeology Institute 2013) and the presence of Shixia cultural features (c. 5,000-4,000 BP), in north Guangdong, at some late Neolithic sites.

Although the specifics of cultural types and a cultural typology in the Pearl River Delta are still under debate (e.g. Gu et al. 2000; Wu and Ye 1993; Xiao 2004; Yang 1997; Zou 1993), some typical features are identified (Table 1.1), that loosely define the cultural sequence of the Pearl River Delta. In the middle Neolithic period (7,000-5,000 BP), Xiantouling culture is the first recognisable archaeological culture in the Pearl River Delta. This is characterized by painted pottery plates with a ring-foot, developed incision decorations, and the decline of white pottery (Bu 1999; Deng 1997; Shenzhen Cultural Relics and Archeology Institute 2013; Yang 2004; 2007; Yang and Lin 1994). Then, Guye culture (c. 5,900-5,000 BP) followed, retaining some Xiantouling features, for example, the ring-foot plate decorated by wave-pattern incisions (Li and Cui 2018). The features of Guye culture includes the innovation of pottery, including new forms (like ring-foot *guan* jars) and new decorations (like the blank stripe on the vessel shoulders), the development of shouldered stone tools, and the inflow of microlithic tools (Li and Cui 2018).

In the late Neolithic period (5,000-3,500 BP), cultural changes are represented by the emergence of geometric stamped pottery and an increasing proportion of stone adzes and axes (e.g. Gu et al. 2000; Guangdong Museum and Foshan Museum 2006; Lu 2007; Shang and Mao 1997; Xiao 2004; Zou 1993). The cultures in the Late Neolithic period are further classified according to the development level of the geometric stamped decorations on the ceramic vessels (Guangdong Museum and Foshan Museum 2006; Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li and Cui 2018). The early phase is the emergence of geometric stamped decoration, such as stripe-pattern and leaf vein pattern, which is named as Yonglang type or Yuanzhou type. And the late phase, called as Hedang type, is the elaborate phase of the geometric stamped pottery, represented by the findings at Hedang site (4,200-3,500 BP) (Figure 2.6 C) (Guangdong Museum and Foshan Museum 2006).

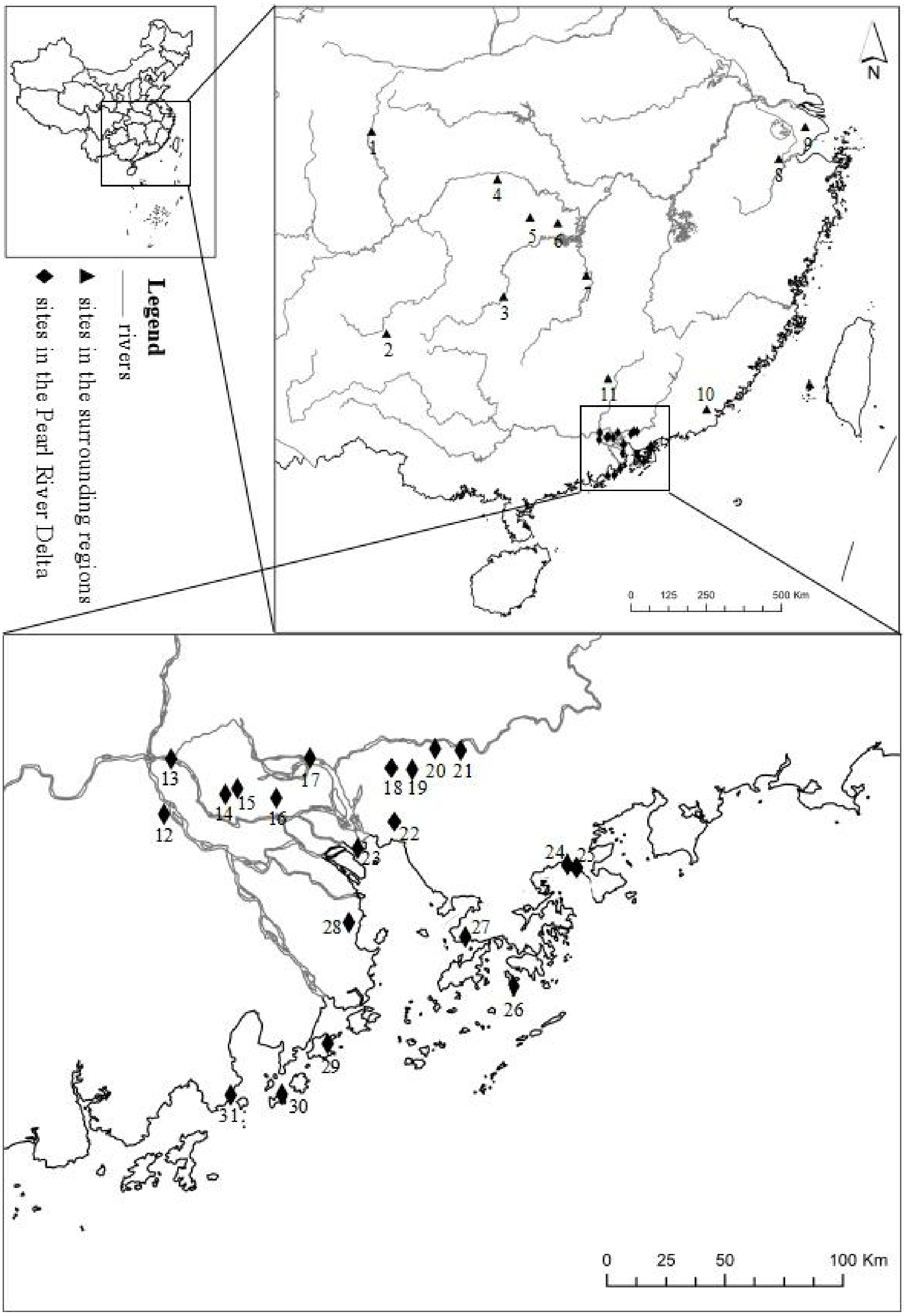


Figure 2. 6 Sites in the Pearl River Delta and the surrounding areas in the middle and late Neolithic period. 1. Zhongzipu site; 2. Niupodong site; 3. Gaomiao site; 4. Daxi site; 5. Zaoshi site; 6. Tangjiagang site; 7. Duiziling site; 8, Liangzhu site; 9. Songze site; 10. Hutoupu site; 11. Shixia site; **12. Guye site**; 13. **Yinzhou site;** 14. Youyugang site; 15. Hedang site; 16. Xiankezhou site; 17. Maogang site; 18. **Haogang site**; 19. Jinlansi site; 20. **Yuanzhou site**; 21. Wanfuan site; 22. **Cuntou site**; 23. Lujingcun site; 24. Xiantouling site; 25. Dahuangsha site; 26. Sham Wan site; 27. Yonglang site; 28. Longxue site; 29. Caotangwan site; 30. Baojingwan site; 31. Xincun site (study sites in this thesis are in bold).

2.2.1 Middle Neolithic period (7,000-5,000 BP)

In the middle Neolithic period, there are nearly a hundred sites distributed in the Pearl River Delta: identified by type as either mainly shell middens or sand dunes (Yang et al. 2015:213). Xiantouling culture (also known as Dawan Culture) is the earliest identifiable archaeological culture, dating from 7,000 to 6,000 BP (Deng and Huang 1994; Institute of Archaeology, Chinese Academy of Social Sciences 2010: 497-500; Shenzhen Cultural Relics and Archeology Institute 2013; Yang 1997). Xiantouling culture sites (around 20 in number) includes sand dunes mainly, such as Xiantouling site (the type site of Xiantouling culture), the fourth layer of Dahuangsha site, Xiaomeisha site, Longxue site and F layer of Sham Wan site, located around the estuarine area, including Hong Kong and Macao (Shenzhen Cultural Relics and Archeology Institute 2013). There are also four shell middens which have Xiantouling features, including Xiankezhou site, Wanfuan site, the lower layer of Jinlansi site, and Haogang site (Figure 2.7) (Feng 2007; Shenzhen Cultural Relics and Archeology Institute 2013).

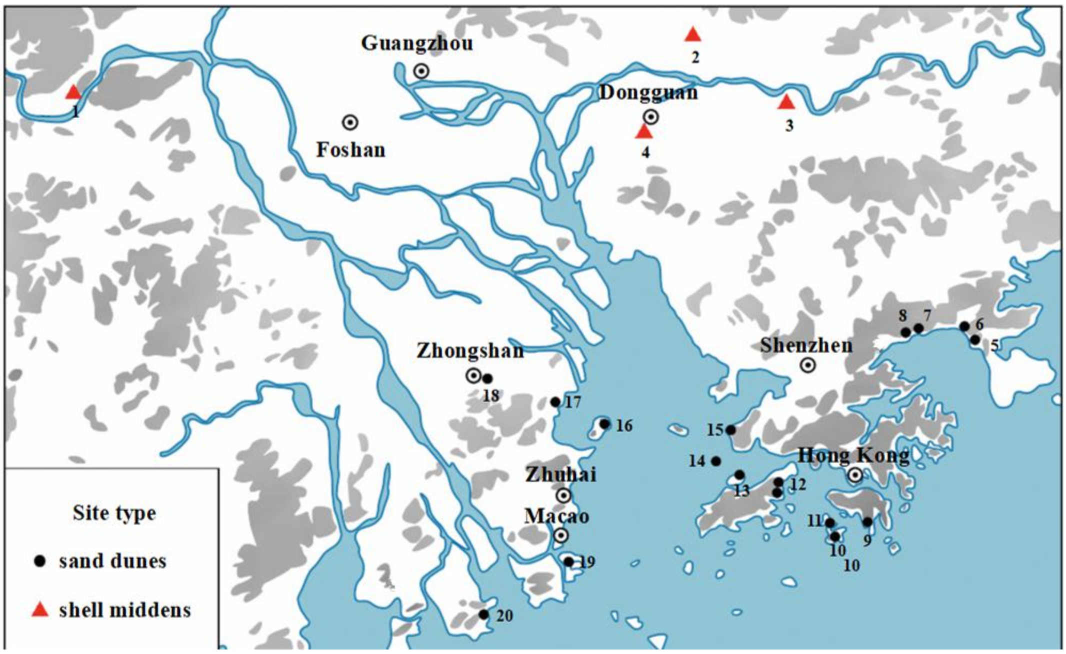


Figure 2. 7 Sites with Xiantouling culture. 1, Xiankezhou site; 2, Jinlansi site; 3, Wanfuan site; 4, Haogang site; 5, Xiantouling site; 6, Dahuangsha site; 7; Xiaomeisha site; 8; Dameisha site; 9; Chung Hom Wan site; 10, Sham Wan site; 11, Dawan site; 12, Xiediwan site; 13; Donggu site; 14; Longguzhou site; 15, Yonglang site; 16 Houshawan site; 17, Longxue site; 18, Baishuijing site; 19, Hesha site; 20, Caotangwan site (modified after Figure 1 of Chen 2017).

The pottery is mainly sand-tempered including *fu* cauldrons and *guan* jars, and the vessels with round-bottom or ring-foot are popular, while the flat-bottom forms are infrequent (Figure 2.8) (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 498). Painted clay pottery is one feature of this culture, including ring-foot plates, bowls, and cups. Within them, painted plates with ring-foot are the most typical, which are designed with various painted patterns, together with incisions and open works (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 498). The white pottery is also prevalent at that time (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 498). According to the ceramic designs, the Xiantouling site could be further divided into two sub-types (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 498): one has the large number of painted pottery, represented by painted plate with ring-foot, including Dahuangsha site, Xiaomeisha site, Longxue site, Xiankezhou site, Jinlansi site, and Wanfuan site; and the other is characterized by developed incision designed pottery, but few painted pottery, such as Xiantouling site and Sham Wan site (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 500).

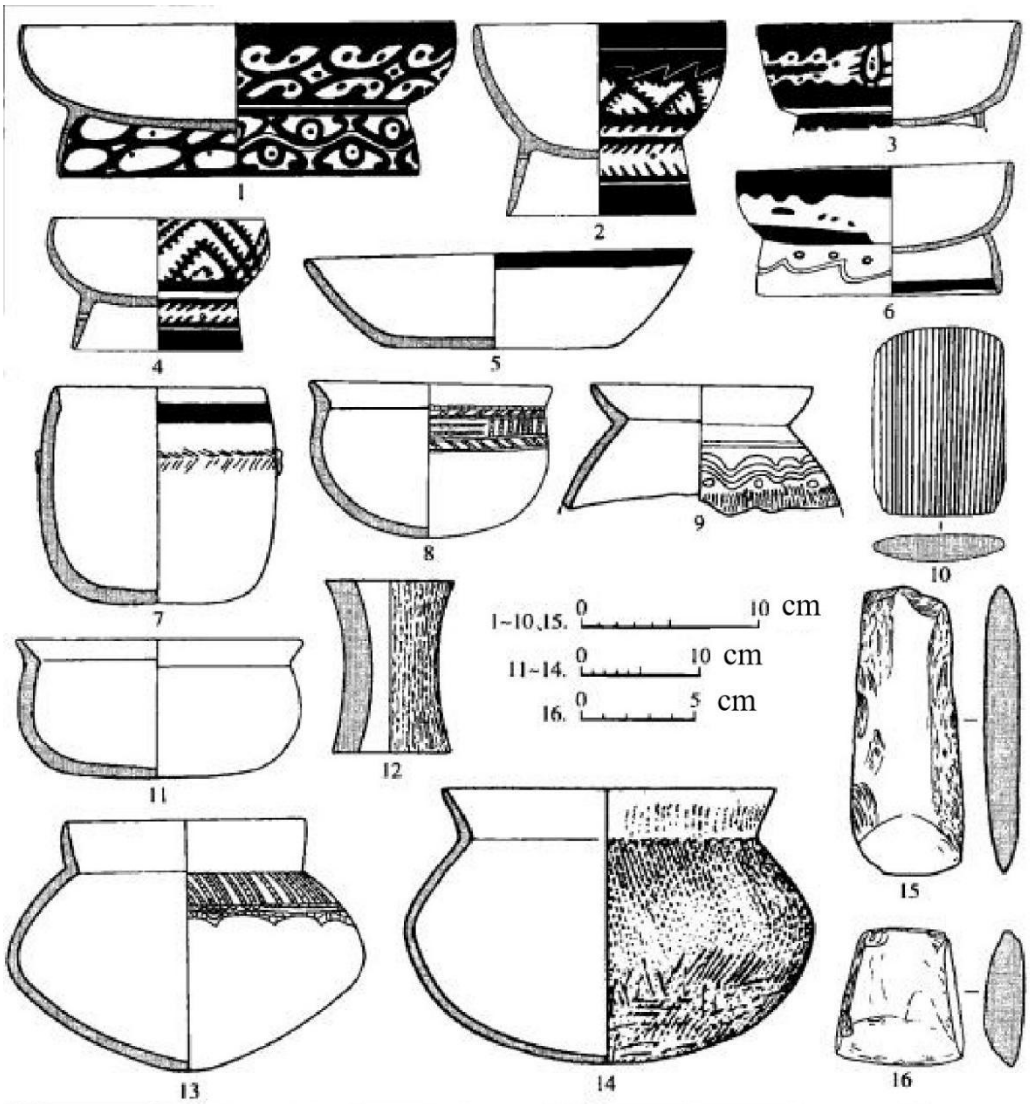


Figure 2. 8 Typical artifacts of Xiantouling culture. 1, 4, 5, 6, painted *plate*; 2, 3 painted *wan* bowl; 7 painted *bei* cup; 8, 9, *guan* jar; 10, stone bark cloth beater; 11, *pen* basin; 12, stand; 13, 14, *fu* cauldron; 15, stone axe; 16, stone adze. (Within them, 1 was unearthed at Xiaomeisha site; 2 and 4 were unearthed at Longxue site; 3 and 6 were unearthed at Chung Hom Wan site; and others were recovered at Xiantouling site).(after figure 5-30 in Institute of Archaeology, Chinese Academy of Social Sciences 2010: 499)

The toolkit of Xiantouling site consists of small and medium-sized stone axes and stone adzes mostly but lacking in agricultural-related tools, such as grain-processing tools (Yang 1997). And some stone tools were unearthed which are rare or not found in other sites in the same period, including disc-shaped handstones (饼形器), pitted stone cobbles (凹石), stone barkcloth beaters, and pestles (Figure 2.9) (Chen 2017; Shenzhen Cultural Relics and Archeology Institute 2013). The disc-shaped handstones (饼形器)

were thought to be used for grinding (Fan 2017; Shenzhen Cultural Relics and Archeology Institute 2013), while the pitted stone cobbles (凹石) could be used for quartz knapping or nut processing (Fu 2019; Liu et al. 2014; Roda Gilabert et al. 2012). Most of the bark-cloth beaters are smaller than 10 cm, and their function is controversial. Feng and Wen (1994) believed it was used to make the cord marking through modern stimulation experiments, while Deng (1994) thought it should be bark cloth making, relied on ethnological materials.

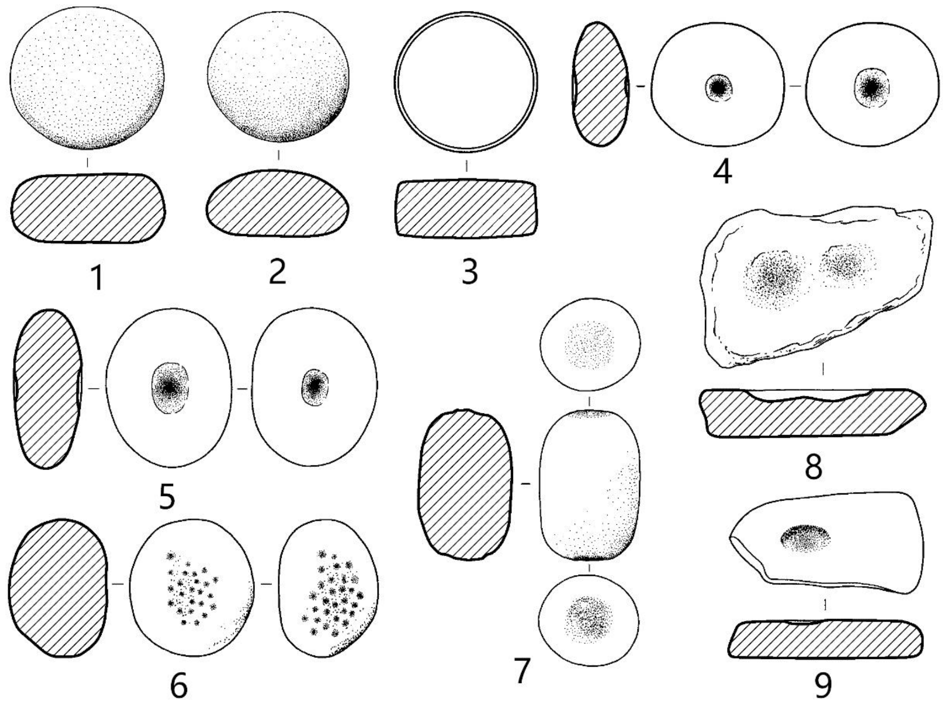


Figure 2. 9 Stone tools from Xiantouling site. 1-3, disc-shape handstones(饼形器); 4-5, pitted stone cobbles (凹石); 6, 8 and 9. netherstone; 7. hammer. (Chen 2017).

Based on the changes in pottery assemblage and toolkits, Xiantouling culture could be divided into 3 phases. 1) In the first phase, white painted pottery is dominant and there are small numbers of stone tools. 2) In the second phase, we see an increase in disc-shaped handstones, the beginnings of a decrease in white painted pottery, and an emergence of sand-tempered pottery vessels with shell impressed decoration. 3) In the final phase, white painted pottery continues to decline in frequency against an increase of sand-tempered pottery vessels and the stone adzes increased (Table 2.1) (Shenzhen Cultural Relics and Archeology Institute 2013).

Table 2. 1 Main sites of Xiantouling culture and its cultural sequences (Shenzhen Cultural Relics and Archeology Institute 2013)

Phrase	**Date (/BP)**	**Period**	**Main sites**		**Features**
			Sand dunes	**Shell middens***	
First	7,000 ~6,400	I	Xiantouling I, Longguzhou I		some white pottery and painted pottery; few kinds of stone tools
		II	Xiantouling II, Dongshan, LongguzhouII		
		III	XiantoulingIII, LongguzhouIII	Wanfo'an, XiankezhouI	
Second	6,400 ~6,200.	IV	Houshawan, Longxue, Biashuijing, Chung Hom Wan	XiankezhouII	Decline in white pottery; emergence of shell impressions, and increase of handstones(饼形器)
		V	Xiantouling IV, Dahuangsha, Xiaomeisha, Heisha, Dawan, Longguzhou IV		
Third	6,000	VI	Xiantouling V, Dameisha, Caotangwan, Tangxiahuan	Jinlansi	White pottery further declines; a majority of sand-tempered pottery; shell impression increased, and stone adze increased

*The white pottery recovered from the first phase of Haogang site indicates that it should be in the same period or slightly later than Xiantouling culture, while the painted pottery in the second phase of Haogang site has similar features as those at Xiankezhou site and Wanfuan site (Feng 2007). But Feng (2007) argued the date of Haogang site is from 6,000 to 4,000 BP, which is later than that of Xiantouling culture (7,000-6,000). Plus, in the Chinese Archaeology-the Neolithic Period (Institute of Archaeology, Chinese Academy of Social Sciences 2010), the key sites of Xiantouling culture do not include Haogang site. Therefore, I temporarily exclude Haogang site from this table.

From 5,900 BP to 5,000 BP, Li and Cui (2018) proposed the culture identified at Guye site could represent a regional type that was influenced by Xiantouling culture. The typical ceramic vessels are *fu* cauldrons and stand-collar *guan* jars, while the presence of ring-foot plates and *fu* cauldrons probably reveal its relationship with Xiantouling culture (Figure 2.10) (Li and Cui 2018). The popular decorations are wave-pattern incisions, continuous open work and the blank stripe on the vessel shoulders, and in the early phase of Guye culture (c. 5,900-5,300 BP), these decorations presented a simplified trend (Li and Cui 2018). A large number of sand-tempered potsherds with cord-marking were unearthed in the late phase of Guye culture (c. 5,300-5,000 BP) (Li and Cui 2018). These potsherds are similar and seem to be polished (Li and Cui 2018). Stone tools recovered in layers dating to the fifth millennium ago include large quantities of shouldered stone adzes and microliths (He and Li 2015; Li and Cui 2018).

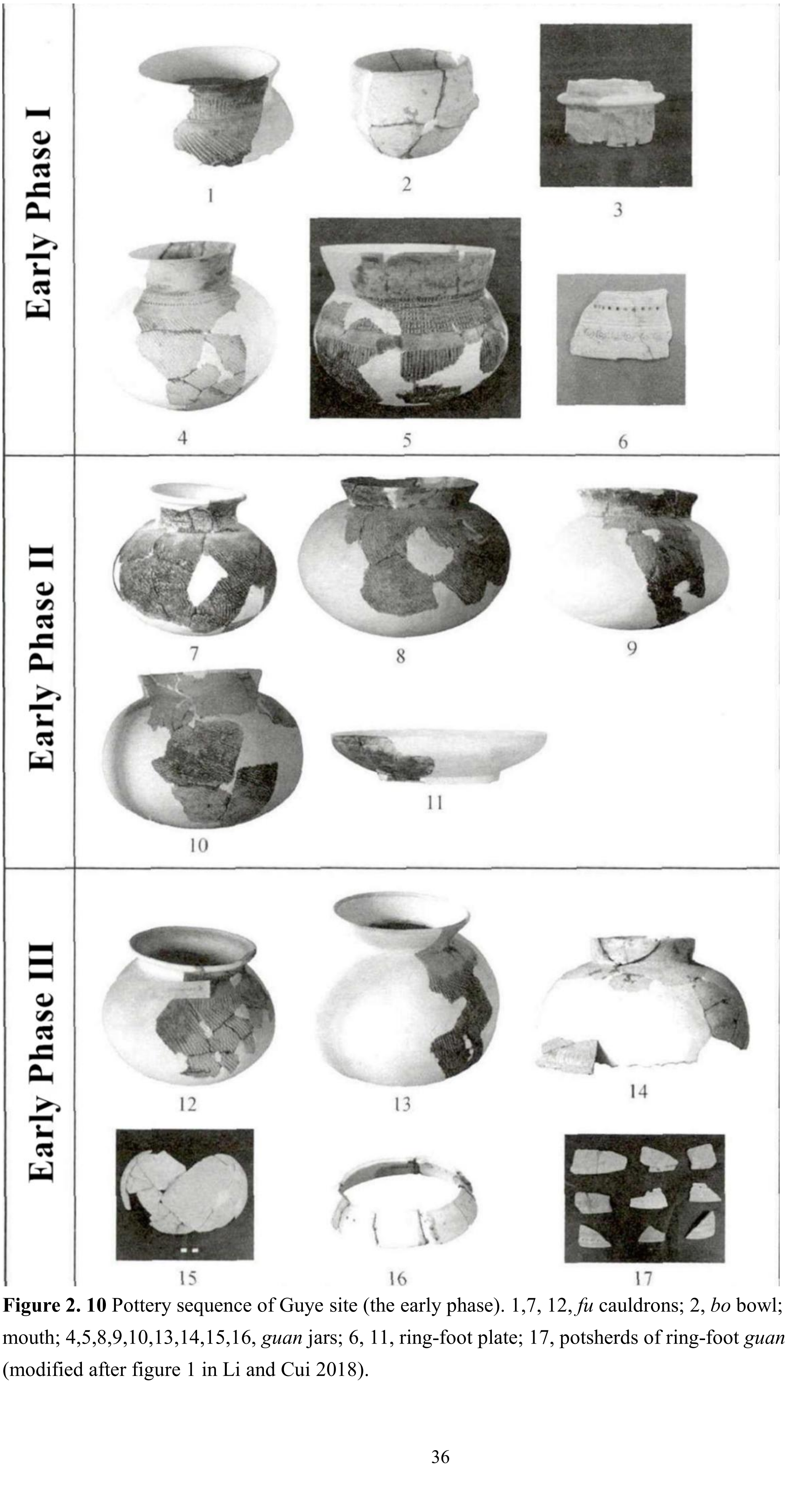


Figure 2. 10 Pottery sequence of Guye site (the early phase). 1,7, 12, *fu* cauldrons; 2, *bo* bowl; 3, vessel mouth; 4,5,8,9,10,13,14,15,16, *guan* jars; 6, 11, ring-foot plate; 17, potsherds of ring-foot *guan* jars (modified after figure 1 in Li and Cui 2018).

Overall, during the middle Neolithic period, sand-tempered *fu* cauldrons with a round bottom is the the most frequent type, but painted plates with ring foot are the most representative of the period (Figure 2.8 and Figure 2.10) (e.g. Bu 1999; Deng and Huang 1994; He 1994; Ren 1994; Shenzhen Cultural Relics and Archeology Institute 2013; Yang 1997; Yang et al. 2015). Elaborate incisions are common in the whole period, and each represented culture has their own popular decorations, such as cord markings and shell impressions are popular in Xiantouling culture, and the blank stripe pattern is a new and prevalent design in the Guye culture (Bu 1999; Li and Cui 2018; Yang 2007; Yang et al. 2015).

The debate on the relationship between white pottery and painted pottery keeps going. The white pottery unearthed in this area is considered as an influence from the middle Yangtze River (e.g. Shenzhen Cultural Relics and Archeology Institute 2013). In the mid-Holocene, these two type of pottery presented three situations (Table 2.2): 1) the painted pottery and white pottery coexisted at some sites; 2) the emergence of painted pottery was earlier than white pottery, such as at Donggu site and Longguzhou site; 3) the white pottery was replaced by painted pottery at Haogang site (Table 2.2).Whether there is a chronological order between painted pottery and white pottery is also unclear (Yang 2007). Although these white pottery unearthed at some Xiantouling culture sites is distinguishable, it is difficult to be identified as one representative cultural feature in the middle Neolithic period, because the abundant white pottery was still found at the Hedang site (c.4,000 BP) (Guangdong Museum and Foshan Museum 2006).

Table 2. 2 Characteristic pottery in the Pearl River Delta during middle Neolithic (data are from Bu 1999; Feng 2007; Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li and Cui 2018; Shenzhen Cultural Relics and Archeology Institute, 2013; Wei et al. 2010; Yang 1997; 2007).

Site type	**Site name**	**Phase/layer**	**Date (/BP)**	**White pottery**	**Painted pottery**	**incision-decorated pottery**
Shell midden	Haogang	First phase	6,000-5,500	X		X
	Haogang	Second phase	5,500-5,000		X	X
	Guye		5,900-5,000			X
	Wanfuan	Lower layer	c. 5,500-5,000		X	
	Xiankezhou	Lower layer	5,230-5,030		X	
	Jinlansi	Layer 3	c. 5,500		X	
Sand dune	Xiaomeisha	Lower layer	c. 6,000-5,500		X	
	Dameisha	Lower layer	6,500-6,000		X	
	Xiantouling		7,000-6,000	X	X	X
	Houshawan	Layer 6	c. 6,000-5,000	X	X	X
	Longxue	Layer 3	c. 6,000	X	X	
	Baishuijing	Layer 2	c.6,000-5,000	X	X	
	Dahuangsha	Layer 5				X
	Dahuangsha	Layer 4	6,500-6,000	X	X	
	Dawan	Layer 4	c. 6,000-5,000	X	X	
	Dawan	Layer lower than 2C			X	X
	Chung Kom Wan	Lower layer	c. 5,500		X	X
	Xiediwan	Lower layer	6,000-5,500		X	X
	Sham Wan	Layer F of E5	5,300-3,800		X	X
	Sham Wan	Layer 5 of D1			X	
	Sham Wan	Layer 4 of D1		X		X
	Yonglang-South	Lower layer	6,700-5,000	X	X	
	Hudiwan	Layer 4		X		X
	Hudiwan	Layer 3	6,000-5,000			X
	Donggu	Layer 3	early phase of middle Neolithic		X	
	Donggu	Layer 2	late phase of middle Neolithic	X		X
	Heisha	Lower layer	c. 6,000	X	X	
	Changshalan	Layer 4	c.6,000-5,000	X		
	Caotangwan	Layer 6	c. 5,000			X

The most common tool in the Pearl River Delta during the middle Neolithic period is the stone adze (Table 2.3). At the Xiantouling culture sites, trapezoidal adzes were prevalent (Shenzhen Cultural Relics and Archeology Institute 2013), but some prototype shouldered adzes with roughly worked shoulders emerged as well (Fu 1988; Institute of Archaeology, Chinese Academy of Social Sciences 2010; Shenzhen Cultural Relics and Archeology Institute 2013; Yang et al. 2015). Then complete shouldered stone adzes were unearthed at Guye site in large quantity (He and Li 2012).

Besides adzes, other common stone tools include pointed tools, stone bark cloth beaters, disc-shaped handstones (饼形器), and pitted cobbles. The pointed tools are argued to be implements for opening shells, indicating a reliance on aquatic resources (Feng 2007; Shenzhen Cultural Relics and Archeology Institute 2013). The stone beaters probably used for bark cloth making, widely distributed in southern China and Southeast Asia, suggest a different regional cloth-making system from textiles with a spinning wheel (Deng 1994). And the disc-shaped handstones (饼形器), pitted stone, and netherstones may have been used for plant food processing, such as nuts and fleshy fruits (Fu 2019; Liu et al. 2014; Shenzhen Cultural Relics and Archeology Institute 2013; Yao et al. 2016).

Table 2. 3 Formal stone tool types during middle Neolithic Period in the Pearl River Delta (data are from Feng 2007; Li and Cui 2018; Shenzhen Cultural Relics and Archeology Institute, 2013).

		Formal stone tool type										
Site	**Date (/BP)**	**Adze**	**Axe**	**Knife**	**Pestle**	**Chisel**	**Beater**	**Handstone (饼形器)**	**Hammerstone**	**Pitted cobbles**	**Netherstone**	**Pointed tools**
Xiantouling-phase 1	c. 7,000-6,400	X								X	X	
Xiantouling-phase 2	c. 6,400-6,200	X			X	X	X	X	X	X	X	
Wanfuan	c. 5,500-5,000	X									X	
Xiankezhou	5,200-5,000	X		X								
Longxue	c. 6,000	X			X		X	X		X	X	X
Baishuijing	c. 6,000-5,000	X					X				X	
Dahuangsha	6,500-6,000	X	X				X	X		X	X	
Changshalan	c. 6,000-5,000	X			X				X	X	X	
Yonglang	6,700-5,000	X										
Xiantouling-phase 3	c. 6,000	X	X	X		X	X	X		X	X	
Dameisha	6,500-6,000	X	X	X			X				X	
Caotangwan	c.5,000										X	X
Jinlansi	c.5,500	X	X									
Haogang-phase 1	6,000-5,500							X			X	
Haogang-phase 2	5,500-5,000	X	X	X			X	X			X	X
Guye	c, 5,900-5,000	X							X		X	

Plant and animal remains

Data on plant and animal remains from sites in the middle Neolithic period are limited (Table 2.4) (Cui 2007; Lu 2013; Mo 2003; Xia et al. 2019; Yang S. et al. 2015; Yang X. et al. 2018). In summary, subsistence economies in this region are believed to have relied on gathering, hunting and fishing without any agricultural activities (e.g. Chen 2017; Denham et al. 2018; Liu and Chen 2012; Ma et al. 2018; Yang et al. 2017; Zhang and Hung 2012; Zong et al. 2012). A study has shown that the palm pith (sago) may have been consumed as an important carbohydrate resource during the middle Neolithic period (Yang et al. 2013). The phytolith analysis at Xiantouling site revealed a wide distribution of palm trees around the site (Lu 2013), and the starch residues recovered from grinding tools at Xincun site (5,300-4,400 BP) directly indicate the consumption of palm pith (Yang et al. 2013). Geophytes are the other choice of carbohydrate, evidenced by the charred tuber remains found in a *fu* caldron from Dahuangsha site (6,500-6,000 BP) (Wen and Chen 1990) and the starch granules recovered at Xincun site (5,300-4,400 BP) identified as lotus (cf. *Nelumbo nucifera*), Chinese arrowhead (*Sagittaria* sp.), and fern (*Angiopteris* sp.) (Yang et al. 2013). Recently, abundant plant remains, including *Lithocarpus* spp., *Canarium album*, and Urticaceae, were recovered through flotation and handpick at Guye site (c. 5,900 -5,000BP) (Yang et al 2017; 2018).

Table 2. 4 Plant remains unearthed during middle Neolithic period (data are from Cui 2007; Lu 2013; Yang S. et al. 2015; Yang X. et al. 2013; 2018).

Site type	**site**	**Date (/BP)**	**Plant remains**		
			Macro remains	**Starch grains**	**Phytoliths**
Sand dune	Xiantouling	c.7,000-6,000			Pooideae, Panicoideae, Oryzoideae, Palmae, Bombacaceae
	Longxue	c. 6,000	*Lithocarpus corneus; Cerbera manghas; Vernicia fordii; Aphanamixis grandifolia*		
	Sham Wan -Layer F	5,300-3,800	*Amaranthus; Ricinus*		
	Xincun	5,300-4,400		palms; *Musa* sp.; cf. *Nelumbo nucifera*; *Sagittari*a sp.; cf. *Eleocharis dulcis*; *Angiopteris* sp.; *Coix* spp; *Quercus* sp.	palms; sedge; fern; *Oryza*; bamboo etc.
Shell midden	Guye	c. 5,900-5,000	*Lithocarpus; Canarium album*; Urticaceae etc.		

The fauna remains are also sparse, mainly recovered from shell midden sites, including Jinlansi site (c. 5,500 BP), Wanfuan site (c.5,500-5,000 BP), and Guye site (c.

5,900-5,000 BP) (Cui 2007; Yang et al. 2015). Except for aquatic resources, such as shellfish, fish bones, turtle, a small number of terrestrial animal bones were also found, such as *Cervus, Sus, Bubalus,* Canidae*,* and *Elephas* (Cui 2007; Yang et al. 2015). Combined with site locations (Figure 2.6) and findings of pointed stones (shell-fish pickers) and net weights, it is speculated that the subsistence practice during the middle Neolithic period showed a tendency towards maritime adaptation (Zhang and Hung 2016).

Regional influences on the Pearl River Delta cultures

Besides the regional features, such as wave-pattern on the pottery, and shouldered stone tools, during the middle Neolithic period, the Pearl River Delta has had cultural interaction with other regions, such as Yangtze River basin and Southwest China, probably through dense river networks (Figure 2.11 A) (e.g. Bu 1999; Fu 1988; Li and Cui 2018; Li and Xie 2011; Peng 2015; Shenzhen Cultural Relics and Archeology Institute 2013; Wu et al. 2013). Xiantouling culture was closely related to the cultures in the middle Yangtze River (Figure 2.12) (Shenzhen Cultural Relics and Archeology Institute 2013). The white pottery and painted pottery recovered at Xiantouling culture were derived from other communities, as it already has proven technique when it emerged but displayed a fading trend in the Pearl River Delta (Shenzhen Cultural Relics and Archeology Institute 2013). The earliest white pottery in China was found in sites with Gaomiao culture (7,800-6,800 BP), then it were unearthed together with painted pottery at sites with Tangjiagang culture (6,800-6,300 BP) and Daxi Culture (6,400-5,300 BP) (He 1994; Yin 2007).

The culture of the Pearl River Delta have more exotic features between 6,000 and 5,000 BP. I have tried to summarise the likely cultural influences derived from a review of key archaeological traits in (Li and Cui 2018). The blank stripe decoration on shoulders was from Duiziling culture (c. 6,800-5,300 BP) in the north of the Pearl River Delta; some pottery shapes, including bowl-shaped *dou* pedestal cup with high stem and ring-foot *guan* jars, are from the lower Yangtze River, northeast of the Pearl River Delta; and the microlithic tools are possibly introduced from southwest China, like Guizhou and Sichuan, which are northwest of the Pearl River Delta (Li and Cui 2018).

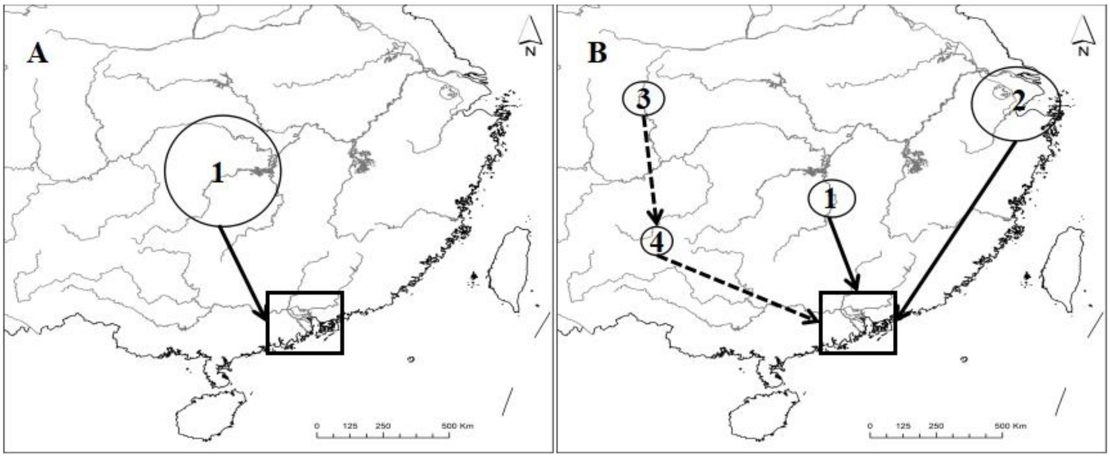


Figure 2. 11 External cultural inflow in the Pearl River Delta in the middle Neolithic period (7,000-5,000 BP). A. Xiantouling culture (7,000-6,000 BP) in the Pearl River Delta was influenced by the cultures in Hunan Province (region 1), such as Gaomiao culture, Tangjiagang culture, and Daxi culture. B. The pottery designs of Guye culture (c. 5,900-5,000 BP) was influenced by Duiziling culture along Xiangjiang River Basin (region 1) and Songze culture and Liangzhu culture in lower Yangtze River (region 2), while the microlithic tools were possibly diffused from Sichuan (for example, Zhongzipu site in region 3) and Guizhou (like Niulandong site in region 4) (referred to Li 2019; Li and Cui 2018; Shenzhen Cultural Relics and Archeology Institute 2013;Yang et al. 2015) (The circles and arrows in this figure do not represent the true distribution of the archaeological cultures and its dispersal routes, and the dotted arrows mean the uncertain relationship).

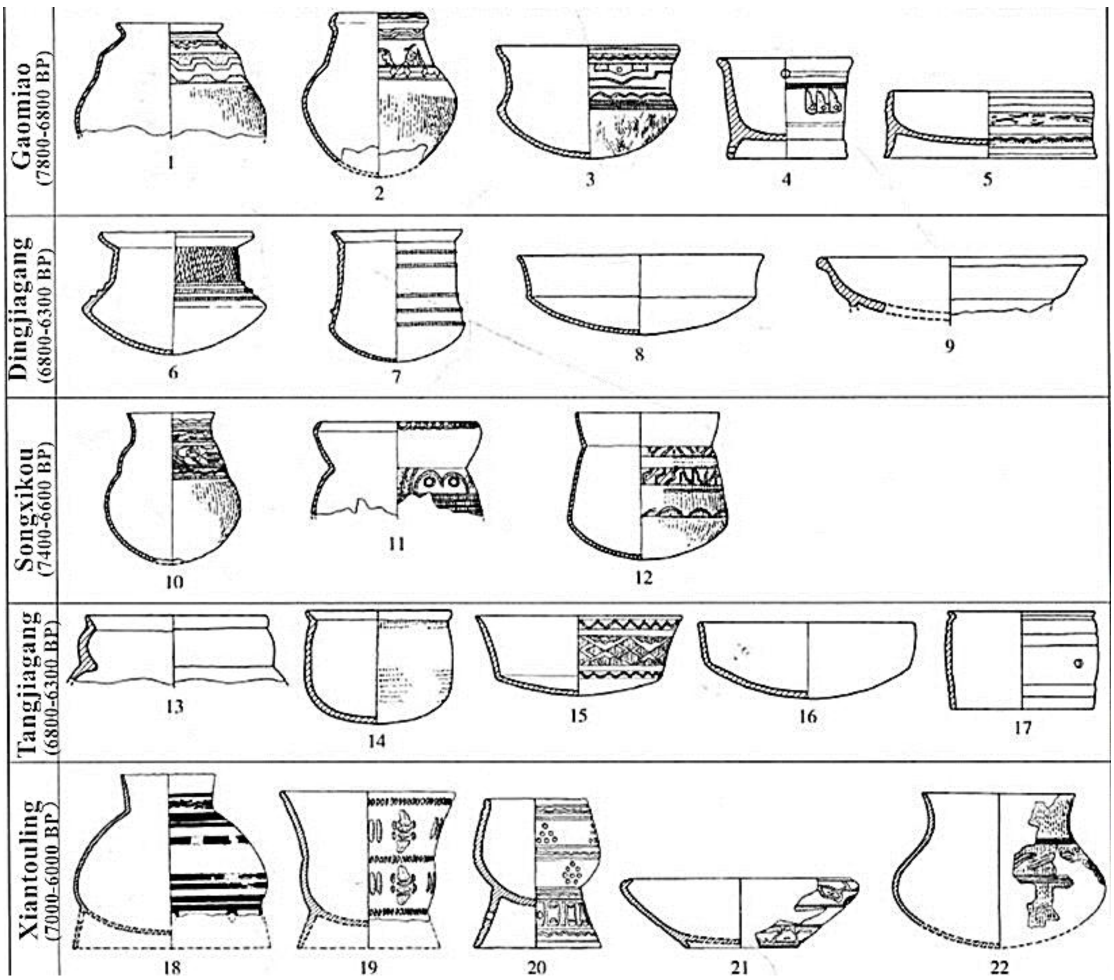


Figure 2. 12 Pottery assemblage comparison among Xiantouling site (7,000-6,000 BP), Gaomiao site (7,800-6,800 BP), Dingjiagang site (6,800-6,300 BP), Songxikou site (7,400-6,600 BP), and Tangjiagnag site (6,800-5,300 BP). 1, 2, 10, 13, and 18, *guan* jars; 3, 4, 8,15,16, and 21, bowl; 5 and 9, plates; 6, 7, 11, 12, 14, and 22, *fu* cauldrons; 17, basin; 19 and 20, cups. (after figure 172 in Shenzhen Cultural Relics and Archeology Institute 2013: 273).

In addition to the cultural inflow, cultural export also occurred during the middle Neolithic period, such as the export of shouldered adzes and bark cloth beaters (e.g. Deng 1999; Fu 1988; Peng 2015). The stone bark cloth beater, for example, were found at seven sites at least in the Pearl River Delta during middle Neolithic period (Table 2.3) and then appears to spread eastward and southward in the late Neolithic period. Key site for evidence of dispersals are Houshan site (3,500-3,000 BP) in eastern Guangdong and sites with Ha Giang culture (c. 5,000-4,000 BP) and Phung Nguyen culture (c. 4,000-3,500 BP) in north Vietnam (Deng 1999; Peng 2015).

It is argued that the shouldered stone adze originated in the Pearl River Delta in the middle Neolithic period and then spread westward and dispersed to Guangxi, Yunnan, and mainland Southeast Asia (Fu 1988; Peng 2015). But Peng and Jiang (1991) have even proposed a different view, arguing that the shouldered tools recovered in Guangxi were earlier than those in the Pearl River Delta, at c. 7,000 BP, and suggested that Guangxi is a possibly independent origin of shouldered stone tools. However, the dating data of the sites in Guangxi where shouldered stone tools were unearthed are unclear (Peng 2015). At around 5,000 BP, the shouldered stone tools arrived in the northeast coastal place of Vietnam and then were largely found in west of Vietnam, for example, at Cai Beo site, together with cord-marking pottery (Higham 2014; Peng 2015). A similar type of shouldered tool was also found at Laos, Shuwuzhai, Myanmar, Thailand (Fu 1988).

2.2.2 Late Neolithic period (5,000-3,500 BP)

Throughout southern China, the density of archaeological sites (number of sites per 1,000 km^2) slightly increases after c. 5,000 BP (Hosner et al. 2016). The number of sites in the Pearl River Delta presented a similar increasing trend as well (Figure 2.13) (Yang et al. 2015). The archaeological cultures of this period still retain some characteristics of the middle Neolithic period, such as the prevalence of round-bottom pottery vessels, ring-foot pottery vessels, but infrequency of three-foot or flat-bottom ones (e.g.Wu and Ye 1993; Yang et al. 2015). There are also obvious changes, like the emergence and development of geometrical stamped pottery and dominance of axes and adzes (e.g. Lu 2007; Wu and Ye 1993; Xiao 2004; Yang et al. 2015). The cultural sequence during this period was further divided into two phases according to the development level of geometric stamped pottery (Guangdong Museum and Foshan Museum 2006; Institute of Archaeology, Chinese Academy of Social Sciences 2010). The early phase was called Yonglang type or Yuanzhou type, dating from 5,000 to 4,000 BP, which is the original period of the geometric stamped pottery (Institute of Archaeology, Chinese Academy of Social Sciences 2010). The later phase was represented by Hedang site (4,300-3,500 BP), which was a developed phase of geometric stamped pottery (Guangdong Museum and Foshan Museum 2006). Some researches further indicate the cultural differences between shell middens and sand dunes (e.g. Institute of Archaeology, Chinese Academy of Social Sciences 2010; Wu and Yang 1993; Zhao et al. 1997; Zhu 1988). In this part, the differences between sand dunes and shell middens were reviewed as well.

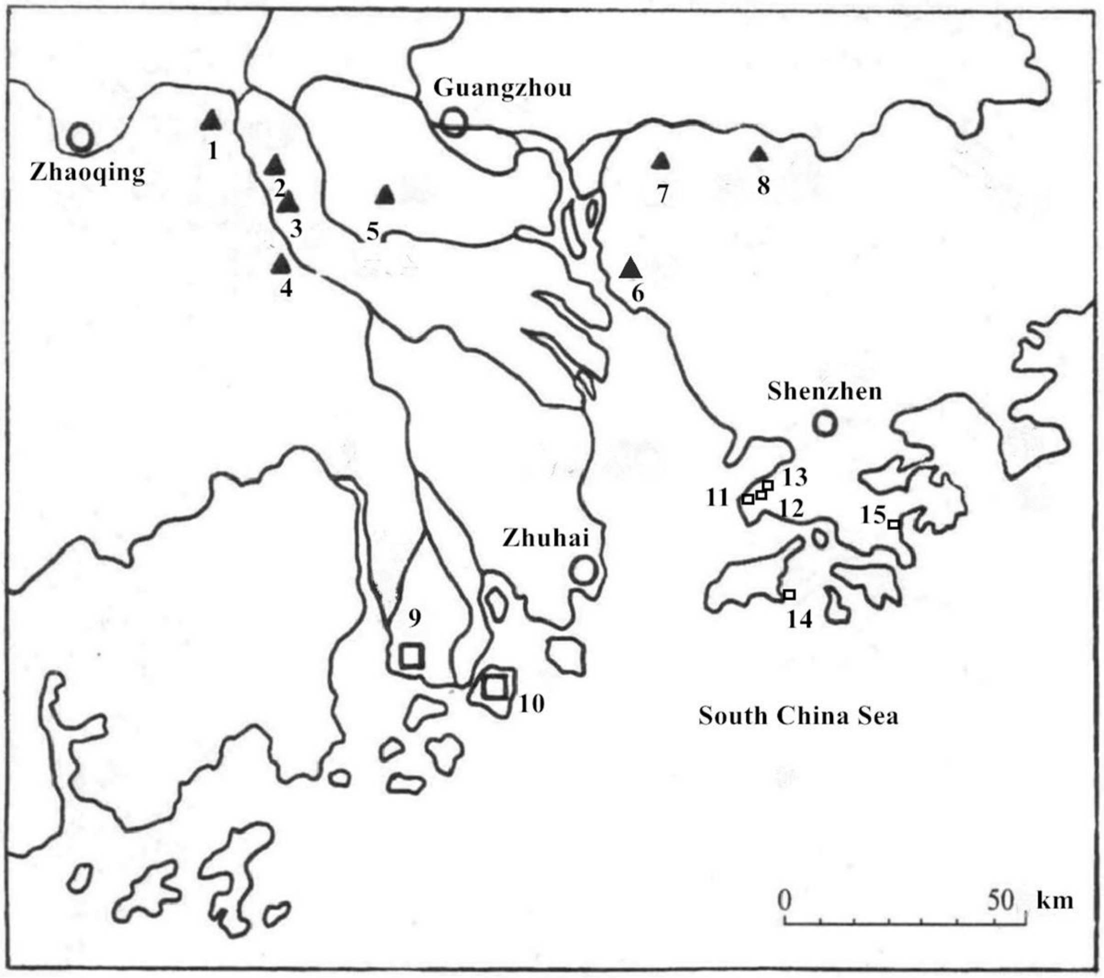


Figure 2. 13 Distribution of some sites in the late Neolithic period (Modified after figure 1 of Zhao et al. 2000). Shell middens (marked with triangles): 1, Maogang site; 2, Yinzhou site; 3, Youyugang site; 4, Liyugang site; 5, Hedang site; 6 Cuntou site; 7, Haogang site; 8, Yuanzhou site; Sand dunes (marked with squares): 9, Caotangwan site; 10, Tangxiahuan site; 11, Yonglang site; 12, Wujiacun site; 13; Chenjiayuan site; 14, Dongwanzai site; 15 Sha Ha site.

During the period from 5,000 to 4,000 BP, Yonglang type culture, named after the second phase of Yonglang site (c. 4,600-4,400 BP) in Hong Kong, is distributed in the Pearl River Delta (Bu 1999; Institute of Archaeology, Chinese Academy of Social Sciences 2010; Zhao et al. 1997). A series of sites, such as Youyugang site (c. 4,500 BP), Yuanzhou site (c. 4,500 BP), and Yinzhou site (c. 4,500 BP), the lower-layer of Chenjiayuan site (c. 4,000 BP), middle layer (L3) of Wujiayuan site (c.4,000 BP) and Houshawan site (c. 4,450 BP), with similar cultural features, are included. (Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li 1991; Ou and Mo 1999; 2002).

The settlements should be large-scale, long-term, and well-organized at that time, according to the unearthed house foundations and burials (e.g. Li 2000; Ou and Mo 1999; 2002; Xiao 2004; Zhao et al. 1997; Zou et al. 1999). For example, Yinzhou site was planned into graveyard, residential area, and garbage area (Li 2000). But the common housing structures during this period were unclear due to the irregular distribution of post holes at these sites (e.g. Li 2000; Ou and Mo 1999; 2002; Xiao 2004; Zhao et al. 1997; Zou et al. 1999). The house foundations recovered at the middle layer of Chenjiayuan site (c. 4,000 BP), which is a 107.5 m^2 west-facing house (Figure 2.14), reveal one housing structure in the delta (Ou and Mo 1999). It (F1) was built on a foundation with seven layers of rammed earth (Figure 2.14 B) (Ou and Mo 1999), which was a popular structural design in north China after around 5,000 BP. And the house was supported by 51 neatly arranged pillars (Figure 2.14 A) (Ou and Mo 1999). It is speculated that the wall and roof of this house were built by bamboo, thatch, or bark (Figure 2.14 C and D) (Ou and Mo, 1999). Besides, there is another house (F2) with the same rammed earth adjacent to F1 (Figure 2.14 A). The function of this large area house is unclear. It has been interpreted as the house of the community head or the place for public activities (Ou and Mo 1999).

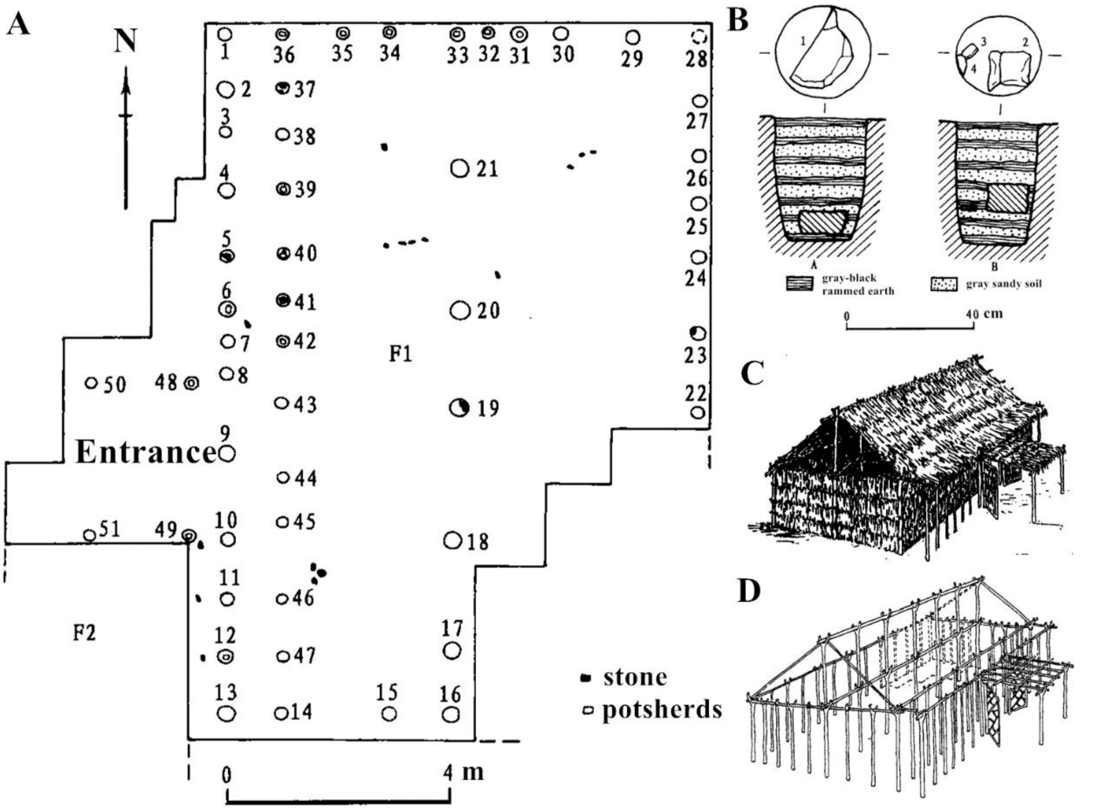


Figure 2. 14 House remains of Wujiayuan site. A Floor plan of F1, 1-51, pillar holes; B Sectional view of the pillar holes, (A) No.5 pillar hole (B), No. 37 pillar hole; 1-2, column base; 3-4 potsherds. C, appearance restoration of F1. D, recovery building structure of F1. (from Ou and Mo, 1999).

Burials from the region are mostly dated to the 4th millennium BP, excavated from shell middens, such as Yinzhou site (c. 4,500 BP) and Youyugang site (c. 4,500 BP), and a few are found at sand dunes, for example, Yonglang site (c. 4,600-4,400 BP) (Figure 2.15) (Li 2000; Li, Z. and Li, Y. 1997; Zhao et al. 1997). The skeletons include not only adults but also children (Huang and Liu 1988; Li 2000; Li Z. and Li Y. 1997). Every burial has one funeral item at least, and the largest number of those items is eight (Figure 2.15 B). Among them, *dou* pedestal cup, *guan* jars, and *fu* cauldrons are popular (Li 2000; Li, Z. and Li, Y. 1997; Zhao et al. 1997).

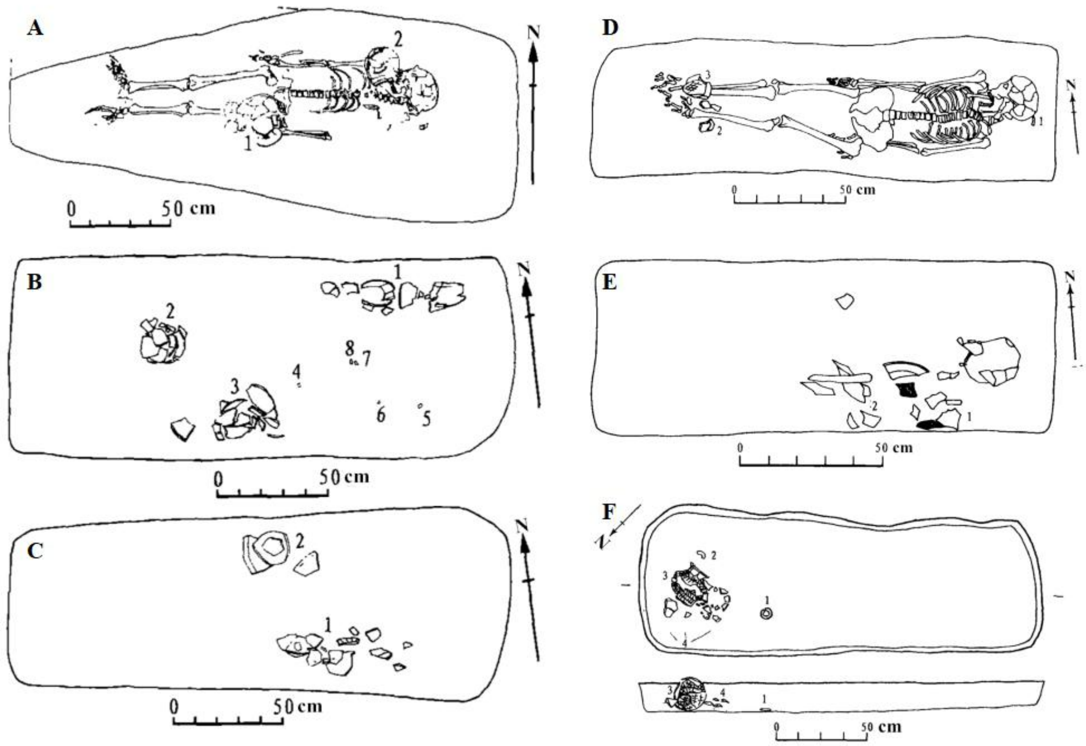


Figure 2. 15 Burials between 5,000 to 4,000 BP. A. M20 of Yinzhou site: 1, *dou* pedestal cup; 2, *guan* jar; B. M32 of Yinzhou site: 1, *fu* cauldron; 2, *guan* jar; 3, *dou* pedestal cup; 4, broken stone ring; 5-8, stone charm; C, M37 of Yinzhou site: 1, *guan* jar; 2, *dou* pedestal cup; D. M12 of Youyugang site: 1, Jewelry made of animal teeth; 2, *fu* cauldron; E. M37 of Youyugang site: 1, *fu* cauldron; 2, *dou* pedestal cup; F. M1 at Yonglang site: 1,2, stone half-circle rings; 3,4, *guan* jars (from Li 2000; Li, Z. and Li, Y. 1997; Zhao et al. 1997).

The pottery assemblage was dominant by sand-tempered vessels, including *guan* jars, *fu* cauldrons, bowls, spinning wheels, and *bi* grills, with a few round-bottom clay vessels with ring foot (Figure 2.16 1-5) (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 710). The cord-marking pattern is still dominant decoration on the pottery (Institute of Archaeology, Chinese Academy of Social Sciences 2010: 710). These characteristics reveal the inheritance relationship between Yonglang type and Xiantouling type. The innovation of Yonglang type was shown in the geometric stamped pottery, such as zigzag patterns and leaf vein patterns, which replaced the painted and incision designs (e.g. Bu 1999; Institute of Archaeology, Chinese Academy of Social Sciences 2010: 710; Liu and Chen 2012; Ou and Mo 1999; 2002; Wu and Ye 1993; Zhao et al. 1997). There are also some new ceramic forms, like *fou* jars, *weng* jars, *zun* goblet, and *bi* grills (Institute of Archaeology, Chinese Academy of Social Sciences

2010; Mo 1982; Ou and Mo 2002; 1999; Zhao et al. 1997).

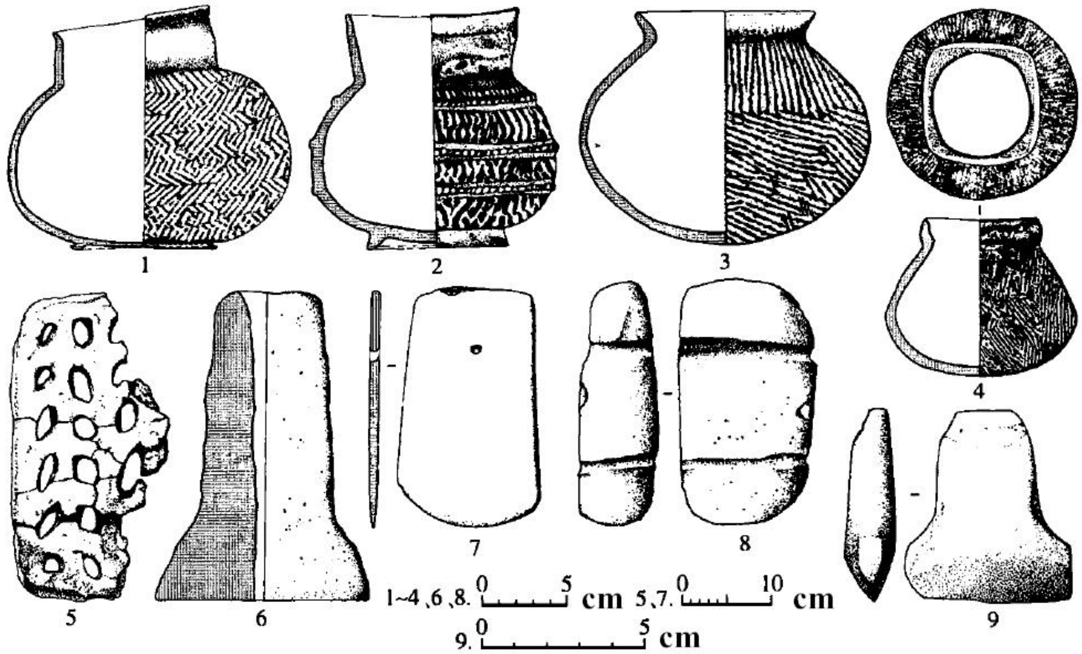


Figure 2. 16 Ceramic and lithic remains of Yongloang type culture. 1, 2, 4, *guan* jars; 3, *fu* cauldrons; 5, grill; 6, stand; 7, battle-axe; 8, net weight; 9, shouldered adze (after figure 7-22 in Institute of Archaeology, Chinese Academy of Social Sciences 2010: 710).

The quantity and quality of stone tools increased as well, including knives, axes, shouldered adzes, net weights, chisels, and arrowheads (Figure 2.16 7-9 and Figure 2.17) (e.g. Bu 1999; Institute of Archaeology, Chinese Academy of Social Sciences 2010; Mo 1982; Ou and Mo 2002; 1999; Wu and Ye 1993; Xiao 2004; Zhao et al. 1997). Besides the stone axes and adzes, the tool kit at this time also contained a large number of stone weights (Figure 2.16, 8 and Figure 2.17 B), for example, a total of 1,096 stone weights were recovered at Baojingwan site (c. 4,000 BP) (Xiao 2004), and a large number of arrowheads (Figure 2.17 C) (Wu and Ye 1993; Zhao et al. 1997). The stone beaters had nearly disappeared, possibly replaced by ceramic spinning wheels (Xiao 2004). During this period, the tool making technique advanced, reflected by some well-polished stone decorative objects, and the popular double-side drilling technology (Figure 2.18) (Zhao et al. 1997).

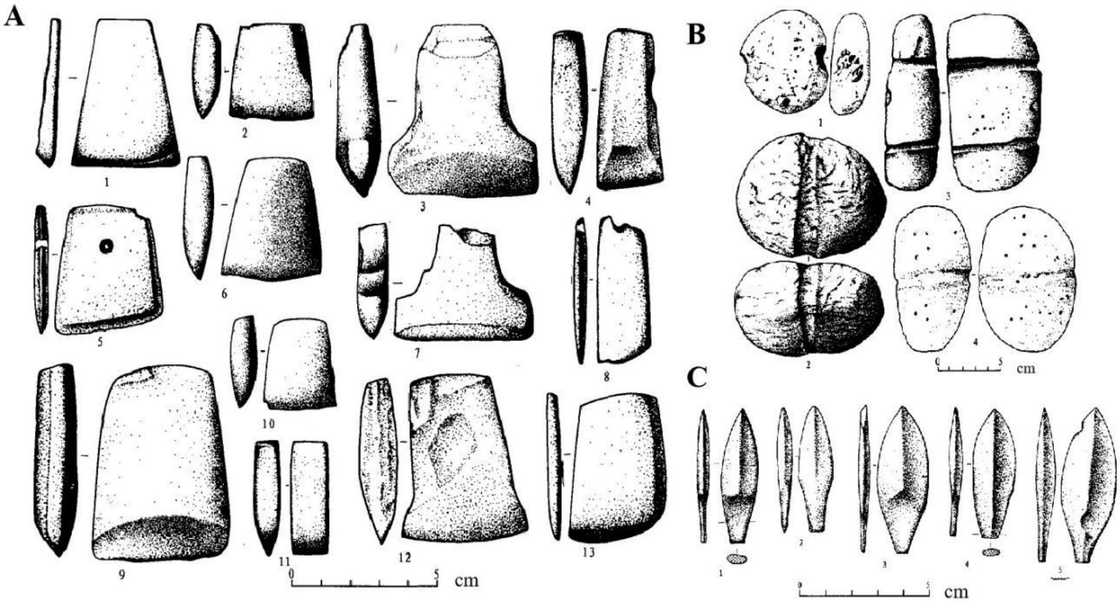


Figure 2. 17 Stone artifacts from Yonglang site.A. stone tools:1 -12. Adzes; 13. Knife; B. stone net weights: C. stone arrowheads. (referred from Zhao et al. 1997).

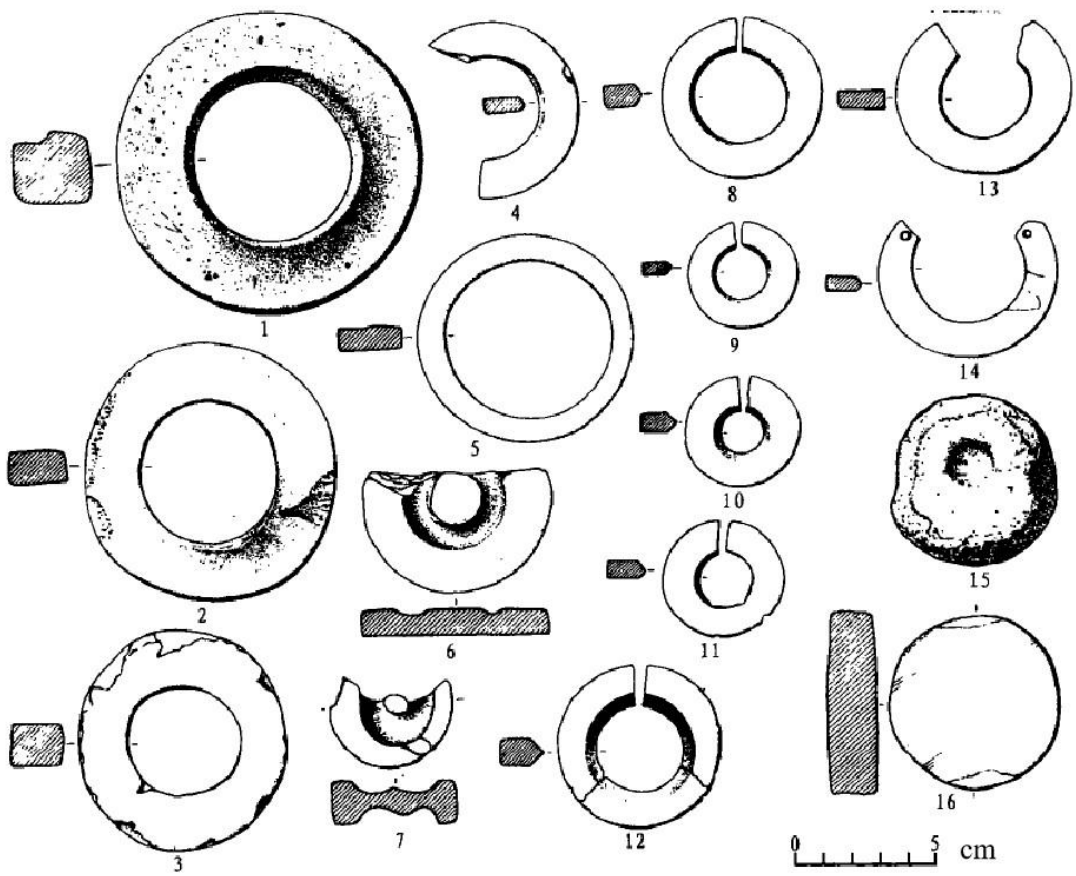


Figure 2. 18 Stone decorative objects from Yonglang site: 1-3,5. Rings; 4, 6-14 *jue* half-circle rings; 15, stone ball; 16, disc-shaped tool. (Zhao et al. 1997).

The subsistence economy at those sites is believed to have relied on hunting, fishing, and gathering. Stone artefacts recovered from sites includes large numbers of stone net weights, such at Yonglang site (N=800) and Baojingwan site (N=1,096) (Figure 2.17 B), and arrowheads (Figure 2.17 C) (e.g. Institute of Archaeology, Chinese Academy of Social Sciences 2010; Liu and Chen 2012; Xiao 2004; Zhang and Hung 2016).

Cultivation practices may have emerged in the Pearl River Delta by the mid-fourth millennium BP. The first clue is the communication with the farming communities, such as Shixia people in north delta, based on some cultural traits, for example, similar battle-axes (Institute of Archaeology, Chinese Academy of Social Sciences 2010; Liu and Chen 2012; Yang et al. 2017; Zhang and Hung 2012). And some biological remains also support this hypothesis, for example, the possibly domesticated-type phytoliths of Cucurbitaceae recovered at Sha Ha site (c. 4,500 BP) (charred rice seeds were also found at Sha Ha site, but whether they were domesticated type were not confirmed) (Lu 2007).

The following phase is a period when the geometric stamped pottery developed, represented by the elaborate patterns recovered at Hedang site (c. 4,300-3,500 BP) (Guangdong museum and Foshan Museum 2006). Therefore, it is argued that there should be a Hedang type culture, dating from c. 4,200 to 3,500 BP, including Hedang site, the second phase of Youyuang site, the second phase of Yinzhou site, the late phase of Yuanzhou site, the first phase of Cuntou site, Zaogang site, the second phase of Chenjiayuan site, the second phase of Tung Wan Tsai site, and the fourth layer of Tangxiahuan site (Chen 2012; Guangdong museum and Foshan Museum 2006; Liu 2006; Yang et al. 2015).

Most house structures are not clear at present, because only post holes with cellars, pits, stoves or burned soil were found (Figure 2.19A) (Guangdong Museum and Foushan Museum 2006; Li 2000; Li, Z. and Li, Y. 1997; Yang et al. 2015). But depending on the distribution of those post holes at every site, it can also be speculated that the areas of all these houses are small, from 10 to 40 m^2, suitable for a small-size family, suggesting the family-based social structure (Cao 2009: 91-144; Chen and He 1984; Li, Z. and Li,

Y. 1997; Yang and Chen 1994; Yang, 2007; Yang et al. 2015).

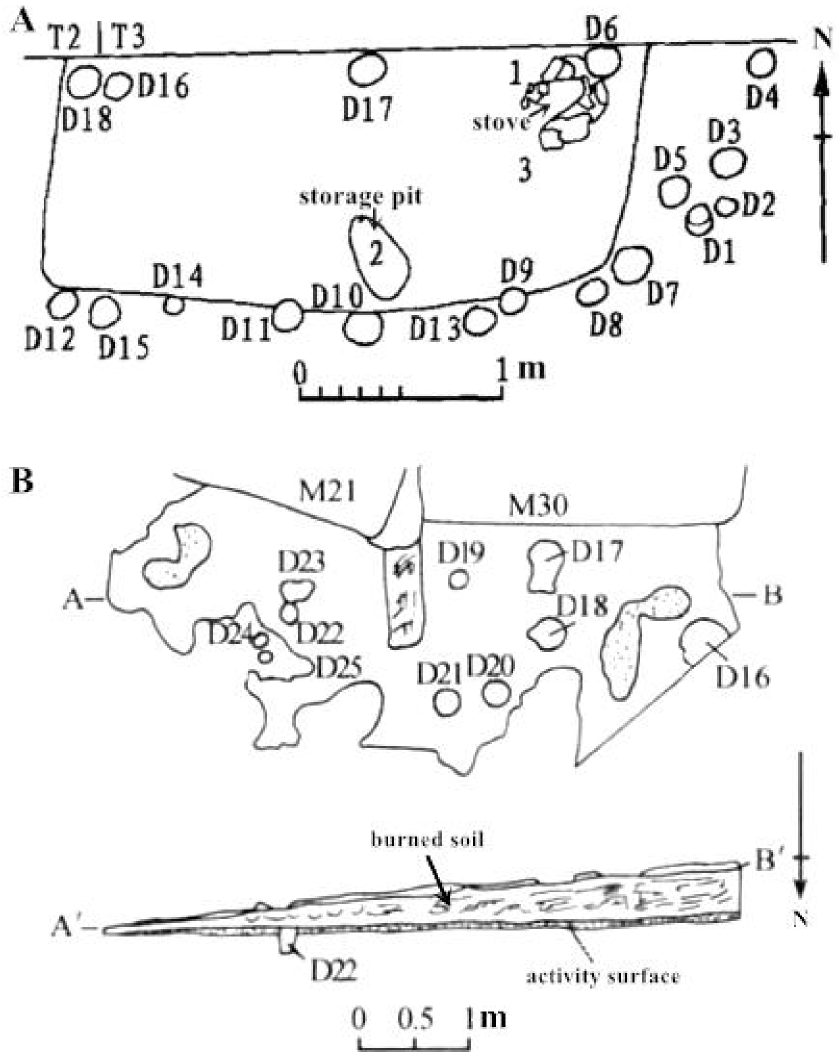


Figure 2. 19 House foundations unearthed during this period. A. F1 at Yinzhou site; B, F3 at Youyugang site (from Li 2000; Li Z.and Li Y. 1997).

Recovered burial numbers increase in the late 4th millennium: N=77 at Hedang site and N=36 at Youyugang site (4,000-3,300 BP) (Guangdong museum and Foshan Museum 2006; and Li, Z. and Li, Y. 1997). Except the north-south direction burial found at the second layer of Chenjiayuan site (c.3,500 BP), most burials are east-west oriented rectangular earthen pits, with a single, stretched and supine skeleton (Figure 2.20) (Chen and He 1984; Li, Z. and Li, Y. 1997; Ou and Mo 1999; Yang and Chen 1994; Yang 2007; Yang et al. 2015). Grave goods were diverse and some are very delicate (e.g.

Guangdong museum and Foshan museum 2006; Ou and Mo 1999), for example, the ivory decorations recovered at Hedang site (Yang 2007). It is also argued that the moon-shape decoration and sun-shape decoration unearthed at Chenjiayuan site are suggestive of primitive religion (Ou and Mo 1999). These items could further reflect the social division of labor to some extent. For example, at Hedang site, burials of males were always furnished with stone axes, adzes, or arrowheads, while female ones usually with ceramic spinning wheel (Yang 2007).

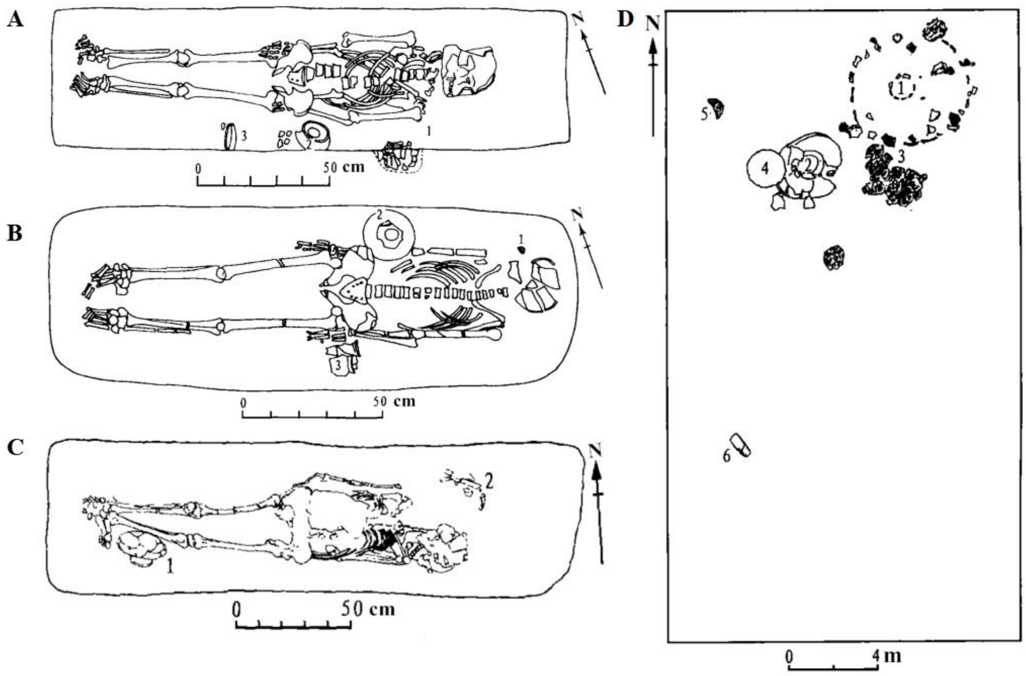


Figure 2. 20 Burials during the period from c. 4,200 BP to 3,500 BP. A, M9 of Youyugang site, 1, *fu* cauldron; 2, 3, *dou* pedestal cup; B, M7 of Youyugang site, 1, spinning wheel; *dou* pedestal cup; 3, *fu* cauldrons; C, M15 of Yinzhou site, 1, *dou* pedestal cup; 2, animal bone; D, M1 of Chenjiayuan site, 1, *guan* jar; 2, *dou* pedestal; *fou* jar; 4, sun-shape decoration; 5, moo-shape decoration; 6, stepped stone adzes with shoulders (modified after figures from Li, Z. and Li, Y. 1997; Li 2000; Ou and Mo 1999).

The pottery assemblage of this type is represented by that of Hedang site (c. 4,300-3,500 BP) (e.g. Peng 2015; Yang 2007; Yang et al. 2015). The common forms are still round-bottom vessels or ring-foot vessels, with infrequent three-foot vessels and flat-bottom vessels, including *fu* cauldrons, *guan* jars, and *ding* tripod (Figure 2.21) (Chen 2012; Guangdong Museum and Foshan Museum 2006; Li 2000; Yang 2007;

Yang et al. 2015; Yang, H. and Yang, Y. 1983). And a few painted potsherds were still unearthed at Hedang site, which reveal its relationship with the culture in the middle Neolithic period (Guangdong Museum and Foshan Museum 2006).

The main development of Hedang type pottery is that the geometric stamped patterns become elaborate.More than 30 patterns were recognised at Hedang site, including checkered pattern, leaf vein pattern, and zigzag pattern (Figure 2.22) (Guangdong Museum and Foshan Museum 2006; Yang 2007; Yang et al. 2015), which are stamped deeply and clearly (Yang 2007). Besides, 70 incision symbols inside of ring foot were found at Hedang site, which could be divided into 46 types (Guangdong Museum and Foshan Museum 2006). These symbols are considered as early inscriptions (Figure 2.23) (Guangdong Museum and Foshan Museum 2006).

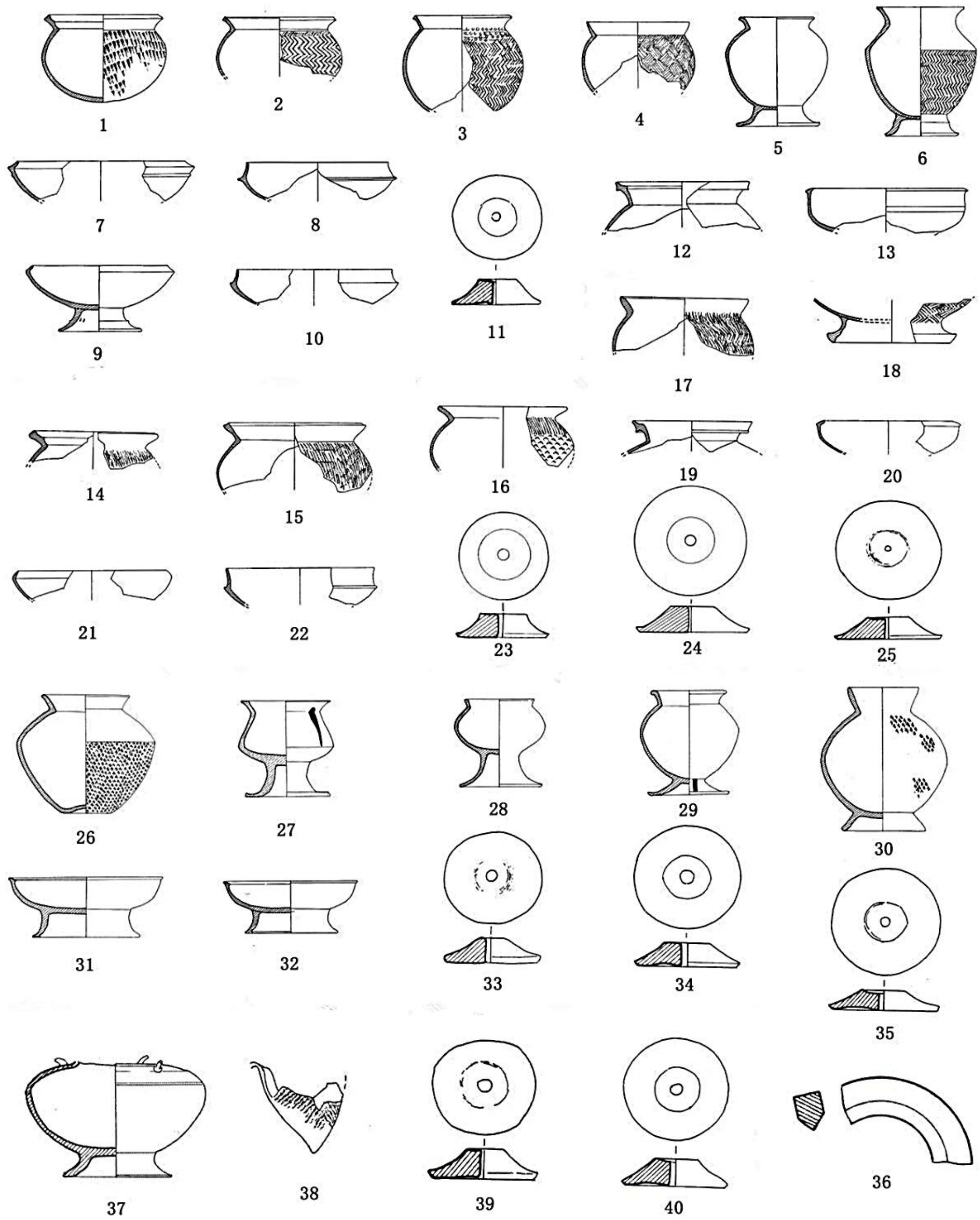


Figure 2. 21 Pottery assemblage of Hedang site (Figure 2 of Chen 2012). 1,14. *fu* cauldrons; 2-6,12, 15-19,26-30, 37. *guan* jars; 7-10, 13, 20-22 *dou* pedestal cup; 11, 23-25, 33-35, 39, 40. ceramic spinning wheel; 31, 32. plates with ring foot; 36 crystal *jue* half-circle ring; 38. foot of *li* tripod.

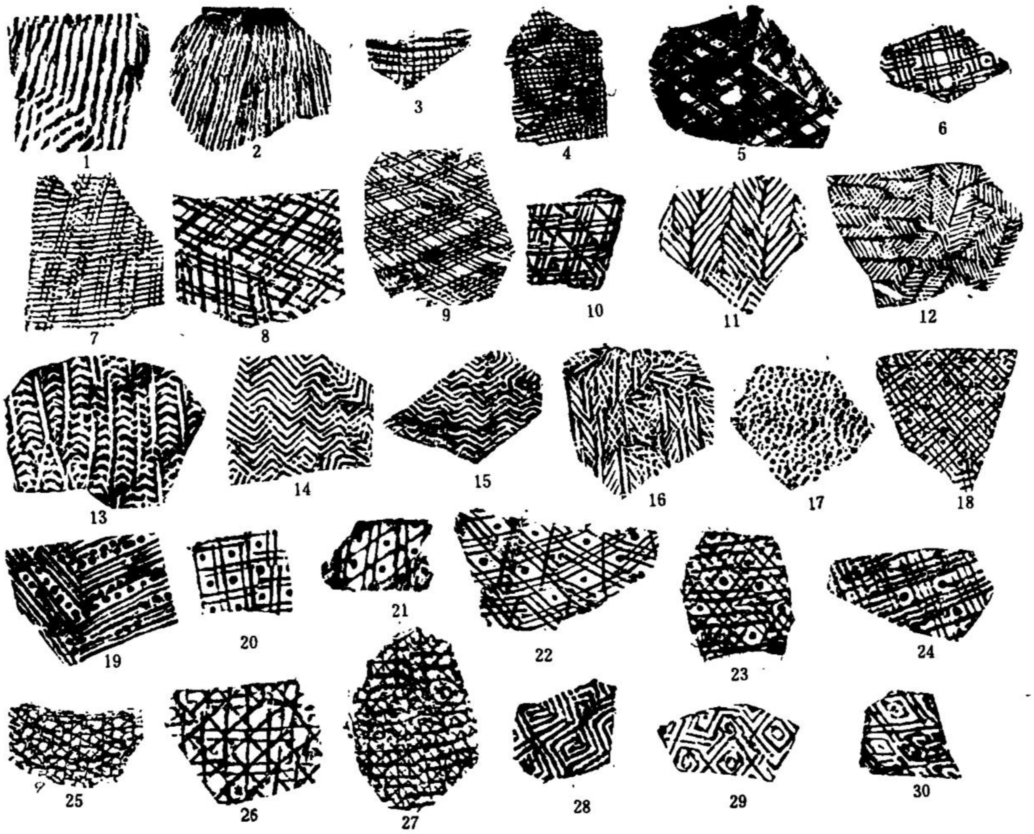


Figure 2. 22 Geometric stamped patterns on pottery at Maogang site (from Yang, H. and Yang, Y. 1983).

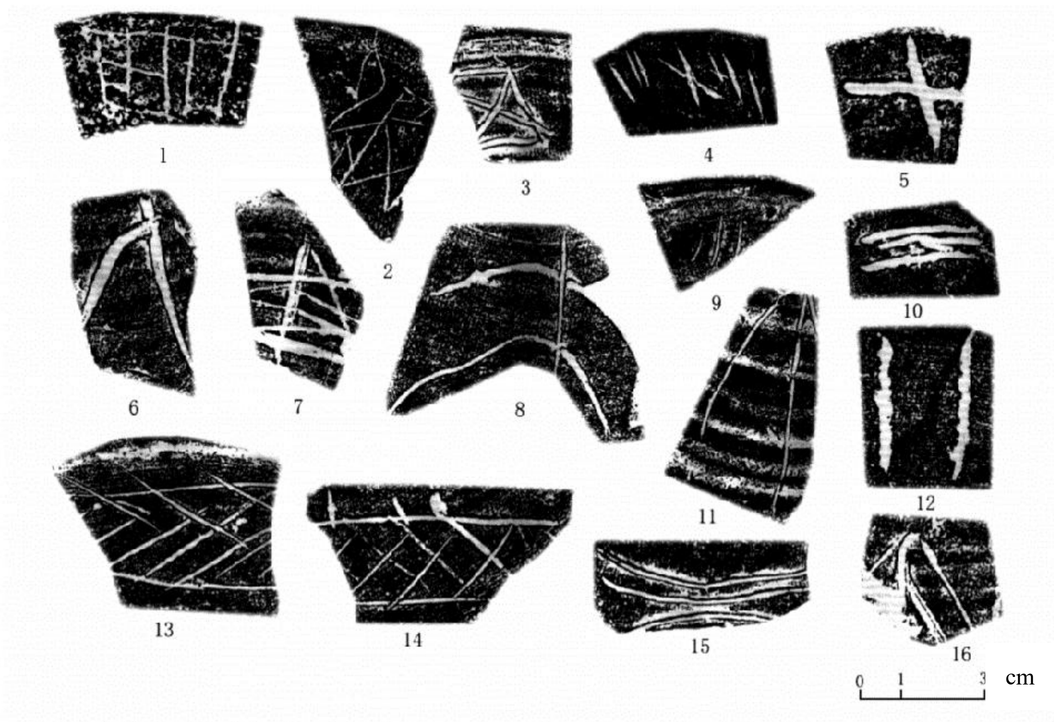


Figure 2. 23 Incision symbols from Hedang site (from Yang 2007).

The stone tools include axes, adzes, chisels, spears, arrowheads, and stone rings (Figure 2.24). Within them, adzes and axes are the majorities, with higher frequency of the shouldered forms (e.g. Chen and He 1984; Feng and Lu 1999; Li, Z. and Li, Y. 1997; Li 2000; Yang 2007; Yang et al. 2015). Meanwhile, the stepped shouldered stone tools, including axes and adzes, were introduced (Chen and He 1984; Li, Z. and Li, Y. 1997; Yang 2007; Yang et al. 2015). On the basis of this new tool type, the stepped tools with shoulders were created and then gradually accepted by the natives, which count increased from only one at Zaogang site to 18 at Hedang site (Chen and He 1984; Yang 2007). But the sizes of those tools are relatively small (e.g. Chen and He 1984; Guangdong museum and Foshan museum 2006). For example, more than half stone adzes unearthed at Zaogang site are 8 to 9 cm long, one in three is under 4 cm, and only a few tools are bigger than 9 cm (Figure 2.24) (Chen and He 1984).

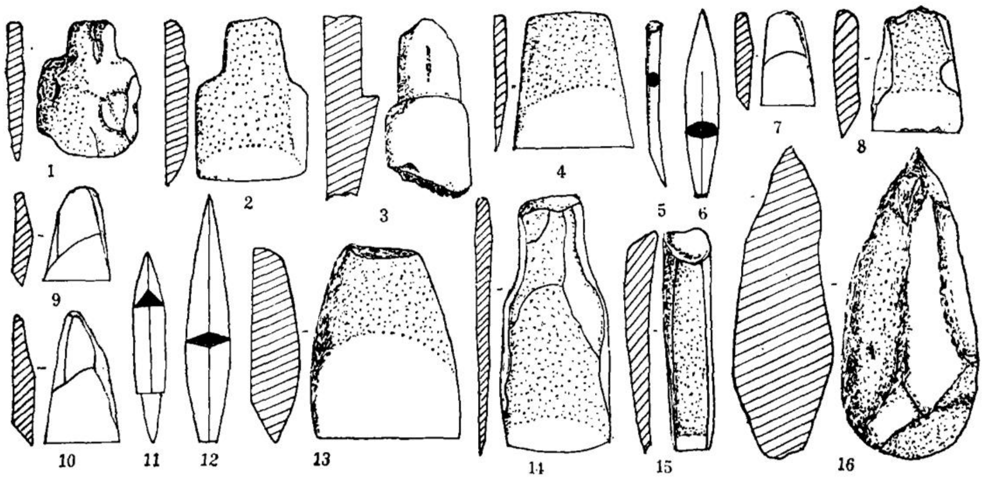


Figure 2. 24 Stone tools from Zaogang site. 1. shouldered stone axe; 2,14. shouldered stone adzes; 3. stepped shouldered adze; 4, 7-10, 13. trapezoidal stone adzes; 5. bone needles; 6,11, 12. bone arrowhead; 15. bone chisel; 16. pointed stone tool (Chen and He 1984)(The scale of 1-3are 1:4. I have measured 1 which is 2.3cm long in the image; the scale of others is 1:2, and the 10 is 2.2cm long in the image).

Plant and animal remains

Domesticated pigs are considered as a symbol of the agricultural emergence in the Pearl River Delta, however, the identification of those bones, for example, at Hedang site, are questioned (see Yang 2007). Besides a large number of shells, every site during this period yielded animal bones more or less, and some of them have marks of burning, cutting, and chopping, considering as the remains of tool making (Chen and He 1984; Li et al. 2015; Li, Z. and Li, Y. 1997; Yang 2007; Yang, H. and Yang, Y. 1983). These animals included deer, buffalo, pig, sheep, tiger, dog, elephant, cat turtle, crocodile (Table 2.5) (Chen and He 1984; Li et al. 2015; Li, Z. and Li, Y. 1997; Yang 2007; Yang, H. and Yang, Y. 1983).

Due to the environment, the preservation of plant remains is still poor. The only archaeobotanical data are found at Maogang site, including macro-remains of *Canarium, Ginkgo, Ziziphus,* and *Diospyros* (Table 2.5) (Yang, H. and Yang, Y. 1983). Recently, the phytoliths and charred rice seeds recovered as Chaling site (4,500-3,700 BP) suggested that the rice farming was introduced into the Pearl River Delta (Xia et al. 2019; Yang et al. 2018). Current view on the local subsistence practice in the delta is that gathering, hunting and fishing were still the most common subsistence practice, while the cultivation activities may emerge during this period (Chen and He 1984; Chen 1998; Li et al. 2015; Li, Z. and Li, Y. 1997; Yang 2007; Yang, H. and Yang, Y. 1983).

Table 2. 5 Biological remains in the Pearl River Delta during late Neolithic period (data are from Chen and He 1984; Guangdong Museum and Foshan Museum 2006; Huang and Zhang in press; Lu 2007; Mo 2003; Shang and Wu 2010; Wu 2000; Xia et al. 2019; Yang 1985; Yang et al. 2018; Yang, H. and Yang, Y. 1983).

Site type	**Site**	**Date (/BP)**	**Plant remains**			**Animal remains (mammal)**	
			Macro	**Starch grains**	**Phytoliths**	**Wild**	**Domesticated**
Sand dunes	Sha Ha	c. 4,500-4,000	Charred rice seed		Cucurbitaceae (possibly domesticated), Oryzoideae		
	Lujingcun	c. 4,500-3,000		Millet, palm, nuts, geophtyes			
Shell middens	Yuanzhou	c. 4,500				*Bubalus, Sus, Cervus*	
	Chaling	4,500-3,700	*Oryza sativa* subsp. *japonica;Leguminosae, Solanaceae, Amaranthaceae; Canarium sp*		*Oryza*; Arecaceae; Cucurbitaceae; Annonaceae; Fagaceae?		
	Hedang	4,300-3,500				*Elephas* sp., *Bubalus* sp.*, Muntiacus* sp., *Cervus unicolor, Cervus* sp., *Sus, Macaca* sp.*, Arctonyx* sp., *Canis* sp.	*Sus domestica*
	Jinlansi -upper layer	c. 4,000				*Cervus, Sus, Bubalus.*	
	Haoyong	c. 4,000			*Oryza* spp., Bambusoideae		
	Zaogang	c. 4,000				*Sus, Bubalus, Cervus.*	
	Maogang	c. 3,500	*Canarium; Ginkgo; Ziziphus; Diospyros*			*Sus, Bubalus, Cervus,* Caprinae*, Elephas;* Erinaceinae	*Sus domestica; Bubalus*

Cuntou	4,100-3,000	*Cervus unicolor, Cervus nippon, Muntiacus* sp.*, Cervisae, Bubalus bubalis, Panthera tigris, Viverra zibethe, Felis silvestris, Hystrix hodgsoni, Rhinocero* sp.*, Elephas maximus.*	*Sus domestica, Canis familiaris*

Regional influences on the Pearl River Delta cultures

Although the pottery assemblages in the Pearl River Delta still kept being dominated by round-bottom type and ring-foot type, several forms were introduced into from other cultures. I have tried to summarise these external influences in Figure 2.25 A (e.g. Chen 2012; Peng 2015; Yang et al. 2015; Zhu 1988). During the early phase, the influence of Shixia culture (5,000-4,100 BP) in north Guangdong is noticed (Figure 2.26) (Chen 2012; Guangdong Provincial Institute of Cultural Relics and Archaeology et al. 2014; Yang et al. 2017; Zhu 1988). For example, the three-foot ceramic vessels, with feature of Shixia culture (Guangdong Provincial Institute of Cultural Relics and Archaeology et al. 2014; Zhu 1988), were seldom unearthed at sites in the Pearl River Delta, like Yinzhou site (c. 4,500 BP), Yuanzhou site (c. 4,500 BP), Hedang site (4,200-3,500 BP), Chaling site (4,500-3,700 BP), and Baojingwan site (c. 4,000 BP) (Guangdong Museum and Foshan Museum 2006; Li 2000; Wu 2000; Xiao 2004; Zhang et al. 2018). Those findings are taken as one evidence for the cultural relationship between north Guangdong and the Pearl River Delta (Chen 2012; Guangdong Museum and Foshan Museum 2006; Xiao 2004; Zhu 1988).

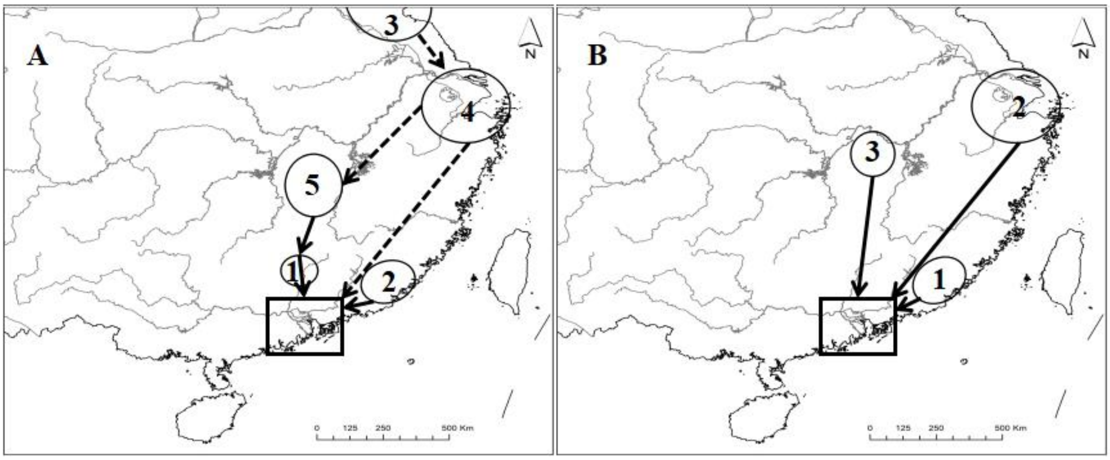


Figure 2. 25 The possible external cultural influences on these in the Pearl River Delta between 5,000 BP and 3,000 BP. A. The late Neolithic period (c. 5,000-3,500 BP): the pottery designs at present similar characteristics from North Guangdong (such as Shixia culture in region 1), which were influenced from Jiangxi (5), and East Guangdong (like Hutoupu culture in region 2) ; the stepped tools originated in the lower Yangtze River (4) were probably introduced through Jiangxi (5) and the North Guangdong (1); the tradition of tooth extraction seems to introduced from the lower Yangtze River (4), which probably originated in Shandong (3). B. Cuntou type (c. 3,500-3,000 BP) in the Pearl River Delta was affected by Hutoupu culture and Houshan culture in East Guangdong (1), Maqiao culture in lower Yangtze River (2), and Jiaoshan site in Jiangxi Province (3). (referred to Excavation report of Cuntou site in press; Fu 1988; Guangdong Museum and Foshan Museum 2006; Institute of Archaeology, Chinese Academy of Social Sciences 2010; Li 2019; Wu 2000; Yang 2007; Yang et al. 2015; Zhu 1989). (The circles and arrows in this figure do not represent the true distribution of the archaeological cultures and its dispersal routes, and the dotted arrows mean the uncertain relationship).

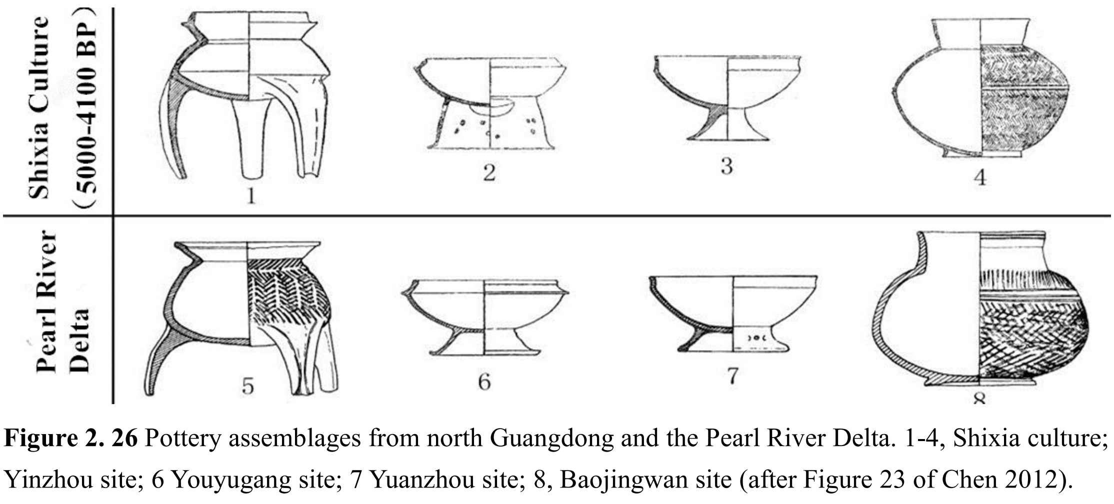


Figure 2. 26 Pottery assemblages from north Guangdong and the Pearl River Delta. 1-4, Shixia culture; 5, Yinzhou site; 6 Youyugang site; 7 Yuanzhou site; 8, Baojingwan site (after Figure 23 of Chen 2012).

The stepped stone adzes that originated in the lower Yangtze River arrived in the Pearl River Delta during the late Neolithic period (e.g. Chen and He 1984; Fu 1988; Li, Z. and Li, Y. 1997; Peng 2015; Yang et al. 2015). Through the study on the number of stepped adzes unearthed in various regions, Fu (1988) argued that the dispersal route of this implement to the Pearl River Delta was from Jiangxi Province, then to the north and east Guangdong, and finally arrived at the Pearl River Delta. Therefore, this influence has weakened in the Pearl River Delta, due to the count is smaller than that in the north or east Guangdong (Figure 2.25 A) (Fu 1988). After its introduction, the indigenous residents in the Pearl River Delta created the stepped adzes with shoulders on the basis of original shouldered stone adzes (Fu 1988; Peng 2015; Peng et al. 2012).

The tradition of tooth extraction appears in individuals from 4,400 to 3,500 BP, such as Hedang site, Youyugang site, and Zaogang site at (Chen and He 1984; Guangdong Museum and Foshan Museum 2006; Yang 2007; Yang et al. 2015). This tradition may originate from Beixin culture (c.7,000 BP) in Shandong Province and spread into the Pearl River Delta through southeast China (Figure 2.25 A) (Han and Nakahashi 1998; Peng S. 2009; Peng C. 2015; Yang 2005).

Comparison between shell middens and sand dunes

The communities in the late Neolithic period have obvious development, including geometric stamped decoration patterns, shouldered stone tools, and organised settlements (Kuang 1998; Wu and Ye 1993; Xiao 2004; Yang et al. 2015). However, some argued that there are characteristic differences between sites associated with shell middens and those located on sand dunes near the coast, in terms of pottery design, tool kit, and house foundations (Table 2.6) (e.g. Kuang 1998; Wu and Ye 1993).

Table 2. 6 Comparison between shell middens and sand dunes (Translate from Kuang 1998).

	Similarities	Differences	
		Shell middens	**Sand dunes**
Stone tools	Major types are adzes and axes; emergence of stepped tools and stepped tools with shoulders	Stone shovels	Cobble tools; large numbers of stone net weights
Bone /shell tools	Fine processing technology; abundant tool types	Large numbers	Infrequent
Pottery	Large number of round-bottom vessels and ring-foot vessels; flat-bottom vessels and three-foot vessels are infrequent; abundant geometrically stamped patterns	Sand-tempered vessels are dominant; the forms of vessels are simple, such as *fu* cauldrons, *guan* jars, *wan* bowls; decoration patterns are also simple, for example water-wave pattern	The proportion of clay pottery is lower than sand-tempered ones; more vessel forms decoration patterns are complex; some incision symbols appeared
Burial	Rectangular shallow grave mainly; a small number of burials have 1-3 funerary objects, and the funerary item seems to have gender distinction		
Settlement	Long-term stable sedentism	Emergence of rammed earth foundation	Silted house structure; already have preliminary planning of settlement
Economy	Relied on hunting, gathering and fishing mainly; cultivation probably has begun		

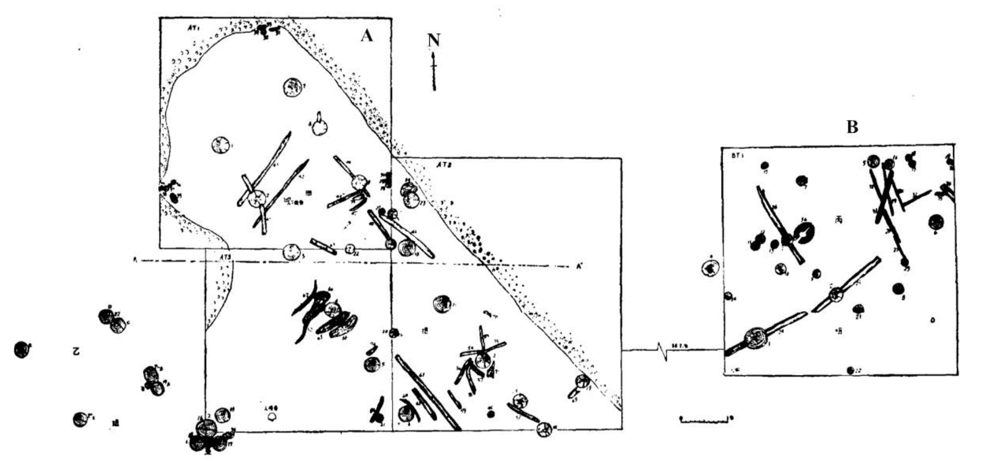
2.2.3 Archaeological cultures between 3,500 BP and 3,000 BP

During this period, a stone mould for bronze item making was unearthed at the fourth layer of Tangxiahuan site (Shang Dynasty, c. 3,600-3,000 BP) , so Chinese archaeologists argued it as the symbol, suggesting that the Bronze Age in the Pearl River Delta began (see Yang et al. 2015). At that time, the concave-bottom vessels and some stone weapons, like spears and dagger-axes, were unearthed at several sites, such as the third phase of Yinzhou site, Maogang site, and the second and third phases of Cuntou site (Figure 2.13) (Excavation report of Cuntou site in press; Li 2000; Yang, H. and Yang, Y. 1983).

The long-term stable sedentary settlements were well organized (Yang et al. 2015: 454-455). For example, at the Cuntou site a total of four activity areas zones have been identified: 1) the garbage area is located in the south coastal lowland, 2) a residential area is in the central part and west part of the site; 3) there is an an area without any deposits of shells, considered as a public area for community activities and 4) a separate burial zone (Excavation report of Cuntou site in press; Li 2000).

House structures in different communities are varied, like the wooden houses above waters at Maogang site (Figure 2.27) and the ground construction with burned soil at Cuntou site (Figure 2.28) (Excavation report of Cuntou site in press; Yang, H. and Yang, Y. 1983). It is inferred that the house shapes included at least rectangular and nearly circular (Figure 2.28) (Excavation report of Cuntou site, in press; Guangdong Museum and Foshan Museum 2006; Li 2000; Yang et al. 2015).

A



B

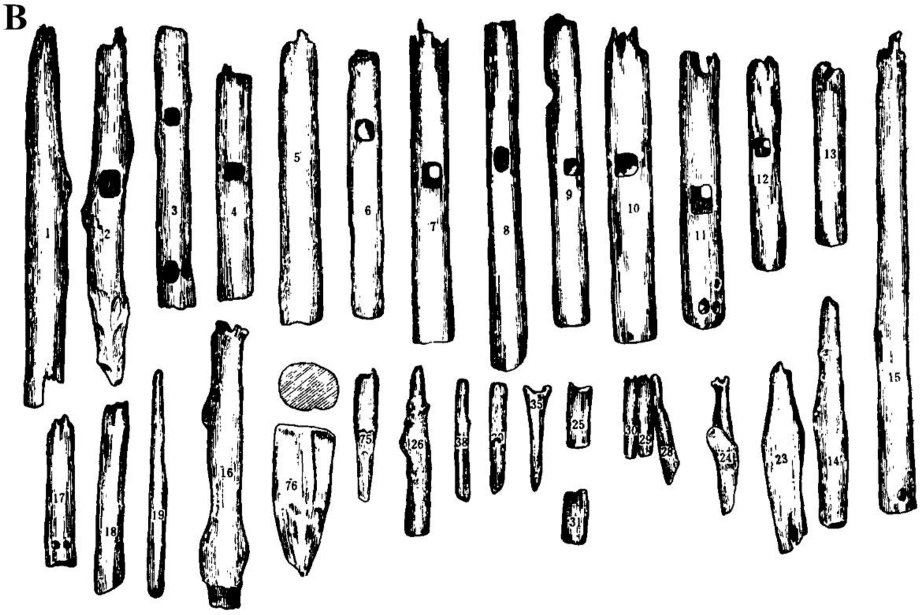


Figure 2. 27 House remains at Maogang site. A. Excavation area of Maogang site; B. Wooden building blocks from Maogang A zone (1-75 used scale 1:60; 15 which is 8.7cm in length in the original figure, which is actually around 522cm; The scale of 76 is 1:3 in the original image, which should be 8.4 cm) (from Yang, H. and Yang, Y. 1983).

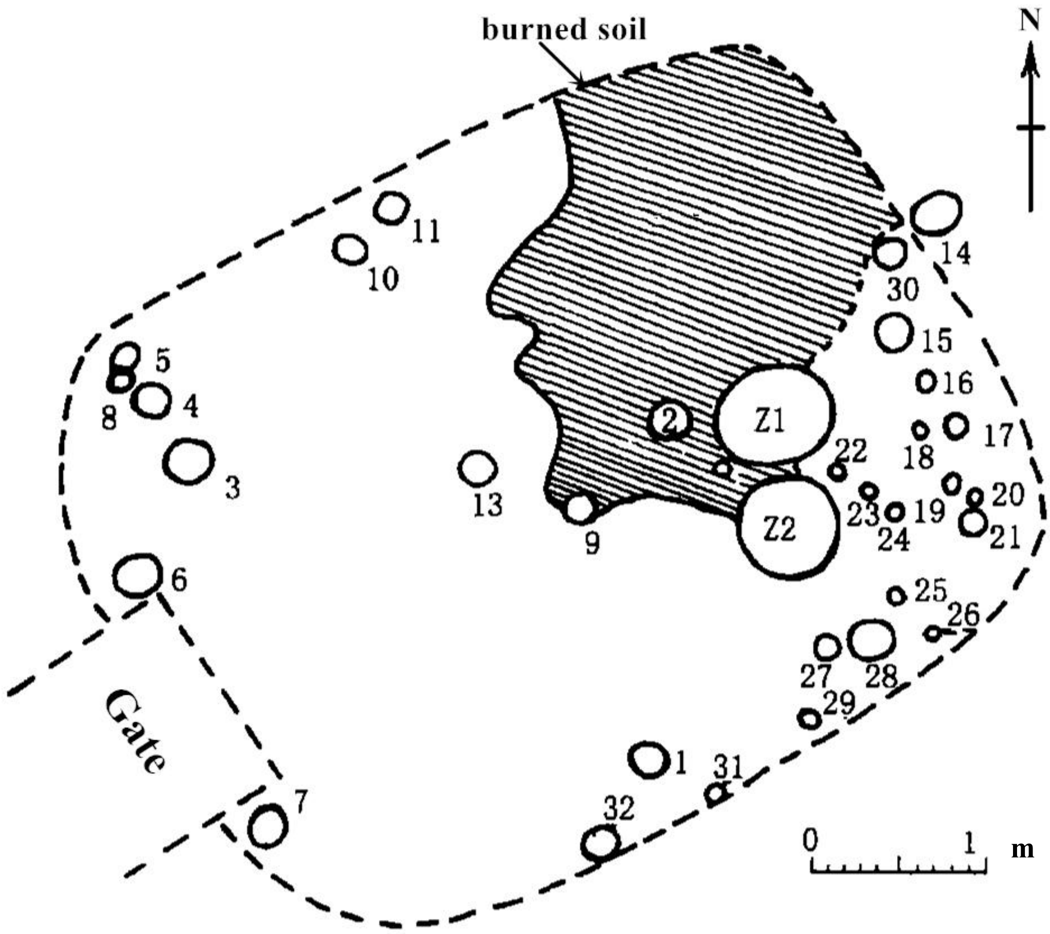


Figure 2. 28 House No. 23 (F23) at Cuntou site (Z1 and Z2 represent the stoves and other circles with number are post holes) (provided by Dongguan Muesum).

Compared with those in the late Neolithic period, the common pottery forms were still ring-foot type and round-bottom type, including *fu* cauldrons, *guan* jars, plates and *dou* pedestal cups (Yang et al. 2015), but the sites where concave-bottom vessels unearthed has increased, such as Cuntou site, Yinzhou site, and Maogang site (Li 2000; Yang H and Yang Y. 1983; Excavation report of Cuntou site in press), which reflect the external impact from Houshan type (3,500-3,000 BP) in east Guangdong (Figure 2.25 B and Figure 2.29) (Excavation report of Cuntou site in press; Wei 2008; Xu and Fan 2013). And the potsherds unearthed are often decorated with geometric stamped patterns as well, including zigzag, checkered, leaf vein, and protruding designs (Yang et al. 2015).

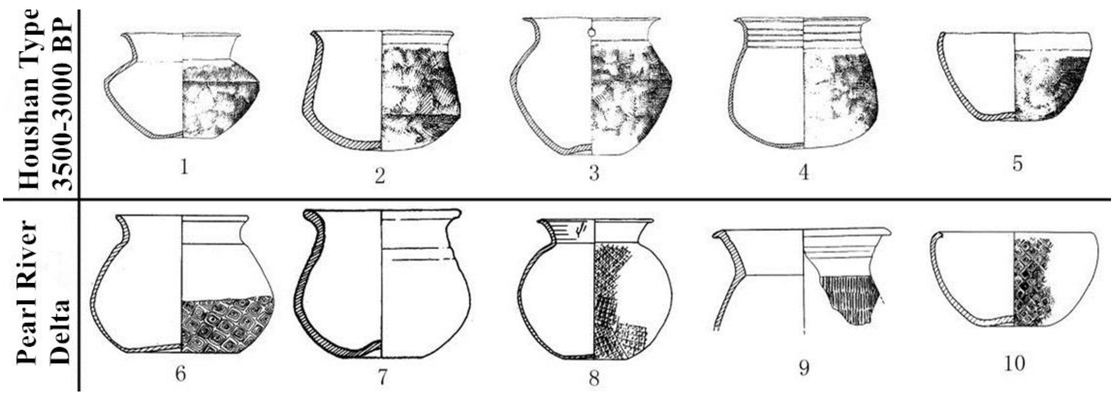


Figure 2. 29 Pottery assemblages from east Guangdong and the Pearl River Delta. 1-5, Houshan site; 6,8,9, Wubeiling site; 7, Cuntou site; 9, Shitanweiling site (after figure 22 of Chen 2012).

Besides the common stone tools, like axes and adzes, there are some weapons and the ritual items, such as dagger-axes and *yazhang* serrated-edged jade tablets (Figure 2.30) (Yang et al. 2015). It is argued that the *yazhang* serrated-edged jade tablets unearthed in Guangdong and Guangxi probably originated from the Cuntou site, which may be used as sacrificial instruments or as an emblem of authority (Chen et al. 2016; Yang et al. 2015).

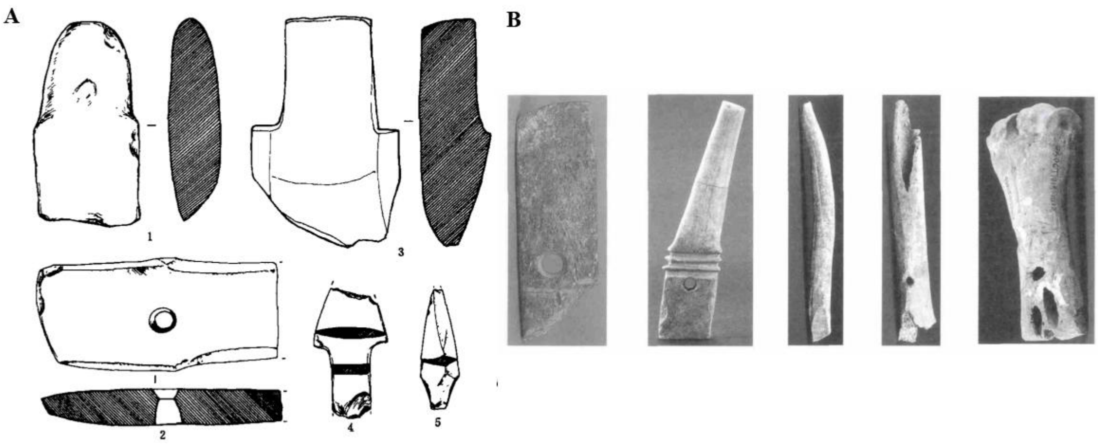


Figure 2. 30 Stone tools unearthed at Cuntou site. A: 1, and 3, stone adzes; 2, dagger-axe; 4, broken spear; 5, arrowhead (from figure 13 in Li 2000); B, ivory zhang serrated-edged tablets unearthed at Cuntou site (from Figure 2 in Chen et al. 2016).

The zooarchaeological study at Cuntou site confirmed that a certain number of pigs and dogs appear to be of a domesticated type (Huang and Zhang, in press). However, on the aspect of plant use, the cereal remains were still not recovered at that time, although rice farming had already been introduced in the Pearl River Delta (Table 2.5) (Li 2000; Yang et al. 2015; Yang H. 1985). Therefore, it is inferred that the subsistence economy still relied on hunting, fishing, and gathering, and that cereal agriculture was not necessarily widespread, but may have had a patchy uptake during this period (Yang et al. 2015).

Chapter 3: Plant use in ancient south subtropical China

In this chapter, I will provide a review of available ethnographic and ethnobotanical data of plant food use and their processing methods from historic records. The oldest historic records reviewed in this chapter dates back to the Pre-Qin Dynasty, such as *Shi Jing* (Book of Odes), including 305 Chinese poetries dating from the 11^{th} to 6^{th} centuries BC, and *Lie Zi* and *Shan Hai Jing*, which were probably finished in the 4^{th} century BC. As there is little information specifically available for the Pearl River Delta, the scope of ethnographic data in this chapter has been enlarged to include all of tropical and south subtropical China.

I have organised the content of this chapter to review first the major starch-rich plant foods by general typological categories: geophytes (roots and tubers); nuts; palm pith; and grains, and then I reviewed the available archaeobotanical data, and finally, the ethnographic data of food processing technology with a focus on stone tool use.

3.1 The ethnobotanic researches of starch food plants

It would be very difficult to list the complete range of plants used by indigenous communities in southern China due to the sheer biodiversity of the region and the fragmentary nature of the ethnobotanical record. In this review I have been able to identify at least a hundred starch-rich plants used for subsistence, as medicinals, or other purposes. This review provides at least some insights into the plant use strategies of the recent historic and further prehistoric periods. It also brings new information on indigenous plant use of southern China that has not previously been published in English.

A total of 55 ethnic minorities are recognised in China, most of which are located in the south, west and north of the country. In the south and southwest of China, a total of 19 minority groups made their livelihoods as swidden farmers up to the 1940s (Table 3.1)

(Yin 2000). These communities, known by a variety of ethnonyms, were all broadly practicing similar kinds of dryland swidden agriculture involving the mixed cropping of grains (including buckwheat, maize, millets (barnyard, broomcorn, panicled, rice, and sorghum), with a variety of root crops: mostly taros and yams (Yin 2000).

Table 3. 1 Ethnic groups from southern China (data are from Yin 2000).

Ethnic Group	Main ethnonyms	Earliest historic record
Quiang Family	Yi/Wu Man/Luoluo	Han-Jin Period
	Hani/Wu Man/He Man/Woni	Han-Jin Period
	Lisu/Lixie	Early Qing Dynasty
	Lahu/Luohei	Early Qing Dynasty
	Kuchong, Guocuo/Little Guocong/Guocong	Early Qing Dynasty
	Jingpo, Xunchuan Man, Luoxing/Man (Naked Barbarians)/Ye Man/Jiexie	Early Ming Dynasty
	Achang/Xunchuan Man/Echang	Early Ming Dynasty
	Pumi, Xifan	Early Ming Dynasty
	Nu, Lu Man	Early Ming Dynasty
	Dulong, Qiao/Qiuren (Qiu People)	Mid-Qing Dynasty
	Jinuo, Sancuomao	Mid-Qing Dynasty
Pu Family	Wa, Wangjuzi Man/Puzi Man/Gula/Hadu/Hayou	Early Ming Dynasty
	Bulang, Puzi Man/Pu Man	Early Ming Dynasty
	De'ang, Pu Man/Bolong/Benglong	Early Ming Dynasty
Miao-Yao Family	Miao, Wuxi Man/Wuling Man, Changsha Man, Miaozi	Qin-Han Dynasty
	Yao, Wuxi Man/Wuling Man, Changsha Man/Moyao	Qin-Han Dynasty
Yue Family	Dai, Dianyue/Jinchi/Baiyi	Qin-Han Dynasty
	Li, Luoyue/Li/Liao	Qing-Han Dynasty
	Zhuang, Xiyuan Man/Dongliao/Tong	Qin-Han Dynasty

3.1.1 Geophytes

The term geophyte refers to plants that have underground storage organs, such as roots, rhizomes, bulbs, or tubers, to store energy or water (Watkinson 2018). In this thesis, I only focus on some starch-rich ones consumed in south China. These plants are repeatedly described as an important plant resource for hunter-gatherers across a variety climate types and habitats, but especially in tropical and subtropical regions (e.g. Barton and Denham 2018; De Vynck et al. 2016; Greaves and Kramer 2014; Herzog et al. 2018;

Marlowe and Berbesque 2009; Messner 2011; Singels et al. 2016). Because of the abundant root crops known or thought to have been used in southern China in prehistory, this region has been argued to be an early location for the emergence of indigenous systems of tropical horticulture (e.g. Li and Lu 1987; Tong 1989; Zhang and Dai 1984). Though this argument has recently been contested on the basis of a lack of primary data regarding horticulture and/or domestication of perennial plants (Denham et al. 2018), several ethnographic investigations have recorded large numbers of geophytes, such as taros (*Colocasia* spp.), yams (*Dioscorea* spp.), and Chinese arrowhead (*Sagittaria* spp.) that had remained in use even after the adoption of rice as a staple crop. For example, Jinuo people in Yunnan province still kept at least 19 species of root crops in their cultivation system (Table 3.2) (Wang and Long 1995).

Table 3. 2 List of root crops used by Jinuo ethnic minority (data are from Wang and Long 1995).

Chinese name	Latin name	Edible part
鱼腥草	*Houttuynia cordata*	Rhizome
辣根	*Piper* sp.	Subterranean stem
假人参	*Campanumoea celebica*	Fleshy root, fruit
奶浆草	*Campanumoea mekongensis*	Fleshy root
攀枝花	*Bombax ceiba*	Root
三叶薯蓣	*Dioscorea arachida*	Tuber
山药	*Dioscorea esculenta*	Tuber
薯蓣	*Dioscorea bulbifera*	Tuber
蓑衣包	*Dioscorea pentaphylla*	Tuber
黄精	*Polygonatum kingianum*	Tuber
卷叶黄精	*Polygonatum cirrhifolium*	Tuber, leaf
野山葵	*Alpinia officinalis*	Tuber
豆薯	*Pachyrhizus erosus*	Root
滇魔芋	*Amorphophallus yunnanensis*	Tuber, leaf
攸落魔芋	*Amorphophallus yuloensis*	Tuber, leaf
菜魔芋	*Amorphophallus* sp.	Tuber, leaf
西蒙魔芋	*Amorphophallus ximengensis*	Tuber, leaf
芋头	*Colocasia esculenta*	Tuber, leaf
紫芋	*Colocasia tonoimo*	Tuber, leaf

Taros and Yams

Taros (*Colocasia* spp.) and yams (*Dioscorea* spp.) were frequently mentioned together in ethnohistoric accounts (e.g. Li and Lu 1987; Li et al. 1982; Wang and Long 1995). And these plants were recorded as the earliest crops in some ethnic minority groups. For example, Jingpo people believe that taros (*Colocasia* spp.) were their earliest crops, prior to their cultivation of rice and legumes (Li and Lu 1987; Li et al. 1982). Li people, in Hainan Province, also said that they cultivated yams before rice (Yan 2005). Until the Qing Dynasty (1616-1912), in Taiwan Province, Gaoshan people still treated taros (*Colocasia* spp.) and yams (*Dioscorea* spp.) as their main crops (Yan 2005).

There are eight species of *Colocasia* (taro) in modern China (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). '*Guang Zhi*'[1] says that there were at least fourteen types of taros in Sichuan Province during the Wei and Jin Dynasty (266-316). The timing of earliest taro cultivation is unclear, but is likely to have used a domesticated variety as wild taro was recorded as poisonous at the time. For example, '*Tai Ping Yu Lan*'[2] referred to '*Bo Wu Zhi*'[3] saying that "wild taros (or feral ones) could cause death" and "if the cultivated taros were not harvested for few years, it will be similar as wild types and cannot be eaten".

The earliest record of cultivated taro is found in '*Guanzi: Qing Zhong I*'[4], in which, the cultivation time of taros was considered as one of six important events for farmers. Then, a detailed method of taro cultivation was introduced in '*The Book of Fan Shengzhi*'[5]. According to this record, the taro cultivation needs fertile soil and enough water, and the planting time of taro cultivation is the rainy time in February of the lunar calendar. In addition, the record emphasized the importance of soil loosening, irrigation and weeding during rhizome growth. This recorded method was treated as the basis of taro cultivation for following periods.

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[1] *Guang Zhi* was written by Guo Yigong in West Jin Dynasty (266-316 AD).

[2] Tai Ping Yu Lan (Readings of the Taiping Era), is a reference book compiled from 977 to 984.

[3] Bo Wu Zhi (Records of Diverse Matters), was written by Zhang Hua (c. 290 AD)

[4] Guanzi is thought to be finished at c. 400 BC. The content of this book is believed to be affected deeply by Guanzhong, who is a politician and philosopher in the Spring and Autumn Period (770 BC- 476/403 BC).

[5] The book of Fan Shengzhi (author: Fan Shengzhi), is an important agricultural book in the late Western Han Dynasty (c. 100 BC), summarizing the ancient agricultural activities in Yellow River Basin.

However, how was the geophyte cultivation at the beginning in south subtropical China? The historic documents of Shengfan (生番, a relatively aboriginal group of Gaoshan people) may provide some clues. The scene of taro cultivated in the 18th century depicted that the taro cultivation was carried out in the forest space, without large-scale deforestation (Figure 3.1), and the space used for taro cultivation was probably cleared by some woodworking tools, like axes (Li and Lu 1987). This description provided information on how the aboriginal communities in the woodlands cultivate taros. Analogue with this image, it can be speculated that prehistoric populations living in the woodlands of southern China would have performed cultivation activities without large scale forest disturbance.

Figure 3. 1 Taro cultivation of Shengfan in Taiwan (Du 1998).

According to the records in '*Guangdong Xinyu*'[6], in Guangdong, there are also fourteen varieties of taros known during the Qing Dynasty . In this book are notes on the quality of different taro varieties. Of the smaller sized plants: the yellow taros have the best quality, followed by the white type and the red type. Larger sized varieties are also

[6] *Guangdong Xinyu* is Qu Dajun's notes of Guangdong society in early Qing Dynasty, including both natural and cultural content, such as geography, flora, foods, and traditions at that time.

noted and of these, the purple type is noted as being the best. The pattern of cultivation was also recorded, saying that taros were often double-cropped in one year. The early taros were planted in spring and harvested in summer, while the late taros were planted in summer and harvested in the autumn.

Besides dietary value, taros also have important religious meanings, like warding off the evils and sacrificing ancestors (Li and Lu 1987). The head of the Jinuo community will plant taros first to express respect for the God of the Land before they slash a new field (Li and Lu 1987). In Guangdong Provinces, according to '*Guangdong Xinyu*', taro was the important food in Mid-autumn Festival, looking forward to reunion and peace of family, and respect for the patriarch.

Records of yams (*Dioscorea* spp.) appear early as well. The earliest is in '*Shan Hai Jing*'[7]. '*Nan Fang Cao Mu Zhuang*'[8] describes characteristics, cultivation and storage methods of yams, for example, "yams were eaten after steaming"/"cut yams into rice-size pieces after steaming and store them after dried" and "(yams) contribute to longevity of local people". '*Qi Min Yao Shu*'[9] records: '甘藷，似芋……南方专食以当米谷' which means that yams like taros, were treated as a substitute for rice or millets in southern China. This record revealed that until in third and fourth century, some peoples in southern China remained dependant on yams as one staple food (e.g. *Dioscorea esculenta*) in case of problems with the rice harvest (Shi 1958). Yams were treated as staple foods in Hainan Island until Northern Song Dynasty (960 to 1127). Su Shi recorded that "土人顿顿食藷芋" and "海南以薯为粮，几米之十六" when he lived in Hainan between 1,097 and 1,100. This means that the native people in Hainan treated yams as staple foods in every meal.

The types of yams consumed in southern China are diverse. In *Nan Fang Cao Mu*

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[7] *Shan Hai Jing*, the Classic of Mountains and Seas, is a compilation of geography and myth, which may be finished as early as 400 BC.

[8] *Nan Fang Cao Mu Zhuang*, Records of Plants in southern China, is attributed to the Western Jin dynasty scholar and botanist Ji Han (263-307).

[9] *Qi Min Yao Shu*, was completed in around 544 by Jia Sixie. It is the earliest and most completely preserved agricultural book in China.

Zhuang[10], there are two type of yams mentioned. Xu (2018) reviewed 35 Products Records Hainan region in Ming and Qing Dynasty, indicating that four categories of indigenous yams were recorded, and each category has several types. And in '*Guangdong Xinyu*'[11], three local types of yams in Guangdong were listed.

Arrowroot (*Pueraria* spp.)

Arrowroot (*Pueraria* spp.) is another plant that is widely consumed in southern China. Although it has been cultivated in many regions, wild ones are still collected as food by some ethnic groups, including the Hakka people, Li people, and Nu people (Cao et al. 2011; Dao et al. 2003; Zheng et al. 2013). Besides being edible, it has an important role as a medicine, reported in many medicinal documents in historic times, such as '*Shen Nong Ben Cao Jing*'[12]. It also has an economic value, where the fiber from the rhizome can be made into cloth and shoes (Ma et al. 2015; Xie 2012).

***Amorphophallus* spp.**

Konjac was one of traditional Chinese medicine, which have more than 30 local names in historic documents (Li and Long 1989). '*Shen Nong Ben Cao Jing*'[12] listed it as one of the poisonous but medicinal plants (Li and Long 1989; Yu 2007). It has several medicinal values, including uses for detumescence, regulate hyperglycemia and cure snake venom (Li 2002; Li and Long 1989). The 10^{th} century volume, '*Kai Bao Ben Cao*'[13] records ways in which the wild tubers were processed to detoxify them and the plant is recorded as being in cultivation since at least the middle of 14^{th} century (Yu 2007).

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[10] *Nan Fang Cao Mu Zhuang* (Records of Plants in southern China) was written by Ji Han, a scholar and botanist in Western Jin dynasty (263-307).

[11] *Guangdong Xinyu* is Qu Dajun's notes of Guangdong society in early Qing Dynasty, including both natural and cultural content, such as geography, flora, foods, and traditions at that time.

[12] *Shen Nong Ben Cao Jing* (Divine Farmer's Classic of Materia Medica) is a book on agriculture and medicinal plants, which is believed as the earliest book of Chinese traditional medicine.

[13] *Kai Bao Ben Cao* is a book of Chinese medicine edited by Liu Han et al. in 973-974.

To be eaten, the tuber must be boiled with solution of plant ash or quicklime first, and then some communities prefer to grind those tubers to release starch. Such method was first recorded in *Kai Bao Ben Cao*[13] (Cui et al. 1995; Yu 2007; Zhang 2001; Zhou et al. 2014). This preparation process often occurred between October to the next spring (Hu 2015). The Dong people in Guizhou Province, for example, always do this work in December (Hu 2015). Konjac tofu, made by extracted starch flour, is a necessary food at the wedding of Hani people in Yunnan Province to represent reproduction (Long 2018). Besides, he tuber can also be fermented and made into a type of wine (Ke et al. 2014; Wang and Long 1995; Yan 2005).

Lily (*Lilium* spp.)

Some species of Lilium are used as vegetables and medicinals in Chinese society. The earliest text record was in the book '*Shen Nong Ben Cao Jing*'[14], which highly evaluated the medicinal value of its bulb (Liang et al. 2013). Cultivation methods of *Lilium* bulbs were first mentioned in the Late Tang Dynasty (Ye 1992b). In the Yuan Dynasty, lily bulbs were listed as vegetables or fruits in some local chronicles (Ye 1992b). They were used as famine foods as well. For example, it was classified as food in Jiangxi Province during the Qing Dynasty (Ye 1992b).

Chinese arrowhead (*Sagittaria* spp.)

The earliest historic record of this plant, as a medicinal plant, is found in *Ming Yi Bie Lu*[15] (Shen and Ye 1982; Ye 1992a). Until the Tang Dynasty, it was often mistaken as water chestnuts (*Eleocharis dulcis*) and the toxicity of this plant was repeatedly mentioned (Shen and Ye 1982; Ye 1992a; Yu 2017). In about 13th century, a record in '*Wu Xing Zhi*'[16] showed that Chinese arrowhead could be cultivated (Ye 1992a). In

[14] *Shen Nong Ben Cao Jing* (Divine Farmer's Classic of Materia Medica) is a book on agriculture and medicinal plants, which is believed as the earliest book of Chinese traditional medicine.

[15] *Ming Yi Bie Lu* is a medicinal book which was possibly finished at the end of Han Dynasty. The original book is no longer available, but some remaining records were found in Ben Cao Jing Ji Zhu, edited by Tao Hongjing (456-536).

[16] *Wu Xing Zhi* is a local chronicle of Wu Xing in Zhejiang Province.

some historical documents of Guangdong Province after Qing Dynasty, such as '*Guangdong Xinyu*'[17], and '*Nanhai Xianzhi*'[18], was recorded as being in cultivation. It was planted after water chestnut (*Trapa natans*); and the plant was harvested in December according to the lunar calendar. The records also suggest that the bulb of this plant should be eaten soon once harvested, as they are difficult to be stored (Ye 1992a).

Ferns

Edible ferns are some of the most popular wild food plants around the world, especially in tropical and subtropical regions (Leach 2003; Mannan et al. 2008). For Chinese people, the ferns were traditionally used as medicines, ornamentals and food for many centuries. (Lu 2007; Shi 2002).

Liu et al. (2012) compiled a timeline on the history of edible use of ferns in China. The first record of edible fern is found in '*Shi Jing*'[19], dating from 3,000 years ago. During the Tang Dynasty (AD 618 to 907), fern consumption became popular and it was praised and admired in several poems. Later, in the Song Dynasty (AD 960 to 1276), the extraction of starch flour from fern rhizomes for food was first recorded. During the Yuan Dynasty (AD 1271 to 1368), fern starch was recorded as one of the main replacements for failed staple crops in famine years. As a famine food, Cao et al. (2007) mentioned that 10 to 12 kg of wet starch could be extracted from per 100 kg fern rhizomes. In Guangdong province, '*Guangdong Xinyu*' also recorded one kind of fern rhizome as alternative for rice before the rice harvest, but it is also warned that this substitute cannot be eaten frequently.

Based on literature studies and field investigations, Liu et al. (2012) reviewed the food uses of ferns in China. Their results showed that 52 species, including four varieties of edible ferns were consumed as food by some ethnic groups throughout China.

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[17] *Guangdong Xinyu* is Qu Dajun's notes of Guangdong society in early Qing Dynasty, including both natural and cultural content, such as geography, flora, foods, and traditions at that time.

[18] *Nanhai Xianzhi* is a local chronicle of Nanhai County in Guangdong Province

[19] *Shi Jing*, Book of Odes, contains 305 Chinese poetries dating from the 11th to 7th centuries BC

According to their statistics, at least 23 of them were used because of the contents of starch in their rhizomes (Table 3.3).

However, some of them may have bad taste, which need tedious preparation process before cooking. For example, the rhizome of *Cibotium barometz,* the only species of genus *Cibotium* in China, has a bitter taste. To remove it, it is necessary to increase water-change frequency and prolong the soaking time (Cao et al. 2007)

Table 3. 3 Ethnobotanical inventory of edible starch rhizomes of ferns in China (extraction from Table 1 in Liu et al. 2012).

Family name	Species Name	Edible parts	Notes
Cyatheaceae	*Alsophila spinulosa*	Starch in stems	Substitute for staple food
Angiopteridaceae	*Angiopteris esculenta*	Starch in rhizomes	Substitute for staple food
Angiopteridaceae	*Angiopteris fokiensis*	Starch in rhizomes	Substitute for staple food
Athyriaceae	*Athyrium brevifrons*	Starch in rhizomes	Starch content 40-50%
Dicksoniaceae	*Cibotium barometz*	Starch in rhizomes	Substitute for staple food
Hemionitiaceae	*Coniogramme emeiensis*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme intermedia*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme intermedia* var. *glabra*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme japonica*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme jingangshanensis*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme robusta*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme rosthornii*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme simillima*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme taipaishanensis*	Fronds, starch in rhizomes	
Hemionitiaceae	*Coniogramme wilsoni*	Fronds, starch in rhizomes	
Dryopteridaceae	*Drynaria baronii*	Starch in rhizomes	
Drynariaceae	*Drynaria fortunei*	Starch in rhizomes	
Onocleaceae	*Matteuccia struthiopteris*	Fronds, starch in rhizomes	Starch content in rhizomes reaches 40–50%
Osmundaceae	*Osmunda japonica*	Fronds, starch in rhizomes	Leaves contain starch, too
Pteridiaceae	*Pteridium aquilinum* var. *latiusculum*	Fronds, starch in rhizomes	
Pteridiaceae	*Pteridium revolutum*	Starch in rhizomes	
Blechnaceae	*Woodwardia japonica*	Starch in rhizomes	
Blechnaceae	*Woodwardia unigemmata*	Starch in rhizomes	

Medicinal geophytes

Native people in southern China also use a series of root crops for medicinal purpose, and sometimes it is hard to distinguish between food and medicine from the written records (e.g. Du et al. 2017; Duan and Hu 2013; Liang et al. 2014; Liu et al. 2003; Zhou et al. 2016). However, there are also some geophytes, the medicinal value of which is more important than its edible value in China. For example, in spite of the toxicity of the tuber of air potato (*Dioscorea bulbifera*), this plant is often used as medicine, which can be used to treat whooping cough, goiter, lymph node tuberculosis, sore throat, hemoptysis and scabies, while Nu people (an ethnic minority in Yunnan) also use it to induce vomiting to detoxify (Dao et al. 2003; Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). The dried bulbs of *Fritillaria* could be used to relieve cough, which is one of Chinese traditional medicines with long history.

Table 3. 4 List of some edible medicinal roots (data are from Liu et al. 2003; Zhou et al. 2016).

Family	Latin name	Chinese name	Medicinal part	Effects
Araceae	*Lasia spinosa*	刺芋	Rhizome	Edema
Araliaceae	*Panax notoginseng*	野三七	Root	Tonic
Basellaceae	*Boussingaultia gracilis*	藤三七	Tuber	Tonic, pain of waist and knees
Botrychiaceae	*Botrychium lanuginosum*	独蕨箕	Root	Weakness of liver and kidney; weakness after parturition
Campanulaceae	*Codonopsis convolvulacea*	鸡蛋参	Root	W akness after parturition of sickness; Tuberculosis; Palpitation
Commelinaceae	*Cyanotis vaga*	露水草	Root	Rheumatoid arthritis; pain of waist and knees; Nephritis edema
Commelinaceae	*Pollia hasskarlii*	粗柄杜若	Root	Tonic
Compositae	*Elephantopus scaber*	地胆草	Root	Cough
Compositae	*Inula nervosa*	黑威灵	Root	Tonic
Compositae	*Inura cappa*	羊耳菊	Root	Numbness; Rheumatism
Compositae	*Vernonia parishii*	滇缅斑鸠菊	Root	Weakness after parturition; Rheumatism and pain of bones; hepatitis
Davalliaceae	*Davallia formosana*	马劳爪	Rhizome	Punch injury, lumbago, rheumatic
Iridaceae	*Eleutherine plicata*	红蒜	Rhizome	
Lamiaceae	*Stachys geobombycis*	地蚕	Tuber	Nourishing kidney, tonifying Qi, activating blood.
Liliaceae	*Asparagus filicinus*	羊齿天门冬	Tuber	Enrich the blood
Liliaceae	*Asparagus cochinchinensis*	天门冬	Tuber	Dizziness; Nourishing kidney; moistening
Liliaceae	*Liriope spicata*	山麦冬	Rhizome	Dizziness; Nourishing kidney
Liliaceae	*Liriope platyphylla*	阔叶山麦冬	Rhizome	Dizziness; Nourishing kidney;
Liliaceae	*Ophiopogon dracaenoides*	大叶沿阶草	Rhizome	Palpitation; Rheumatic heart disease
Liliaceae	*Polygonatum cirrhifolium*	卷叶黄精	Tuber	Blood deficiency, nourishing lung, spleen and kidney.
Liliaceae	*Polygonatum kingianum*	滇黄精	Tuber	Blood deficiency, nourishing lung, spleen and kidney.
Menispermaceae	*Aristolochia fangchi*	白怪	Root	Toothache, sore throats
Menispermaceae	*Stephania cepharantha*	金钱吊乌龟	Tuber	Stomachache, cancer
Menispermaceae	*Tinospora capillipes*	金果榄	Tuber	Sphagitis

Nephrolepidaceae	*Nephrolepis auriculata*	肾蕨	Tuber	Heat cleaning, detoxication, dissolving dampness,
Orchidaceae	*Habenaria buchneroides*	鬼箭玉凤花	Tuber	Weakness after sickness; nourishing stomach and spleen.
Orchidaceae	*Habenaria dentate*	鹅毛玉凤	Tuber	Weakness after sickness
Orchidaceae	*Pholidota chinensis*	石仙桃	Pseudobulb	Cough, swellling
Papilionaceae	*Millettia speciose*	美丽崖豆藤	Tuber	Nourishing lung, stimulating meridians, activating collaterals.
Polygalaceae	*Polygala arillata*	荷包山桂花	Root	Weakness after sickness; irregular menstruation; Neurasthenia; weakness of stomach and spleen.
Rosaceae	*Rubus multibracteatus*	多苞梅	Root	Weakness of kidney; pain of waist
Rubiaceae	*Luculia intermedia*	中型滇丁香	Root	Weakness
Rubiaceae	*Rubia cordifolia*	茜草	Root	Tonic
Rubiaceae	*Morinda officinalis*	巴戟天	Rhizome	Nourishing kidney, stimulating meridians, rheumatism.
Sapindaceae	*Nephelium chryceum*	山韶子	Root	Dizziness
Schisandraceae	*Schisandra lancifolia*	狭叶五味子	Root	Tonic
Smilacaceae	*Smilax glabra*	土茯苓	Rhizome	Dissolving dampness, relieving summer-heat, carbuncle
Triliaceae	*Paris polyphylla*	多叶重楼	Rhizome	Inflammation; Gynecology
Triliaceae	*Paris polyphylla*	滇重楼	Rhizome	Inflammation; Gynecology
Umbelliferae	*Angelica sinensis*	当归	Root	Tonic; Gynecology
Umbelliferae	*Foeniculum vulgare*	茴香根	Root	Tonic
Umbelliferae	*Heracleum bivittatum*	滇南白芷	root, leaf	Stomachache
Umbelliferae	*Pimpinella candolleana*	杏叶防风	Root	Diarrhea
Vacciniaceae	*Vaccinium ardisioides*	红梗越桔	Root	Cough; tuberculosis
Zingiberaceae	*Alpinia japonica*	山姜	Rhizome	Prevention of cold after parturition
Zingiberaceae	*Amomum villosum*	砂仁茎	Rhizome	Tonifying spleen, eliminating dampness, smoothing Qi and dispelling wind.
Zingiberaceae	*Stahlianthus involucratus*	土田七	Tuber	Punch injury, rheumatism, snakebite.

3.1.2 Nuts of Fagaceae

Fagaceae is a family comprised of eight genera with about 927 species in the world (Christenhusz and Byng 2016), consisting of several economic genera, including *Quercus* (oaks), *Castanea* (chestnuts) and *Fagus* (beeches). In China, there are seven genera, including *Fagus, Castanea, Castanopsis, Lithocarpus, Trigonobalanus, Quercus, and Cyclobalanopsis*, with a total of around 300 species; widely distributed across country with the peak of them in Yuannan, Guangdong and Guangxi (Yang 2014; Wu et al. 2016; 2017).

Some nuts of this family, with higher comestible value, served an important role in the diet of many cultures around the world (e.g. Kosňovská 2013; Mason1995; McCorriston,1994). In early Chinese historical documents, chestnuts and acorns were often recorded together. For example, '*Liezi*'[20] mentioned '夏日则食菱芰，冬日则食橡栗' which means people (in Shandong, northern China) who lived near the sea ate water chestnut (*Trapa* sp.) in the summer, and acorns and chestnuts in the winter. The poems and prose of the Tang Dynasty, such as '岁拾橡栗随狙公，天寒日落山谷里.' and '几曝复几蒸，用作三冬粮.', state that acorns and chestnuts were collected in the autumn as food, and stored after in repeatedly steaming and parching as famine food in winter. Such records were still found during the Qing Dynasty.

Chestnut (*Castanea* spp.)

There are four species of chestnuts, including two endemic and one introduced, in China, that are cultivated for edible nuts and durable wood for craft and construction activities (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). Early accounts of cultivated chestnuts are found in the pre-Qing period, such as '*Shi Jing*'[21], *Analects*[22] and *Zhuangzi*[23]. In these records, chestnuts are noted as being eaten without preparation

[20] *Liezi* is a Daoist text, which may be finished in 4th century BC.

[21] *Shi Jing* (Book of Odes) contains 305 Chinese poems dating from the 11th to 7th centuries BC.

[22] *Analects* is an ancient Chinese book recorded sayings and ideas of Confucius, written in the Warring States period (475–221 BC)

[23] *Zhuangzi* is an ancient Chinese Daoist text in the late Warring States period (476–221 BC), which contains stories

and the wood of these plants was used as firewood. In 6th century, '*Qi Min Yao Shu*'[24] summarized the methods of cultivation. At that time, farmers believed that chestnut trees could only be planted by sprouted chestnuts rather than transplanting trees directly. The selected chestnuts need to be buried in the wet soil at a certain temperature and need to be protected from the wind. In the next March of the lunar calendar, the chestnuts in the soil will sprout, then transplanted into gardens. Harvest time of chestnuts is in around August or September of the lunar calendar. In the record in *Ben Cao Gang Mu*[25], chestnuts should be harvested when the spiny cupule opens, if not, the fruits will easily perish. Three methods of chestnut storage were mentioned in '*Qi Min Yao Shu*' and *Qun Fang Pu*[26]. The fresh fruits of chestnuts could be stored in dry fine sand from harvest until the next spring. In another method, chestnuts were soaked in plant ash solution for a day, then removed and sun dried. In a third method, chestnuts were soaked in the concentrated brine for a day, taken out and dried, then hung in a ventilated place in a bamboo basket or burlap bag, shaken once or twice a day and then sun dried.

Acorns

Current archaeobotanical research demonstrates that the nuts of Fagaceae, mainly acorns, once constituted a dietary staple in China, though they have largely been replaced by grains (rice and millets) in the Neolithic period (e.g. Fuller and Qin 2010; Liu et al. 2010; Wu et al. 2014). However, acorns were still consumed as famine food during the historic period. Such record could be found from 3rd century BC, for example *Han Fei Zi*[27], to 16th century, like *Jiu Huang Ben Cao*[28]. And in *Ciyuan*, the earliest

and anecdotes that exemplify the nature of the ideal sage.

24 *Qi Min Yao Shu* was completed by Jia Sixie in around 544 AD, which is the earliest and most completely preserved agricultural book in China.

25 *Ben Cao Gang Mu* (Compendium of Materia Medica) is a Chinese herbology volume written by Li Shizhen in the Ming dynasty.

26 *Qun Fang Pu* is a Flora written by Wang Xiangjin in the Ming Dynasty.

27 *Han Fei Zi*, an ancient Chinese book on legalist tradition, was named after a political philosopher Han Fei. Most of chapters should be written mid-3rd century BC.

28 *Jiu Huang Ben Cao* (Famine foods listed in the Chiu huang pen ts'ao) was edited by Zhu Su, which was completed

modern encyclopedic Chinese phrase dictionary first published in 1915, acorns are still recorded as food for humans in famine times.

Acorn cultivation emerged no later than the reign period of King Zhaoxiang of Qin (306-251 BC). *Han Fei Zi*[27] recorded that Fan Ju suggested King Zhaoxiang of Qin to grant these oak trees cultivated in the royal gardens, including acorns and chestnuts, to the people in famine. Some acorns could be eaten without processing because of their higher sugar content and lower tannin content, such as *Castanopsis eyrei, Castanea seguinii*, *Castanea henryi*, *Lithocarpus glaber, Lithocarpus cleistocarpus, Castanopsis carlesii, Castanopsis fargesii* (Liu et al. 2009; Yang et al. 2005), though most of them need to be processed before consumption. The most important step is to remove the tannins which give the nuts a bitter, astringent taste and the classic brown colouration. Tannins are soluble in water, therefore, the most common processes to remove it involve soaking in cold water, hot water, or an alkaline such as lime or plant ash. If soaked in water, the water should be changed every two hours until the water becomes clear (Dong 1994). Another method for tannin removal is steaming. In some poems in the Tang Dynasty, the acorns should be steamed several times before consumption.

Oaks have a wide range of economic uses (Table 3.5) (e.g. Cao et al. 2011; Chen 2016; Liu et al. 2012; Zhou et al. 2014). The young leaves can be consumed as vegetable or tea. After tannin leaching, the acorns could be used to make tofu or wine (Cao et al. 2011; Liu et al. 2012; Zhou et al. 2014). The husks of acorns could be used as a source of dye, and the wood of oaks also widely used as firewood and for house construction (Cao et al. 2011; Chen 2016; Zhou et al. 2014).

Acorns are seasonal food, which fruiting stage is around September to November (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). It should be noted that the peak period of nut collecting is generally quite short in a particular area, since the nuts only need about one to three weeks from maturity to fall. To store nuts for future use, they need to be collected and dried as soon as possible to prevent parasitic

in early 15th century.

infestation, germination and spoilage (Messner 2011). So, nut collection would have been a relatively concentrated, labor-intensive activity.

Table 3. 5 List of nuts used by some ethnic minorities in southern China (from Cao et al. 2011; Liu et al. 2012; Zhou et al. 2014).

Chinese name	Latin name	Minorities	Used part	Consumption method
麻栎	*Quercus acutissima*	Dong people	Nut; wood	tofu; firewood
板栗	*Castanea mollissima*	Dong people	Nut	dried fruit
青冈	*Cyclobalanopsis glauca*	Dong people	Wood	Firewood
多穗石栎	*Quercus acutissima*	Wa people	Leaves	Leaves made of sweet tea
短刺栲	*Castanopsis echidnocarpa*	Wa people	Nut	eat directly or fried
小果栲	*Castanopsis fleuryi*	Wa people	Nut	eat directly or fried
银叶栲	*Castanopsis argyrophylla*	Wa people	Nut	eat directly or fried
刺拷	*Castanopsis hystrix*	Wa people	Nut	eat directly or fried
瓦山栲	*Castanopsis ceratacantha*	Wa people	Nut	eat directly or fried
钩栲	*Castanopsis tibetana*	Hakka people	Nut	eat directly or make wine
南岭栲	*Castanopsis fordii*	Hakka people	Nut	eat directly or make wine
罗浮栲	*Castanopsis faberi*	Hakka people	Nut	eat directly or make wine
苦槠	*Castanopsis sclerophylla*	Hakka people	Nut	Tofu
茅栗	*Castanea seguinii*	Hakka people	Nut	eat directly; make cuisine or wine
甜槠	*Castanopsis eyrei*	Hakka people	Nut	eat directly or make wine

3.1.3 Starchy piths: palms and cycads

Palms (Palmae) and cycads (Cycadaceae) are mainly cultivated as ornamental plants in modern China (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004), but piths of some palms and cycads are rich in starch. Depended on the Flora of China (2004) and Woody Starch Plants in China (Xie et al. 2008), there are seven plants, from three genus, in the lowlands of Fujian, Taiwan, Guangdong, Guangxi, Yunnan and Guizhou province of China (Table 3.6). The starch flour released from these plants are colloquially called as sago or guanglang. Research shows that, on average, one palm could feed a family (two to four persons) for nearly three months (Tarver and Austin 2000). In historic documents and ethnographic surveys, some species of palms and cycads were consumed as a staple food in southern China before the 3rd century (Ge

2015; Long 1999). There is also a poem in Qing Dynasty recording that some people believed that the guanglang palms (*Arenga*) are the best food staples rather than rice in southern China (Geng 2019).

Table 3. 6 Some edible plants with starchy pith in China (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004; Xie et al. 2008).

Species	Distribution	Environment	Altitude
Cycas revoluta	Fujian, Taiwan, Guangdong. Widely cultivated in China	Thickets on hillsides on islands, sparse forests on mainland;	100-500 m
Arenga engleri	Fujian, Taiwan. Cultivated in Guangdong, Yunnan	Open places or lowland rain forests;	below 900 m
Arenga westerhoutii	Guangxi, Hainan, Yunnan	Lowland rain forests;	below 600(-1400) m
Caryota mitis	Guangdong, Guangxi, Hainan	Lowland rain forests, secondary forests, disturbed areas, and often cultivated;	below 1000 m.
Caryota monostarchya	Guangxi, Guizhou, Yunnan	Lowland to montane rain forests, often on limestone soils;	below 1400 m.
Caryota maxima	Guangdong, Guangxi, Hainan, Yunnan	Lowland to montane rain forests or disturbed areas, often planted or naturalized;	200-1800 m.
Caryota obtusa	Yunnan	Scattered localities in montane rain forests, usually on limestone soils;	1400-1800 m.

Arenga westerhoutii

Arenga westerhoutii is a significant economic species, found in Guangxi, Hainan, and Yunnan. According to Flora of China (2004), it is a plant of high economic value: the juice of its inflorescence can be used to refine sugar or make wine; its leaves are used for thatching and rope-making; the endosperm of flowers is used for candied preserves; the fresh stem as a vegetable; and its starchy pith is occasionally eaten. Historical records of various ethnic groups in southern China mention that their starch flour was considered as a staple food. Based on the records in '*Shan Hai Jing*'[29], Ge (2015)

[29] Shan Hai Jing (the Classic of Mountains and Seas) is a compilation of geography and myth, which may be finished as early as 400 BC.

speculated that this plant was in use prior to the Han Dynasty (202 BC-220 AD). An early clear record of this plant consumption appeared in late 3rd century, in '*Bo Wu Zhi*'[30] and '*Nan Fang Cao Mu Zhuang*'[31] saying that the flour made by this plant could replace conventional flour. Later '*Qi Min Yao Shu*'[32] recorded its preparation methods: first, mashed, maybe through the tools of mortar and pestle; secondly rinsed with water. The productivity of this palm is mentioned in '*Nan Fang Cao Mu Zhuang*', *Qi Min Yao Shu*[29], and '*Tai Ping Yu Lan*'[33]: One pith of sugar palm could produce dozens of kilograms of flour. In '*Guangdong Xinyu*'[34], the sugar palm flour was recorded as famine food, together with yams and some millets, in Hainan Province. It is also noteworthy that the seeds of *Arenga westerhoutii* were used to pray for rain in Guangdong, mentioned in '*Guangdong Xinyu*'[34].

The flour made from *Arenga westerhoutii,* called sugar palm flour, has played an important role in people's economic and cultural life in southern China. Wei (2000), through linguistic analysis, inferred that sugar palm flour was first consumed by Zhuang people in Guangxi Province and it is still considered as a famine food in some places. Generally, this flour is produced in the summer, before the palm flowering. Today, Longzhou city in Guangxi Province is still famous for its sugar palm flour. The popular cooking method is to mix the flour with boiled water. The modern methods to obtain sugar palm flour are listed below, which are considered to be similar to the historic processes (Ge 2015).

1) Choose a suitable plant to cut down, remove the pith and cut into small pieces;

2) Put them into stone mortar to crush;

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[30] Bo Wu Zhi (Records of Diverse Matters) was written by Zhang Hua (c. 290 AD).

[31] Nan Fang Cao Mu Zhuang (Records of Plants in southern China) is a flora recorded by Ji Han, a scholar and botanist in Western Jin dynasty (263-307 AD).

[32] Qi Min Yao Shu, was written by Jia Sixie, completed in around 544. It is the earliest and most completely preserved agricultural book in China.

[33] Tai Ping Yu Lan (Readings of the Taiping Era) is a reference book edited by Li Fang et al. from 977 to 984 AD.

[34] *Guangdong Xinyu* is Qu Dajun's notes of Guangdong society in early Qing Dynasty, including both natural and cultural content, such as geography, flora, foods, and traditions at that time.

3) Grind the pith into powder;

4) The powder should be put into a cloth bag and rubbed repeatedly in a jar filled with water so that the starch will seep out from mesh of cloth bag;

5) After precipitation, the starch solution will form a wet starch block. Dry this block to get sugar palm flour.

Fishtail palms (*Caryota* spp.)

Besides *Arenga westerhoutii*, the fishtail palms (*Caryota* spp.) were also an important food source for minority peoples. Important species includes *Caryota obtuse, Caryota ochlandra, Caryota mitis* and *Caryota urens*. Wu (1987) argued that *Dugou* tree in the literatures, such as '*Tai Ping Yu Lan*'[35] and *Ben Cao Gang Mu*[36], is one plant of *Caryota*. In such records, these plants were often compared to guanglang palms because their pith could be used to produce similar flour. A few ethnobotanical investigations indicate that some ethnic groups in southwest China also regarded flour extracted from the starchy piths of fishtail palms as an important source of carbohydrates, even when rice was their staple food. For example, in traditional collection list of plants in Jinuo communities, *Caryota obtuse* and *Caryota ochlandra* are included (Wang and Long 1995). Li people in Hainan prefer *Caryota mitis* and Nu people also regarded *Caryota obtuse* as one of their important foods, which could be used as a substitute for rice (Dao et al. 2003; Liang et al. 2016; Zheng et al. 2013).

Another important species is *Caryota urens*, which had been used as one of staple foods by Dulong people and which is still regarded as a famine food in many modern families (Long et al. 1999). Long et al. (1999) investigated the method to process *C. urens*, which seems to be little different from that of *Arenga westerhoutii* (Ge 2015):

1) Chop the palm from the roots to find the place where starch pulp stains the edge of

[35] Tai Ping Yu Lan, translated as Readings of the Taiping Era, is a reference book compiled by a number of officers under Li Fang from 977 to 984.

[36] Ben Cao Gang Mu, Compendium of Materia Medica, is a Chinese herbology volume written by Li Shizhen during the Ming dynasty (around 1578)

the knife, then cut down the palm;

2) Chop the palm from the top. After finding the white exudate, cut away the top of the palm. The rest of the trunk is the part rich in starch;
3) Divide this part into small pieces, each one about 80 cm. Split each section into four segments along the grain then separate each piece into 4 parts;
4) Put the starchy pith on banana leaves, then rub it and trample it;
5) Wash it with spring water, and then precipitate and filter the flour

For sustainable use of those palms, local residents emphasized that only palm trees that have grown for more than a decade can be cut down for flour-making (Long et al. 1999).

Other starch pith

During the historical period, edible starch flour extracted from *Cycas revoluta* was also called sago. In Guizhou, it is reported as a wild plant which is rich in edible starch (Lei et al. 2002). Even now, the starchy piths are often used for making wine in southwest China, and its fresh leaves were eaten as vegetable by Jinuo people (Wang and Long 1995). According to Flora of China (2004), seeds of *Cycas revoluta* seeds are also rich in starch, although accompanied by mild toxicity, and can be used as food or medicine.

There is another wild tree, named *A Dou* by Dulong people, which has an edible starch-rich pith (Li and Lu 1982). However, its biological name is unclear. According to Li and Lu (1982), its processing methods are as follows: 1) Slice the piths after remove the barks of the tree; 2) Dry it for several days to make it moldy; 3) Wash off the moldy part in the basket; 4) After filtering off the dregs, the starch is deposited.

Rhoads (1982) defined three methods to manage palms: harvest; horticulture, namely planting suckers or replanting seedlings; and cultivation. There is no historic evidence that the fishtail palms or sugar palms were cultivated as food in southern China. Ethnobotanical investigations indicate local communities often regard them as wild, but edible plants (Dao et al. 2003; Lei et al. 2002; Liang et al. 2016; Zheng et al. 2013). Some wild species are endangered at present, like wild sugar palms, which is thought to be the result of excessive deforestation (Ge 2015). Because of the decline of wild population of *C. urens*, Dulong people began to cultivate the palm trees near their village to continue harvesting sago flour (Long et al. 1999). However, whether sago palms were parts of a horticultural system in South China needs further study.

3.1.4 Grains

In modern southern China, rice is the traditional staple food, however, ethnological research indicated that the rice was not as important as previously thought for some ethnic minorities in this region (Li and Lu 1987). In contrast, besides root crops, some grains, such as buckwheat (*Fagopyrum esculentum*), finger millets (*Eleusine coracana*), and barnyard grass (*Echinochloa crusgalli*), were included in native swiddens before rice farming was introduced (Li and Lu 1987; Yin 2000).

Rice

According to the pollen sequences and research on *Legend of Five Goats* of Guangzhou City[37], the adoption of rice farming in the Pearl River Delta could be as early as c. 3,000 BP (e.g. Huang et al. 2014; Liu 2003; Peng et al. 2015). In the Han Dynasty (202 BC to 220 AD), according to the agricultural remains unearthed in burials, rice cultivation in the Pearl River Delta was widespread with evidence of cultural interaction and immigration from north of Nanling Mountains (e.g. Li 2017; Peng 2012; Xu 1981; Yue 2000).

In some place of southern China, dryland rice cultivation play an important role in the local agricultural system. Hainan is an example where dryland rice cultivation has a

[37] Guangzhou has a nickname "City of Five Goats" or "City of Goats", which comes form the Legend of Five Goats. The legend says that five gods, wearing five different color clothes and riding five goats in different color separately, left the goats and rice to Guangzhou residents, which saved Guangzhou people in famine. From then on, rice cultivation emerged in Guangzhou.

long history. The early record was in Treatise on Geography of *Han Shu*[38]. The poem in Tang Dynasty, "五月畲田收火米"[39], stated that dry rice in this area, was cultivated through slash-and-burn and harvested in lunar month of May. Even today dry rice is still cultivated by Li people in the same region, which is called as Shanlan rice (Chen et al. 2018). Besides, the dry rice was widely cultivated by other ethnic groups in southern China as well, such as Dulong people, Nu people, and Wa people, in hilly regions in Yunnan province (Li and Lu 1987; Yin 2000).

The historical documents and ethnological investigations of rice cultivation in Li communities, including its cultivation methods and slow process of becoming the most important staple food, may, to some extent, reflect early rice cultivation in southern China. Besides relied on slash-and-burn, according to '*Li Qi Ji Wen*'[40], rice cultivation in the Li community relied on an unusual method where seeds were sown in naturally occurring wet areas that had been disturbed by cattle. However, it seemed unable to be self-sufficient through dry rice production in Hainan until Song Dynasty, as Su Shi mentioned when he lived in Hainan between 1097 and 1100 AD: the usual situation was that rice was only available when the merchant ship came. And Xu (2018) reviewed the product records in chronicles of Hainan, indicating that rice slowly replaced yams as the staple food until the Ming Dynasty (1,368-1,644).

Foxtail millets (*Setaria italica*) and broomcorn millets (*Panicum miliaceum*)

In some hilly or upland areas in southern China, one or two of these plants are cultivated as important crops by some ethnic minorities, such as Hani people, Lisu people, Nu people, and Yao people (Li and Lu 1987; Yin 2000).

In the historical documents, the early records of these two crops in South China emerged in Warring States period (475 -221 BC). In '*Lu Shi Chun Qiu*'[41], a kind of

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[38] *Han Shu* (The History of Han Dynasty) was edited by Ban Gu and Ban Zhao, covering the history of Western Han Dynasty from 206 BC to 23 AD

[39] This poem was written by Li Deyu on his way to Hainan, recording the scene of Lingnan region.

[40] *Li Qi Ji Wen* is an ethnological record of Li people in Hainan, written by Zhang Qingchang in 18th century.

[41] *Lu Shi Chun Qiu* (Lü's Spring and Autumn Annals) is a classic Chinese encyclopedic book compiled around 239

broomcorn millets with black color in South China was recorded as a better-quality type. And *Shi Ji*[42] indirectly presented the importance of foxtail millet in this region, saying that, a boat of foxtail millets was seized from Nanyue Kingdom in 111 BC, which may suggest that in Han Dynasty, foxtail millets became an important crop in southern China. In some local chronicles and products records of Ming and Qing Dynasties, the millets were widely cultivated in the hilly regions of southern China, such as Guangdong, Guizhou, Jiangxi, and Hainan. For example, '*Guangdong Xinyu*'[42] recorded that people in south Hainan treated foxtail millet, together with yams, sugar palm flour, and finger millets, as food. In the case where the environment in southern China is not suitable for millet cultivaiton, some argued that one reason for these crops becoming important is that they were designated as tax crops by ancient government because they are easy for storage and transportation (Geng 2019).

Job's tears (*Coix lacryma-jobi*)

Job's tear (*Coix lacryma-jobi*) is native to tropical and subtropical Asia, and South and Southwest China, including Yunnan, Guangxi, Hainan. Guizhou is probably an original center of this crop, while Yangtze River Basin and north China are its secondary diversity center (Huang et al. 1995; Luo et al. 2018). This plant is used as a traditional crop by ethnic minorities in southern China, and in Guizhou province, wild job's tears are still gathered by local minorities. (e.g. Tang et al. 2012; Xie 2012; Yang et al. 2012; Zheng et al. 2017).

Job's tears are traditionally recorded as a crop with both edible and medicinal value. As recorded in '*Hou Han Shu*'[43], in the 1st Century, job's tears in southern China were consumed as food which could promote urination and remove heat. And '*Shen Nong*

BC.

42 *Shi Ji* (the Records of the Grand Historia) is a monumental history of ancient China, which was completed in around 94 BC by Sima Qian.

43 *Hou Han Shu*, (the History of the Later Han) covered the history of the Han dynasty (Eastern Han) from 6 to 189 AD. The book was compiled by Fan Ye *et al.* in the 5th century.

Ben Cao Jing'[10] and *Ben Cao Gang Mu*[44] documented that it as a medicine which could also invigorate the function of the spleen and facilitate the drainage of pus. The record of '*Guangdong Xinyu*'[45] also showed that job's tears have both edible and medicinal values, saying that it could replace of rice or be cooked together with rice.

Besides edible and medicinal use, is has cultural and spiritual significance as well. In *Shi Ji*[46], job's tears were once recorded as magic beads in the birth myth of Yu[47], saying that Yu's mother swallowed the job's tear and then gave birth of Yu. Yang et al. (2012) mentioned that the job's tear is also regarded as a lucky plant and its seeds are made into Buddha beads or bracelets for children or used as decorations on clothes for blessing.

Other grains with weed properties

Based on the ethnological investigations, Li and Lu (1987) mention that some small-size grains with obvious weed properties were cultivated as early crops in some ethnic communities, such as finger millet, barnyard grass and amaranth grains. Li and Lu (1987) also recorded the reason for these choices, that is, these grains are more competitive with weeds, which can be harvested in extremely harsh environments, in addition, the grains are easily stored and preserved.

Finger millets (*Eleusine coracana*)

Finger millet is a widely cultivated grain in southern China (Li and Lu 1987; Zhu 2002). In Song Dynasty (960-1279), finger millet was recorded as a staple food of Tujia people in Hunan province and Chongqing city, and similar records could still be found until

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44 *Ben Cao Gang Mu* (Compendium of Materia Medica) is a Chinese herbology volume written by Li Shizhen in Ming dynasty.

45 *Guangdong Xinyu* is Qu Dajun's notes of Guangdong society in early Qing Dynasty, including both natural and cultural content, such as geography, flora, foods, and traditions at that time.

46 *Shi Ji* (the Records of the Grand Historian) is a monumental history of ancient China, which was completed in around 94 BC by Sima Qian

47 Yu is a prehistoric clan chief in Chinese traditional legends, who is well-known for his flood control, establishment of Xia Dynasty, and upright moral character.

Qing Dynasty (1,636-1,912) according to chronicles (Zhu 2002). Besides, it was recommended as an important famine food in the books such as '*Qun Fang Pu*'[48] and *Jiu Huang Ben Cao*[49], because it can be harvested quickly after being cultivated without environmental limit.

According to ethnological research, it is one earliest crop of Wa people, which is cultivated together with dry rice, and it is also a staple food in the diet of some ethnic groups in Tibet (Li and Lu 1987). At present, it is still cultivated as a food crop in Guizhou province (Gao et al. 2015).

Barnyard grass (*Echinochloa crusgalli*)

Starch and phytolith evidence recovered at Shangshan site (11,000-9,000 BP) shows that barnyard grass is another millet that has been in use in the initial Neolithic rice cultivation system but gradually being abandoned (Yang et al. 2015). In modern agricultural rice farming system, it is often treated as field weeds, but barnyard grasses were recorded in historic period as a critical famine crop owing to its non-fussy about growing conditions (e.g. Gao et al. 2016; Li and Lu 1987; Zheng et al. 2017). For example, '*The Book of Fan Shengzhi*'[50], regarded barnyard grass as early crop which can be cultivated in whether waterlogged or drought conditions and suggested that it could be stored as a famine food.

This millet was always recorded as one of staple food together with buckwheat in local chronicles and ethnography of some ethnic groups, such as Lisu people, Pumi people, Bulang people, and Nu people (Li and Lu 1987; Yin 2000). An elder Dulong person depicted that barnyard grass was one of their earliest cultivated plants, similar to taros (Li and Lu 1987). Now in Guizhou province, barnyard grasses are still treated as a main food crop in some ethnic minorities (Gao et al. 2016; Zheng et al. 2017).

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[48] *Qun Fang Pu* is a flora written by Wang Xiangjin in Ming Dynasty.

[49] *Jiu Huang Ben Cao* (Famine foods listed in the Chiu huang pen ts'ao) was edited by Zhu Su, which was completed in early 15th century.

[50] *The book of Fan Shengzhi* (author: Fan Shengzhi), is an important agricultural book in the late Western Han Dynasty (c. 100 BC), summarizing the agricultural activities in Yellow River Basin.

Amaranth grain *(Amaranthus hypochondricus*)

Amaranth grains are treated as food by some ethnic groups in southwest China, such as Menba people, and Luoba people (Li and Lu 1987). In the legend of the Nu people, amaranth grains, which were called *Tian Xiong Mi*, have already been a component of their early agriculture (Li and Lu 1987). Amaranth grains are still consumed as coarse grains by Dulong people, and grown in small-scale cultivation in southwest China (Sun and Yue 2017; Tang et al. 2012; Zhou et al. 2011).

An early record of amaranth could be found in *Er Ya*[51]. And in '*Shen Nong Ben Cao Jing*'[52], the medicinal value of amaranth grains was recorded, saying that this grain is good for eyes, weight loss and nutritious supplement. And in some lists of famine foods, such as *Jiu Huang Ben Cao*[53], amaranth could be found, but it was mainly listed as a vegetable.

3.2 Archaeobotanical analysis

Present archaeobotanical research in south subtropical China has focused on the development of agricultural systems, including crop assemblages, the arrival time of agriculture, and the possible routes of dispersal (e.g. Deng et al. 2018; Dal Martello et al. 2018; Ge et al. 2019; Yang et al. 2018; Zhang and Hung 2010).

Within the two main agricultural systems in China, rice cultivation originated in the Yangtze River Basin by at least 10,000 years ago, with evidence of grain domestication first occurring around 6,800 years ago at the site of Tianluoshan (e.g. Castillo et al. 2016; Higham 2014; Zhang and Hung 2010; 2012; Zhao 2018). The two main millet crops, foxtail millets (*Setaria italica*) and broomcorn millets (*Panicum miliaceum*), were

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51 *Er Ya* is the oldest Chinese dictionary, dating from 3rd century BC.

52 *Shen Nong Ben Cao Jing* (Divine Farmer's Classic of Materia Medica) is a book on agriculture and medicinal plants. It is believed as the earliest book of Chinese traditional medicine.

53 *Jiu Huang Ben Cao* (Famine foods listed in the Chiu huang pen ts'ao) was edited by Zhu Su, which was completed in early 15th century.

domesticated in northern China as early as 10,000 BP, forming the initial dryland agriculture in China (e.g. Dal Martello et al. 2018; Liu et al. 2012; Lu et al. 2009; Yang et al, 2012).

Although the southward dispersal processes are still unclear, archaeobotanical evidence reveals that a mixed agricultural system, including rice and millets had emerged between 5,000 to 4,000 BP in the western and eastern areas of south subtropical China, (e.g. Dal Martello et al. 2018; Deng et al. 2018; Fujian Provincial Museum et al. 2016; Ge et al. 2019; Tsang et al. 2017; Yang et al. 2018). In Guangdong and Guangxi, however, things seem to be different. The earliest evidence of domesticated rice cultivation in Guangdong province has been found at Shixia site (c.5,000-4,100 BP), which is argued to be culturally influenced by immigrants from the Yangtze River Basin (Guangdong Provincial Institute of Cultural Relics and Archaeology et al. 2014; Li 2011; Yang et al. 2017). But the introduction of dryland farming of millets in these regions was probably late. The date of millet remains, recovered together with rice, in Guangdong and Guangxi was later than 4,000 BP, as seen at Gantuoyan site in Guangxi (the millet seeds were identified as *Eleusine coracana*) (3,800-3,000 BP), at Shixiongshan site (2,500-2,100 BP) in Guangdong Province (including charred foxtail millet and broomcorn millet) and some Han-Dynasty burials (Cultural Relics Administration Committee of Guangzhou City and Guangzhou Museum 1981; Museum of Guangxi Zhuang Autonomous Region 1988; Guangzhou Institute of cultural relics and Archaeology 2006; Li et al. 2016; Wei and He 2003; Xiang et al. 2018).

In the Pearl River Delta, the earliest direct evidence of rice cultivation is recovered at Chaling site (4,500-3,700 BP), however, no millet remains were found (Xia et al. 2019; Yang et al. 2018). But the pollen and charcoal records indicate that significant disturbances involving landscape clearance and burning occurred at c. 2,500 BP (e.g. Huang et al. 2012; Peng et al. 2015). This disturbance pattern is probably consistent with the spread of dryland agriculture, probably swidden systems, and likely for the cultivation around cereal crops such as rice, millets and buckwheat.

Besides agricultural activities, the debates of plant-related subsistence in south subtropical China are relatively limited. The reviews in section 2.2 and section 3.1 show that geophytes, acorns, and palm pith were all probably included in the diet of Neolithic communities. Geophytes are the main plant resources for long-term consumption in south subtropical China. The starch granules were recovered from every studied sites in Guangdong, such as Niulandong site (~12,000 BP), Xincun site (5,300-4,400 BP), Lujingcun site (c.4,000 BP), and Shixiongshan site (2,500-2,100 BP) (Li et al. 2016; Wan 2012; Wang 2017; Yang et al. 2013). The identifiable starch grains of geophytes include Angiopteridaceae, Zingiberaceae, *Caryota*, and *Heleocharis* (Wan 2012; Yang et al. 2013). On the aspects of Palmae, the phytoliths of this family were recovered from sediments of Dingsishan site (c. 10,000-6,000 BP) in Guangxi and Xiantouling site (c. 7,000-6,000) in Guangdong, but there is no direct evidence on the consumption of these plants until the starch residues analyzed at Xincun site (5,300-4,400 BP), which indicates the importance of sago-type palms prior to rice (Lu 2013; Yang et al. 2013; Zhao et al. 2005).

Acorns are also crucial in prehistoric China, which was consumed in north China as early as c.23,000 BP, through starch analysis at Shizitan site (Liu et al. 2013). The archaeobotanical evidence of acorns recovered in the lower Yangtze River were concentrated during Early and Middle Holocene. In the early Holocene, the *Quercus* starch granules were identified at Shangshan site (11,400-8,600 BP) and Kuahuqiao site (8,000-7,000 BP) in Zhejiang Province (Lower Yangtze River Basin) (Liu et al. 2010a; 2010b; Yang and Jiang 2010). And in middle Holocene, along the Lower Yangtze River, a large number of macro remains of acorns were unearthed at Tianluoshan site (7,000-6,000 BP) (Fuller et al. 2011). After around 5,000 BP, there is almost no data on tree nut remains, suggesting that this kind of resource was given up possibly because of the development of the agricultural system or vegetation changes caused by environmental events (Fuller and Qin 2010). In south subtropical China, a few acorn remains were unearthed, such as *Lithocarpus corneus* were identified at Longxue site (c. 6,000 BP) (Yang et al. 2015). But the acorn exploitation did not attract attention until a large number of macro remains, especially *Lithocarpus* spp., recovered at Guye site (c.

5,900-5,000 BP) (Cui 2007; Yang et al. 2018). Currently, a possible acorn starch grain recovered from the dental residues at Nanshan site (5,800-4,300 BP) in Fujian Province suggested the acorn consumption in south subtropical China (Guan et al. 2018).

3.3 Plant food-processing technologies

In this section, I will review some archaeological evidence and ethnographic literature of plant-food processing technologies. These are some of the primary activities that we know occurred with those formal or informal grinding and pounding tools. This section also provides some expectations of tool function in the chapter that follows which presents the results of the starch granule analysis.

The archaeological findings of grinding stone in both north and south China are no later than 20,000 years ago, such as at Shizitan site (29,000-13,000 BP) in north China and Xianrendong site (c. 22,000-12,000 BP) in south China (Table 3.7). The netherstones at that time are probably natural stone slabs, with one or two grinding surfaces, which edges were trimmed simply (Figure 3.2), and some handstones are unmodified cobbles (e.g. Song and Shi 2017; Guo and Li 1963; Liu et al. 2018).

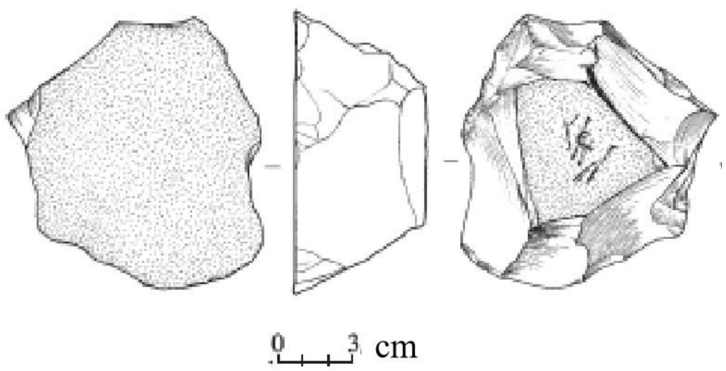

Figure 3. 2 Grindingstone unearthed at Shizitan locality 29 (Song and Shi 2017).

These grinding tools became popular in early Holocene, like Cishan site (c. 8,000-7,000 BP), Peiligang site (c. 7,500-7,100 BP), and Xiaohuangshan site (c. 9,000-8,000 BP)

(Table 3.7). The difference between north and south China became noteworthy. In north China, the combinations of delicate and formal millstones and handstones were unearthed (Figure 3.3 A to C). For example, those millstones unearthed at Peiligang site (c. 7,500-7,100 BP) are large, which are generally about 60 to 70 cm long and 20 to 30 cm wide, and the largest ones could be up to 90 cm (Zhao 2005). Some of them are designed with feet up to 8cm high (Zhao 2005). But in south China, these tools were still informal, like those unearthed at Xiaohuangshan site (c. 9,000-8,000 BP) (Figure 3.3 D and E) and Haogang site (c. 6,000 to 5,500 BP) in Dongguan city (Figure 3.3 F).

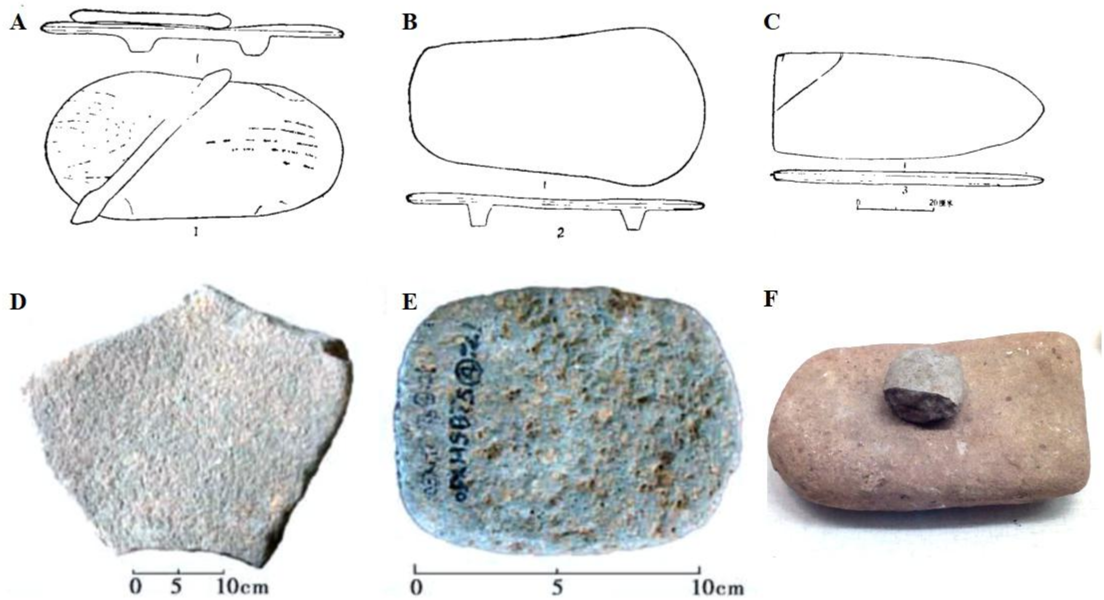

Figure 3. 3 Grinding tools unearthed at some Chinese sites. A-C, millstones and grinding rod unearthed at Peligang site (Kaifeng Cultural management committee and Xinzheng Cultural management committee 1978); D, grinding slab unearthed at Xiaohuangshan site (He et al. 2012); E, handstone unearthed at Xiaohuangshan site (He et al. 2012); F, grinding stones displayed in Haogang Museum. (picture was taken during the sample collection trip in 2017).

Table 3. 7 Grinding and pounding tools unearthed at some Chinese sites during the upper Paleolithic period and the early-middle Neolithic period.

Location	Site	Date (/ BP)	Netherstone	Handstone	Pestle	Mortar	Hammer	Reference
Northern China	Shizitan-S29	29,000-13,000	12				4	Song and Shi 2017
	Xiachuan	29,000-13,000	28	6			4	Institute of Archaeology, Chinese Academy of Social Sciences and Shanxi Institute of Archaeology 2016; Du et al. 2019; Wang et al. 1972; Han 2017
	Longwangchan	c.25,000	1					Yin and Wang 2007
	Shizitan-S14	23,000-18,000	4					Song and Shi 2013
	Shizitan-S1	13,000-10,000	2	1				Xie et al. 1989
	Shizitan-S9	12,800-11,700	3	1				Shi and Song 2010; Liu et al. 2011
	Nanzhuangtou	11,500–11,000	5	4			2	Li et al. 2010; Xu et al. 1992
	Bianbiandong	c. 11,000-9,600	1	2				Sun and Cui 2008
	Lijiagou	11,000-9,000	1					Wang et al. 2011
	Cishan	c. 8,000-7,000	80	56			13	Sun et al. 1981
	Tabuaobao	c. 8,000-7,000	8	42		1		Yao and Xia 2011
	Peiligang	c. 7,500-7,100	41	25				Ren et al. 1984; Cultural Relics Management Committee in Kaifeng and Cultural Relics Management Committee in Xinzheng 1978
	Shawoli	c. 7,200	18	6			1	Wang 1983
	E'gou	7,400-7,100	13	10				Ding 1986
	Shuiquan	7,400-7,000	58	43				Zheng 1992; Wang 1979
Southern China	Xianrendong	c. 22,000-12,000	8					Guo and Li 1963; Li 1976
	Wumingshan	c. 20,000-12,000	2	1				Jiao 1994
	Dushizai	21,000-13,000	1				14	Chen 2016; Qiu et al. 1980
	Huangyandong	21,000-10,000	3				40	Song et al. 1983; 1992; Chen 2016
	Niulandong	20,000-10,000					1	Jin et al. 1998
	Liyuzui	c. 12,500	1					He et al. 1983
	Zengpiyan	12,000-10,000	22		3		283	Institute of Archaeology, Chinese Academy of Social Sciences et al. 2003
	Dingsishan-II	c. 10,000-9,000	7					Fu et al. 1998
	Baozitou	c. 10,000-9,000	12				1	Zhang 2003
	Dingsishan-III	c. 9,000	2				9	Fu et al. 1998
	Xiaohuangshan	c. 9,000-8,000	112	543				He et al. 2012
	Hemudu	c. 7,000-6,000	117	8				Relics and Archaeology Institution of Zhejiang Province 2003
	Xiantouling	c. 7,000-6,000	31	46	17		4	Shenzhen Cultural Relics and Archeology Institute 2013

These stones were ever thought to be related to cereal agriculture (e.g. Ma et al. 1984; Chen 1990). But ongoing researches, including residue analyses and use-wear analyses, indicate that these tools have complex life histories, which were applied for grain seed dehusking and grinding (e.g. Panicoideae and tribe Triticeae), wild plant processing (such as *Quercus, Lithocarpus, Cyclobalanopsis, Dioscorea* and *Nelumbo*), as well as pigment grinding and tool manufacturing since these tools emerged in the late Pleistocene (Table 3.8) (e.g. Chen 2019; Liu et al. 2011; 2018; Song 1997; Wang and Yang 2015; Yang et al. 2009; Yao et al. 2016). For example, the studies at locality 29 of Shizitan site confirm that at around 26,000 to 24,000 year ago, the grinding stones were used for processing wild grain seeds (such as Panicoideae possibly job's tears, wild millet, and tribe Triticeae), geophytes, and hematite as well (Liu et al. 2018). The starch analysis of grinding slabs uncovered at Xiaohuangshan site (9,000-8,000 BP) indicates that they were more like to be processing tools of wild plants, such as *Nelumbo nucifera, Dioscorea opposita, Vigna*, and *Quercus*, rather than rice (Yao et al. 2016). Overall, within the starch assemblages, the cereals, including millets and job's tears, are the most frequent types, followed by acorns and geophytes (Table 3.8).

But they were probably still applied as dehusking tools according to ethnological records (Song 1997), although this may be an inefficient processing method, as it can only process a small amount of seeds (e.g. Lu and Huang 2000; Wang 1996). Song (1997) reported that Dulong and Nu communities in Yunnan were still used this method to dehusk dried seeds of foxtail millet, barnyard grass, and barley.

Table 3. 8 Starch analysis and use-wear analysis of grinding tools in China.

Location	Site name	Date (/BP)	Studied tools	Identifiable starch grains recovered	Use-wear analysis	Reference
North China	Shizitan	28,000-10,000	grinding slabs/ handstones	Wild Panicoideae; job's tear (*Coix lacryma-jobi*); tribe Triticeae; *Vigna; Lilium*; yam; snake gourd (*Trichosanthes*)	Plant and pigment processing	Liu et al. 2011; 2013; 2018
	Nanzhuangtou	11,500-11,000	grinding slabs/ handstones	Foxtail millet; tribe Triticeae; water chestnut; yam; snake gourd		Yang X. et al. 2012; 2015
	Donghulin	11,000-9,000	grinding slabs/ handstones	Acorns, foxtail millet, tribe Triticeae	Acorn and cereal processing	Liu et al. 2010a
	Kengnan	10,000-9,000	grinding slabs	Tribe Paniceae; *Coix*		Li et al. 2014
	Jiahu	9,000-7,500	grinding slabs/ handstones	*Oryza*; job's tear; tribe; Triticeae; lotus roots; *Trapa*; yam; Vigna		Li et al. 2019
	Egou	8,500-7,000	millstones	Acorns; edible legume; foxtail millet; yams		Liu et al. 2010b
	Peiligang	8,500-7,000	millstones	*Quercus*; tribe Triticeae; grass seeds; geophytes		Zhang et al. 2011
	Zhaigen	8,500-7,000	millstones	Tribe Triticeae; job's tear; acorns; snake gourd	Plant processing, such as geophytes, acorns, and cereals; stone tool or hard wood tool manufacturing	Liu et al. 2013
	Shunshanji	8,500-7,000	Millstones/handstones	Job's tear; snake gourd; tribe Triticeae		Yang et al. 2016
	Beishan-East	~8,200	millstones	wild millet; domesticated millet; other millet; *Quercus*; *Hordeum*		Ma et al. 2016
	Beishan-West	~8,200	handstones	Wild millet; domesticated millet; other millet; *Quercus*		Ma et al. 2016
	Aohanziying-East	8,200-7,400	Millstones/handstones	Wild millet; domesticated millet; other millet; *Quercus*; *Hordeum*		Ma et al. 2016
	Aohanziying-West	8,200-7,400	handstones	Wild millet; domesticated millet; other millet; *Quercus*		Ma et al. 2016
	Chahai	8,200-7,000	Millstones/ handstones	Foxtail millet; broomcorn millet; tribe Triticeae; Poaceae;		Wu et al. 2015

			geophytes; edible legume		
Yuezhuang	8,000-7,500	grinding slabs/ hansontes	*Quercus; Oryza*; broomcorn millet	Acorn and cereal processing	Wang et al. 2010
Xinglonggou	8,000-7,500	Millstones/handstones	*Lilium*; yam; snake gourd; job's tear; foxtail millet; broomcorn millet;tribe Triticeae; *Quercus*	Geophtye and cereal processing	Liu et al. 2015
Baiyinchanghan	8,200-5000	Millstones/handstones	*Lilium*; snake gourd; geophytes; job's tear; foxtail millet; broomcorn millet; tribe Triticeae; *Oryza*; edible legume; acorns	Plant processing and occasionally stone tool processing	Liu et al. 2016a
Shigu	8,000-7,000	Millstones/ handstones	Acorns	Plant processing	Liu et al. 2010b
Niubiziwan	8,000-7,000	Millstones/ handstones	*Quercus*; tribe Triticeae; tribe Paniceae; *Vigna*; snake gourd	Plant processing, especially geophyte and cereals	Liu et al. 2014
Tanghu	7,800-7,000	Millstones/ handstones	Tribe Triticeae; foxtail millet; *Oryza; Quercus; Nelumbo*		Yang Y.et al. 2015
Jiangjialiang	~7,700	Millstones/ handstones	Foxtail millet; wild millet; tribe Triticeae; geophytes		Ma et al. 2018
Liujizhuangzi	~7,500	Millstones/ handstones	Millet; tribe Triticeae; tubers		Wu et al. 2014
Shangzhai	7,400-6,700	Millstones/ handstones	*Quercus*; foxtail millet; broomcorn millet; *Vigna*; weeds; tubers		Yang et al. 2009
Shishanzi	~7,000	Millstones/ handstones	Job's tear; tribe Triticeae; yam; lotus root; *Vigna; Avena*; Zingiberaceae		Dong et al. 2014
Shihushan-locality 2	7,000-6,700	Millstones/ handstones	snake gourd; geophytes; *Typha*; acorns; foxtail millet; tribe Triticeae	Acorn and geophyte processing	Liu et al. 2014
Toudaozhangfang	7,000-6,400	handstones	Wild millet; domesticated millet; other millet		Ma et al. 2016
Shihushan-locality 1	6,530-6,440	Millstones/ handstones	Snake gourd; geophytes; acorns; foxtail millet; tribe Triticeae	Plant processing, including geophytes	Liu et al. 2014

	Jiangou	6,500-5,000	handstones	Wild millet; domesticated millet; other millet; *Hordeum*; edible legume		Ma et al. 2016
	Luojiayingzi	6,500-5,000	handstones	Wild millet; domesticated millet; other millet		Ma et al. 2016
	Sanjianfang	6,500-5,000	handstones	Wild millet; domesticated millet; other millet; *Hordeum*		Ma et al. 2016
	Tabu Aobao	6,500-6,000	Millstones/ handstones	Foxtail millet; broomcorn millet; tribe Triticeae; Poaceae; geophytes		Wu et al. 2018
	Wangmushan	6,000-5,500	Millstones/ handstones	*Lilium* or yam; snake gourd; *Typha*; job's tear; millet	Plant and occasionally stone tool processing	Liu et al. 2016b
	Miaozigou	5,500-5,000	Millstones/ handstones	*Lilium* or yam; snake gourd; job's tear; millet	Plant processing. especially geophytes	Liu et al. 2016b
	Yuanzigou	4,500-4,300	grinding slabs	*Lilium* or yam; snake gourd; job's tear; millet; tribe Triticeae	Plant processing	Liu et al. 2016b
	Erbaihu	~4,000	millstones	tribe Triticeae; job's tear; foxtail millet; broomcorn millet; *Oryza*; *Rheum rhabarbarum*; geophytes	Cereal and geophyte processing	Ge et al. 2015
South China	Niulandong	c. 12,000	grindstones	Grass seeds; geophyte; and possible cycad		Wan 2012
	Shangshan	11,400-8,600	grinding slabs/ handstones	Barnyard grass; tribe Triticeae; job's tear; acorns; water chestnut		Yang et al. 2017
	Xiaohuangshan	9,000-8,500	grinding slabs	*Oryza*; tribe Triticaea; job's tear; lotus roots, *Vigna; Quercus*		Yao et al. 2016
	Xincun	5,300-4,400	Grindstones/ handstones	Palms; *Musa* sp; *Sagittaria* sp. water chestnut; job's tear		Yang et al. 2013
	Fanchengdui	c. 5,000-4,000	pestle	Poaceae; geophytes; edible legumes; tribe Triticeae; and possible cycad		Wan 2012
	Shinianshan	c. 5,000-3,000	Pestle/grinder	Job's tear; *Oryza*; edible legumes; and tribe Triticeae		Wan 2012
	Lujingcun	c. 4,000	Grindstones/hammers	Acorns; geophytes; palm pith; tribe Triticeae		Wang 2017

The grinding stones in some excavation reports may include some with grooves, which are considered as tools for polishing stone tools or bone tools (Figure 3.4 C and D) (e.g. He and Li 2012; Lu and Huang 2000; Wang and Yang 2015). However, besides tool polishing, these grooved grinding stones may also have the potential to be used to process starch plants. This speculation is based on the Queensland rainforest example, where the grinding stones with similar morphological features (Figure 3.4 E and F) were argued to be related to the toxic yellow walnut (*Beilschmiedia bancroftii*) preparation (Cosgrove et al. 2007).

Although their function has not been analyzed archaeologically or recorded ethnographically in China, there are studies on pottery with similar morphological features, which probably provide some evidence. The ancient grooved basins could be used for pounding/grinding some seeds and geophytes, supported by use-wear analysis, and starch residues (Figure 3.2 A and B) (Ding 2007; Sun et al. 2019). The starch residues recovered from grooved basin potsherds at Lingjiatan site (5,500-5,300 BP) include *Coix lacryma-jobi*, Poaceae and tribe Triticeae, *Quercus*, *Vigna* sp., *Dioscorea opposita*, *Nelumbo nucifera* and some unidentified roots and tubers (Sun et al. 2019), which assemblage is similar with those recovered from some grinding slabs (e.g. Liu et al. 2011; Yang et al. 2009; Yao et al. 2016). These ceramic vessels are still used in southern China for taro/yam starch obtaining (Song 1997; Xu 2017). For example, in Hunan, women often grind the plants, such as taros, yams, and pumpkins, in such basins to obtain the starch (Song 1997). Therefore, I did not distinguish those grooved grinding stones from when I counted netherstones in Table 3.7.

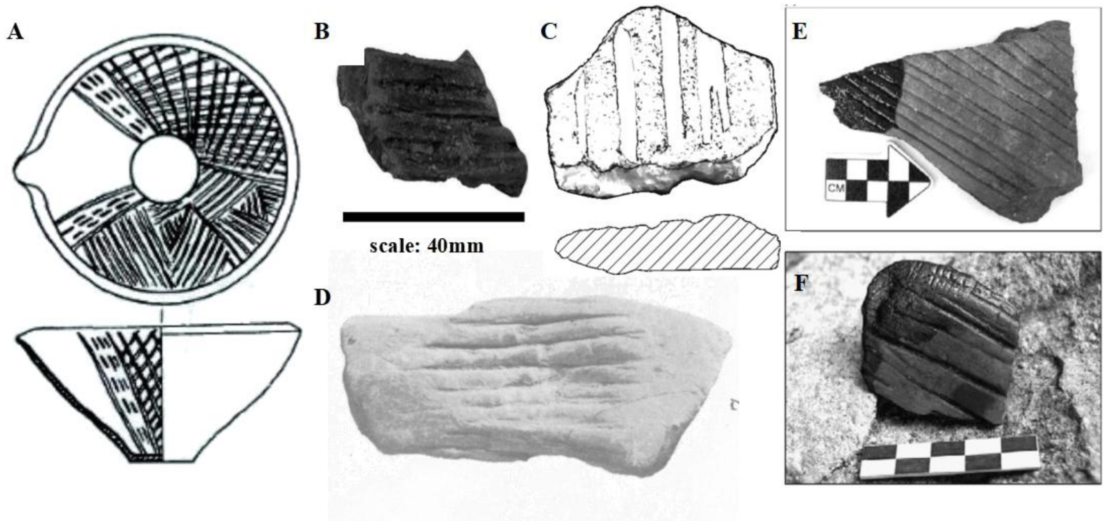

Figure 3. 4 Grooved pottery and stones. A: One ceramic vessel with internal grooves unearthed at Meishan site (c.4,500 BP) in Henan Province (Xu 2017); B: potsherd of grooved basin unearthed at Lingjiatan site (5,500-5,300) in Anhui (Figure 2.16 in Sun et al. 2019); C, grooved grinding slabs unearthed at Guye site (c. 5,900-5,000 BP) in Guangdong (Figure 25 in He and Li 2012); D, grooved grinding slab unearthed at Xianrendong site (22,000-12,000 BP) (Guo and Li 1963); E and F, Koombaloomba Dam grindstones (Cosgrove et al. 2007).

Another tool combination for plant processing is pestles and mortars, which have several types (Figure 3.5) (e.g. Lu and Huang 2000; Song 1997; Zhang and Wang 1986). The ancient pestles included wooden type, such as those at Baligang site (c. 8,000 BP) and Hemudu site (c. 7,000-6,000 BP) along Yangtze River (Figure 3.5 A and B), and stone type, like those at Fanchengdui site (c. 5,000-4,000 BP) in Middle Yangtze River, Baozitou site (c.10,000-9,000 BP) (Figure 3.5 C) and Xincun site (5,300-4,400 BP) in South China (Huang and Lu 2000; Wan 2012; Xu 2017; Yang et al. 2013). Besides stone mortars, such as that unearthed at Huanglianshu site (c. 4,500 BP) in Henan (Figure 3.5 D), there are also some ceramic ones uncovered, for example, at Hemudu site (c. 7,000-6,000 BP) in Zhejiang (Figure 3.5 E) (Xu 2017). It is also inferred that the earth mortars and wooden mortars were also present, according to historical documents and ethnological records (e.g. Song 1997; Xu 2017; Yin et al. 1964). For example, the record listed in *Zhou Yi*[54] says 断木为杵，掘地为臼, which means chopping wood as pestles and digging a hole as mortar. Some burned pits unearthed at Dadunzi site

[54] *Zhou Yi* (the Book of Changes) is a divination manual in the Western Zhou period (1000–750 BC)

(c.6,000-4,500 BP) in Jiangsu were speculated as such mortars (Xu 2017; Yin et al. 1964). Some ethnic minorities, like Li people, still used wooden mortars (Song 1997). Such mortars are large, made from single pieces of wood, which are scooped and singed from the center repeatedly until the mortar is complete (Song 1997).

It is argued that the combination of pestles and mortars should be efficient dehusking tools (e.g. Lu and Huang 2000; Song 1997; Zhang and Wang 1986). Some ancient images of this toolkit were saved in *Wang Zhen Nong Shu*[55] (Figure 3.6 A), showing that the wooden pestles are held by two hands for rice dehusking (Chen 2019). The same application could still be found in southwest China, like what Li people, Wa people, Hani people, and Yi people do (Song 1997). The starch residues recovered from pestles at Fanchengdui site (c. 5,000-4,000 BP) and Shinianshan site (c. 5,000-4,000 BP) in Jiangxi province also revealed that they were used for grass seeds mainly, possibly including *Coix* spp. and *Oryza* spp., and a small number of geophytes, like Zingiberaceae, and edible legume (Wan 2012). But current starch evidence provides more clues of the multiple functions of these tools in southern China (Wan 2012; Yang et al. 2013). In the starch residue assemblage recovered from pestle-shape stones at Niulandong cave site (~12,000 BP) in north Guangdong, these from several types of geophytes, Panicoideae and possible cycads are identified (Wan 2012). And during the period from 5,000 to 4,000 BP, these tools were mainly used for processing palm, for example, *Caryota* spp., and geophyte, including lotus roots (*Nelumbo*), Chinese arrowhead (*Sagittaria*), and ferns, along with some job's tears (*Coix lacryma-jobi*) and acorns at Xincun site (5,300-4,400 BP) in coastal Guangdong (Yang et al. 2013).

At present, the wooden pestle and stone mortars are indispensable tools (Figure 3.6 B) during the traditional processes of palm pith in Guangxi (Guangxi TV Official Channel 2018). Furthermore, some small-size stone pestles used by Yi people in Sichuan are used to pestle chili or salt (Song 1997).

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[55] *Wang Zhen Nong Shu* is a classic Chinese agricultural book compiled in around 1313 by Wang Zhen. It recorded the differences of agriculture system in north and south China and provided a relatively complete images of agricultural tools at that time.

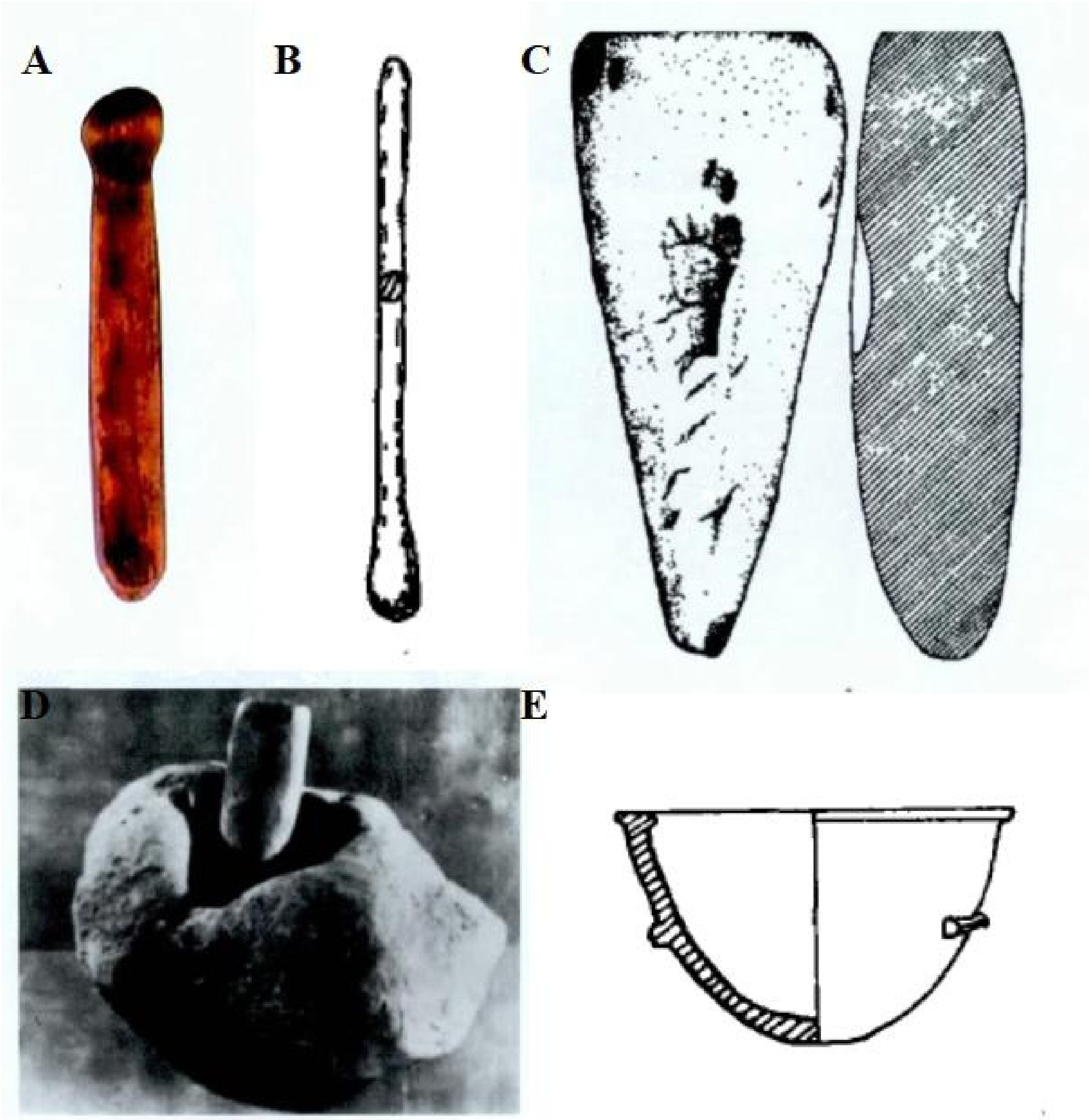

Figure 3. 5 Pestles and mortars unearthed at some Chinese archaeological sites.A, wooden pestle unearthed at Bashidang site (c. 8,000 BP) in Hunan; B, wooden pestle unearthed at Hemudu site in Zhejiang (c. 7,000-6,000 BP); C, stone pestle unearthed at Baozitou stie (c.10,000-9,000 BP) in Guangxi; D, stone pesltes and mortars unearthed at Huanglianshu site (c. 4,500 BP) in Henan; E, ceramic mortars unearthed at Hemudu site (c. 7,000-6,000 BP) in Zhejiang (A, B, and D referred from Xu 2017; B and E are from Huang and Lu 2000).

Figure 3. 6 Mortars and wooden pestles for plant processing. A, pestle and mortar in Wang Zhen Nong Shu (from Chen 2019); B, pounding tools for guanglang palm processing (Guangxi TV Official Channel 2018)

The pounding tools were also used for acorn processing (e.g. Liu et al. 2010; Ortiz 1996). Ortiz (1996) recorded the acorn processing method in California, showing that each acorn should be cracked by hammerstone against a flat, rough bedrock (Figure 3.7 A), and the kernels after winnowing are pounded by pestles in the small mortars or the large, flat bedrock mortars (Figure 3.7 B). Japanese ethnographic investigation also provides some information. The toolkit, including hammerstones and netherstones, is traditionally used for horse chestnut processing in Japan(Figure 3.7) (Liu 2010). Additionally, the observations in Japan indicate that the short-term used hammerstones (several years) look unmodified, but the tools used for 20 years or 50 years bear clear use wear (Liu 2010). These results possibly suggest that some unmodified hammer-shape pebbles should not be ignored, which may be likely used for acorn processing as well.

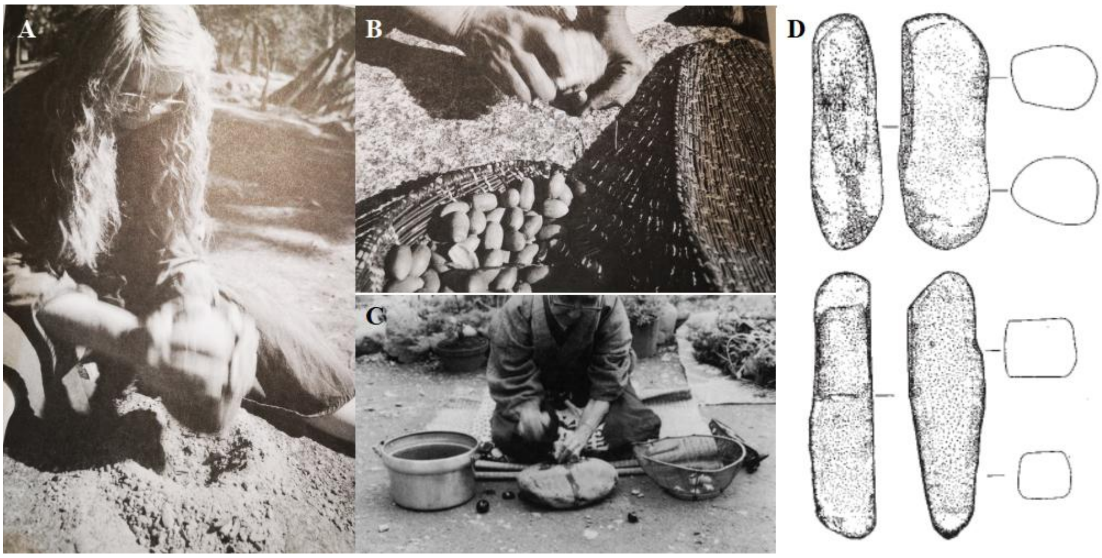

Figure 3. 7 Pounding tools used for acorn processing. A, Julia was using 'two-hand rock' to pound acorns in bedrock mortar in California (Ortiz 1996: 67); B, acorn cracking by hammerstone against a flat, rough rock in California (Ortiz 1996: 50); C, Ms. Kato Fuji was using her hammerstone to crack the shell of horse chestnut (Liu et al. 2010); D, hammerstones used for horse chestnut processing in modern Japan: the upper hammerstone belonged to Ms. Kato Fuji, which used for 50 years, the below one belongs to Ms. Yamanaka, used for 20 years (Liu et al. 2010).

3.4 Summary

The review in this chapter expands the understanding of the range of starch-rich plants used in southern China, which forms the foundation for the construction of modern starch granule reference database in this thesis. Geophytes, including taros and yams, are undoubtedly the one most important resource, which has been repeatedly mentioned in both archaeobotany and ethnobotany (e.g. Li and Lu 1987; Wan 2010; Wang 2017; Yin 2000; Zhao 2005). Some of them are even recorded as the earliest crops, prior to cereals including rice and millet, in oral history of some ethic minority groups, and considered as the basis of the native horticulture (e.g. Li and Lu 1987; Yin 2000). In addition to the geophytes, some woody starch-rich plants, like acorns and sago palms, are often recorded as substitute food or famine food in Chinese historic documents, suggesting that they would have been played significant roles in prehistoric food uses. So far, traditional use of these plants is almost missing in modern China, meanwhile the archaeobotanical evidence is limited, which explains the poor understanding of the prehistoric use of arboreal resources in the Pearl River Delta. All the information reviewed forms the basis of my modern reference collection in Chapter 5.

Correspondingly, the tool kit that can be used for plant processing is also broadened. Besides grinding tools, including netherstones and handstones, which are commonly analysed in previous studies, the pounding tools can also be used for starchy plant processing (e.g. Huang and Lu 2000; Liu 2010; Song 1997; Xu 2017). Furthermore, it is noteworthy that no use-wear was observed on some short-term acorn-processing hammers (Liu 2010). This recognition provides the basis for the selection of archaeological stone tools from the Pearl River Delta in this thesis. Besides the grinding tools, I also selected some pounding tools, like pestles and hammers, and some unmodified pebbles unearthed from the study sites, which are described in detail in section 4.2.

Chapter 4: Description of site and sampled tools

The sites in the Pearl River Delta are mainly classified into two types: the shell middens, one type of settlement, alongside rivers mostly, characterized by large-scale shell depositions related to human activities (Zhao 2014), such as Guye site (5,900-5,000 BP), Xiankezhou site (c. 5,000 BP), and Hedang site (c.4,000 BP) (Cui 2007; Guangdong Museum and Foshan Museum 2006; Yang et al. 2015), and the sand dunes, settlements distributed on the dunes along the estuary and island (Xiao 2004), including Xiantouling site (c. 7,000-6,000 BP), Xincun site (5,300-4,400 BP), and Baojingwan site (c. 4,000 BP) (Shenzhen Cultural Relics and Archaeological Appraisal Institute 2013; Yang et al. 2013; Xiao 2014). Such environment close to waters, together with recovered shells, stone weights for fishing, and pointed tools for shellfish processing, suggest that fishing played essential roles in the indigenous subsistence system (e.g. Xiao 2004; Yang et al. 2015; Zhang and Hung 2010; Zhao 2014). But the current archaeobotanical remains (reviewed in section 2.2) cannot reveal the plant-related subsistence before the adoption of rice farming at around 3,000 BP (e.g. Ma et al. 2018; Peng et al. 2015).

In this thesis, I selected six sites, consisting of Guye site, Yinzhou site, Hengling site, Haogang site, Yuanzhou site, and Cuntou site, in the Pearl River Delta to explore the plant-related subsistence in the Neolithic period. All the sites distributed along rivers (Figure 4.1 A). Except Hengling site, other five sites are identified as shell middens, owing to unearthed shell layers (Cui 2007; Feng 2007; Li Y 2000; Li Z 2000; Wu 2000). These five shell middens were once located in the ancient estuary region, based on the paleoenvironment analysis (Figure 4.1 B and C). Therefore, these settlements should share similar surrounding environmental features. What is different is that Guye site and Yuanzhou site are along the West-North River, but Haogang site, Yuanzhou site, and Cuntou site, are near the East River. Hengling site is not close to the two main tributary system of the Pearl River, but it is located in the north-more transitional zone from delta to hilly area, which was selected to analyse the spatial similarity and differences of the starchy plant diet in the study region more completely.

Besides, the temporal difference is another factor for site selection. As reviewed in section 2.1, the cultural differences between the middle and late Neolithic periods could be identified easily. Among the studied sites, Guye site and Haogang site (the second cultural phase) belongs to the middle Neolithic period, dating from 6,000 to 5,000 BP, while others, Yinzhou site, Hengling site, Haogang site (its third cultural phase), Yuanzhou site, and Cuntou site, are identified as settlements in the late Neolithic period and early Bronze Age, dating between 4,500 and 3,000 BP. Therefore, the research results of these sites could be used to investigate the temporal changes of the plant-related subsistence in the Pearl River Delta.

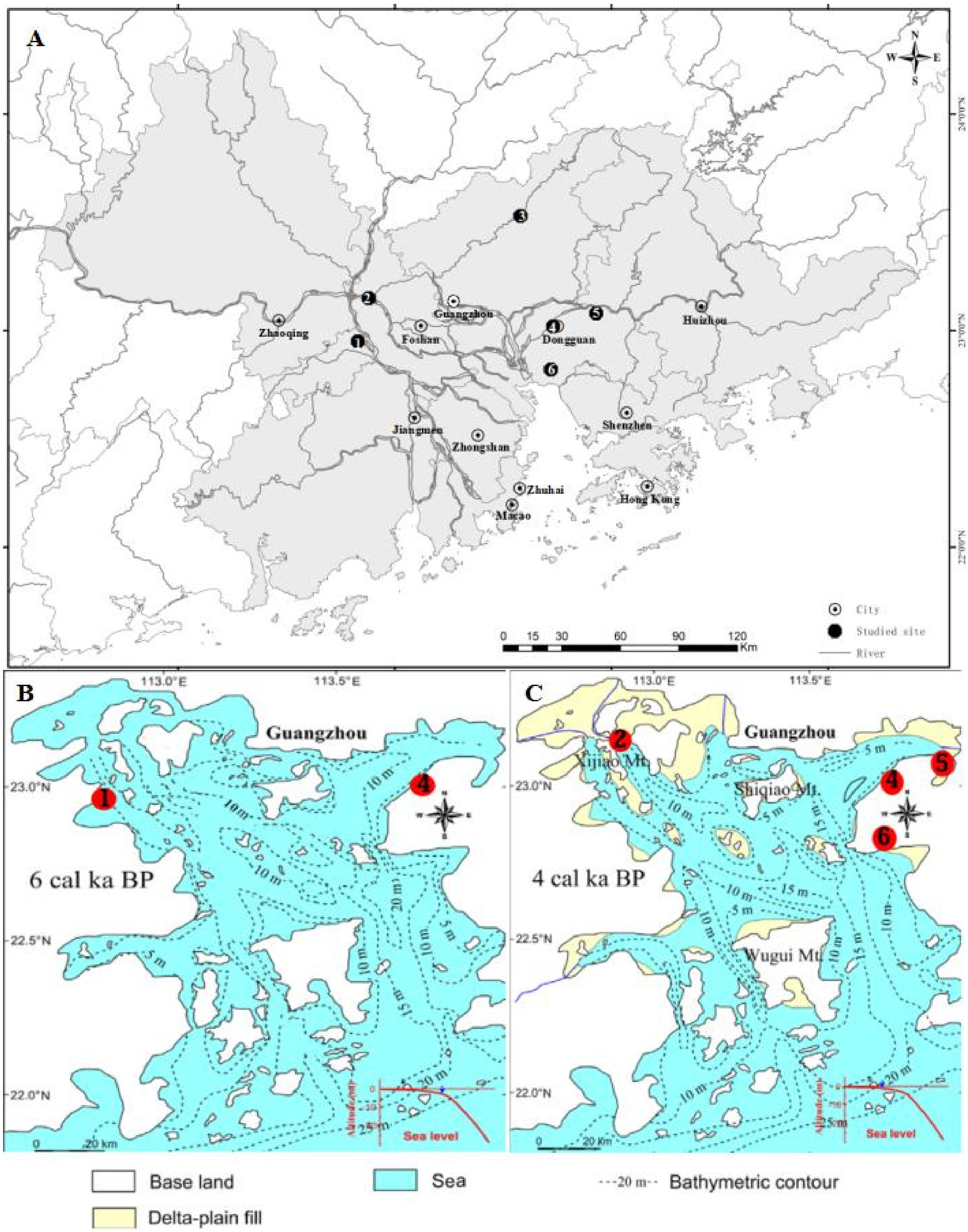

Figure 4. 1 Sketch palaeogeographical map of site locations. A, Location of studied sites in the Pearl River Delta; B, Early Holocene outline of the Pearl River Delta, c. 6,000BP; C, Late Holocene outline of the Pearl River Delta,c. 4,000 BP. (Base maps of B and C are from Wei et al. 2016). Sites:1, Guye site; 2, Yinzhou site; 3, Hengling site; 4; Haogang site; 5; Yuanzhou site; 6, Cuntou site.

4.1 Site description

4.1.1 Guye site (c. 5,900-5,000 BP)

Guye site (22°49.2′N, 112°40.2′E) (Figure 4.1 A) is one typical Neolithic shell midden site in the Pearl River Delta. The remains recovered at this site are divided into two period and further four phases, dating from c. 5,900-5,000 BP (Table 4.1 and Figure 4.2).

Table 4. 1 Radiocarbon dating of Guye site (Yang et al. 2017).

Sample No.	**Sample**	**^{14}C dating/BP**	**Lab No.**
06GGLTS09W08⑤-01*	Pottery soot	4730±30	BA111813
06GGLTS10W09⑥-01	Pottery soot	4905±30	BA111814
06GGLTS10W08⑦-01	Pottery soot	4715±30	BA111815
06GGLTS09W08⑤-C3-2	*Canarium* sp.	2350±140	BA111816
06GGLTS09W08⑥-H1-1	*Canarium* sp.	4355±40	BA111817
06GGLTS09W08⑦-A3-1	*Canarium* sp.	4825±35	BA111818
06GGLTS09W08⑤-C8-11	*Cordia dichotoma*	4850±30	BA111819
06GGLTS09W08⑥-P1-8	*Cordia dichotoma*	4895±30	BA111820
06GGLTS09W08⑦-F11-1	*Cordia dichotoma*	5095±30	BA111821
06GGLTS09W08⑤-B3-1	*Lithocarpus glaber*	4595±30	BA111822
06GGLTS09W08⑥-J3-4	*Lithocarpus glaber*	4890±35	BA111823
06GGLTS09W08⑦-A3-2	*Lithocarpus glaber*	4755±25	BA111824
06GGLTS10W07⑤-Z10	*Oryza sativa*	275±40	BA111825
06GGLTS09W08⑥-Z14	*Oryza sativa*	modern	BA111826
06GGLTS09W06⑦-Z2	*Oryza sativa*	15±35	BA111827

*Note: Chinese archaeologists often code the samples as follows: 06 is the excavation year of Guye site: 2006; GGL is the site code; TS09W08 is the trench number; ⑤ is the layer number; 01 is the sample number.

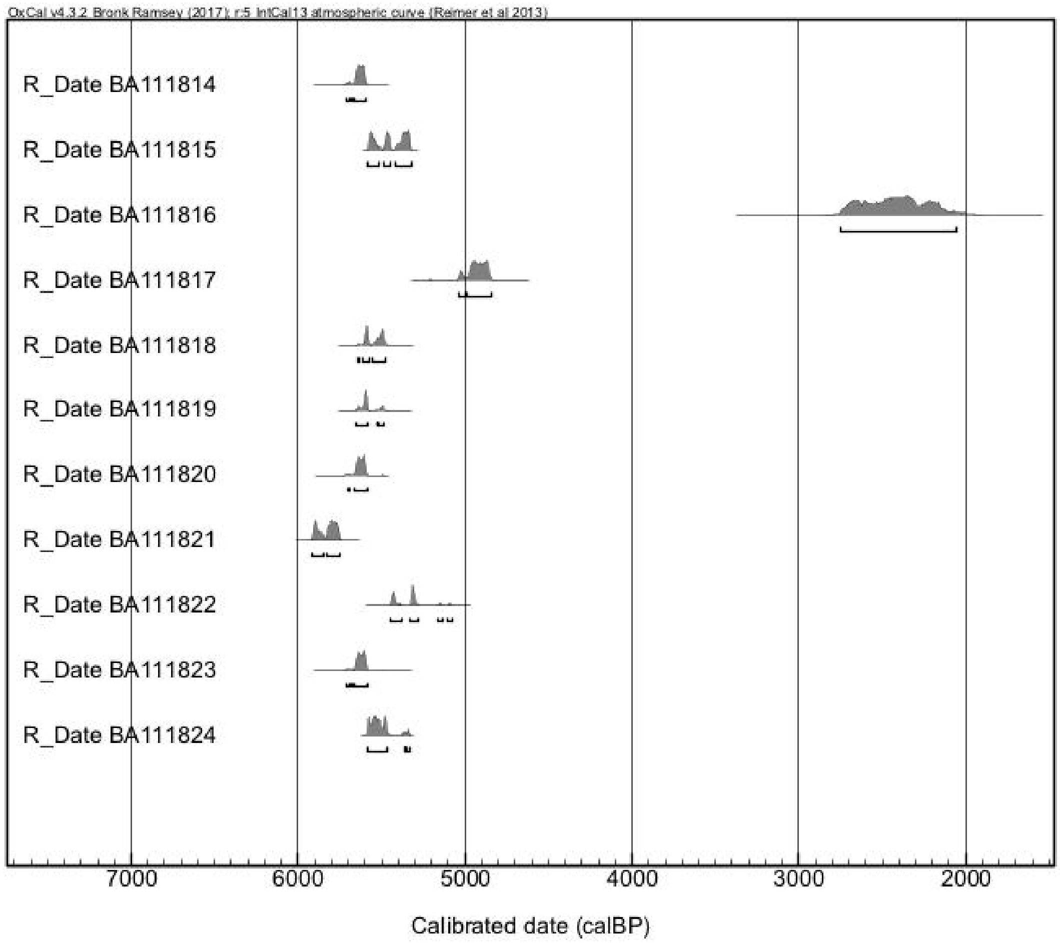

Figure 4. 2 Calibrated ^{14}C dates of Guye site.

The figure is modified from Table 4.1. All the data are calibrated based on IntCal 13 atmosphere curve (Reimer et al, 2013) through OxCal v4.3.2 (Ramsey 2017).

Abundant potsherds and stone tools, including axes, adzes, chisels and grinding tools, along with some wooden tools with use wear, were unearthed during the excavation in 2006 (Cui 2007; Yang et al. 2017). He and Li (2012) counted the stone artifacts unearthed at Guye site, which is more than 700 pieces, including unfinished tools and remains during the making processes. Among the complete stone tools, the shouldered stone adzes are in the largest number (N=136), together with grinding slabs (N=90) and hammers (N=118) in different shapes (He and Li 2012). And the raw materials of those stone artifacts are tuff mainly, which is possibly from Xiqiaoshan site, followed by quartzite and sandstone, from the near regions (He and Li 2012).

The waterlogged environment of the Guye site preserved hundreds of acorns and Chinese olives well, together with bamboo chips and some leaves (Cui 2007). The large number of acorn remains, especially *Lithocarpus* spp., suggested the acorn consumption in this region, which is not mentioned in the previous studies. Meanwhile, animal remains, such as turtle and spine of wild boar, were uncovered (Cui 2007). According to the recovered plant remains, South China Botanical Garden, Chinese Academy of Sciences reconstructed the environment of Guye site (Figure 4.3). The results reveal that the modern paddy field regions of Guye site have ever been a freshwater marsh, and the subtropical forest at that time is more typical than the modern vegetation.

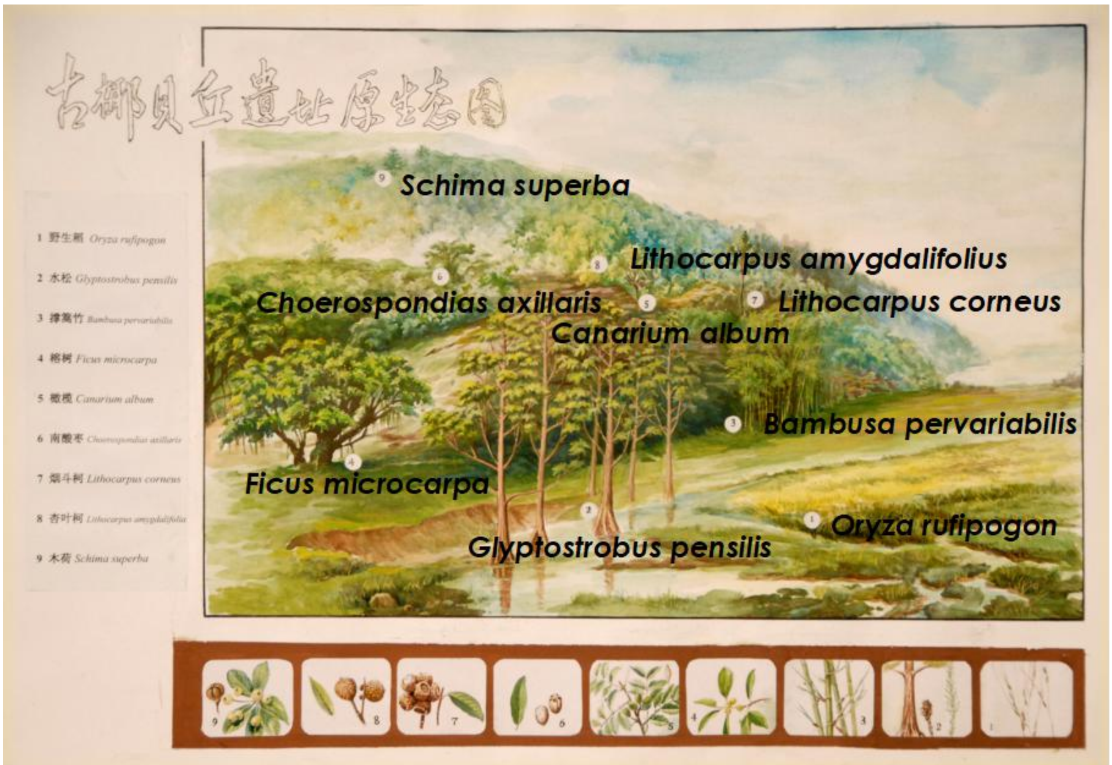

Figure 4. 3 Ecological restoration map of Guye site (provided by Gaoming Museum).

The stratigraphy of Guye site is relatively clear (Figure 4.4). The Neolithic remains unearthed at Guye site could be classified to two phases: the early phase contains the remains from layer 5 to layer 7, dating from c. 5,900-5,300 BP according to the radiocarbon dates (Table 4.1), and the late phase contains the findings from layer 2 to layer 4, which date should be earlier than 5,000 BP based on ceramic features (Li and Cui 2008). The pottery sequence at Guye site suggested that the culture recovered at this site could be grouped as a new regional archaeological culture, between Xiantouling culture and the culture characterized by geometric painted pottery (Li and Cui 2018). The features of this culture include the continuous presence of the *guan* jar with stand rim and *fu* cauldron, the shouldered stone tools in large quantities, and the inflow of microlithic tools in the late phase (Li and Cui 2018).

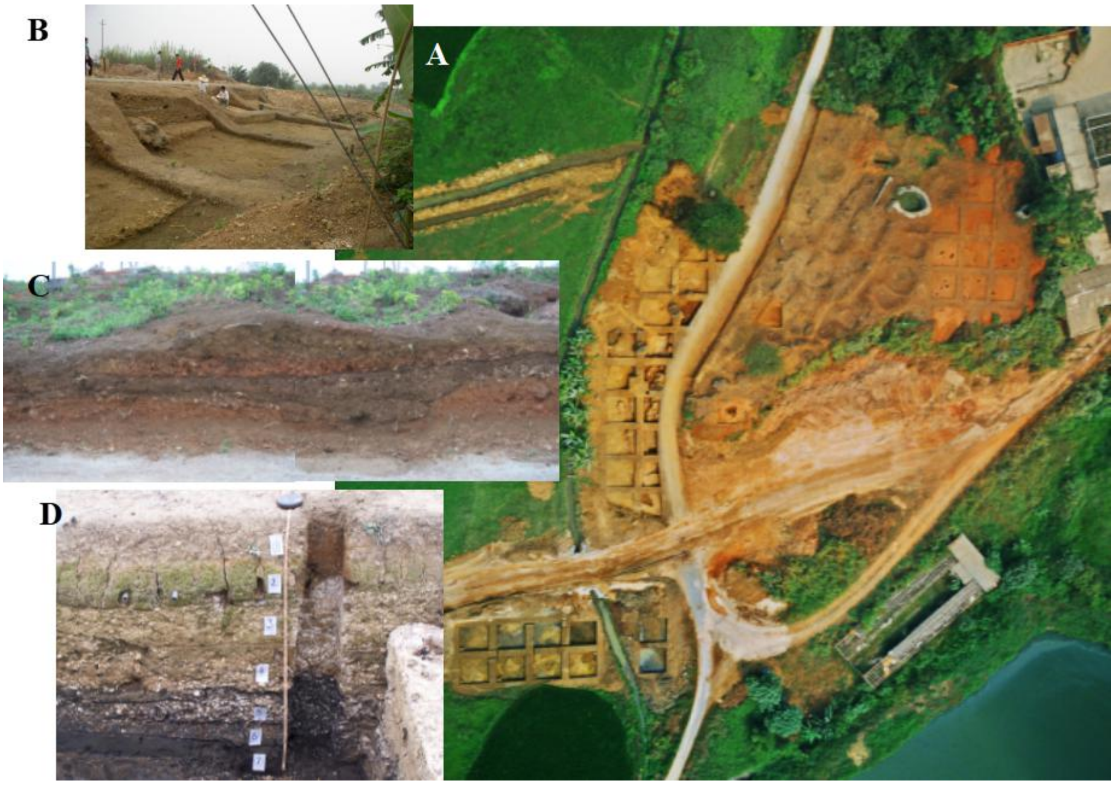

Figure 4. 4 Map of Guye site. A, Aerial image of Guye site; B, Excavation map on the hill top; C, Stratigraphy of the gentle slope area; D, Stratigraphy of paddy field (images provided by Gaoming Museum).

4.1.2 Yinzhou site (c. 4,500-3,500 BP)

Yinzhou site (Figure 4.1 A) lies in the east of Yinzhou village in Sanshui city, which is one important shell midden site in the Pearl River Delta (Figure 4.5). This site was excavated three times between 1990 and 1995, and its first two excavation areas are about 480 m^2 (Li 2000). The early cultural features of this site present the similarities as those of late phase of Shixia culture, therefore, according to the radiocarbon dates of the Shixia site (Table 4.2), this settlement may have started at around 4,500 years ago (Li 2000; Yang et al. 2016; Zhu 2012).

Table 4. 2 AMS ^{14}C dates of Shixia Site (data are from Yang et al. 2016; Zhu 2012).

	Sample source	Samples	^{14}C/BP	Lab No.+
Early Shixia Culture	M79*	Charcoal	4220±110	BK76024
Middle Shixia Culture	M26	Charcoal	4020±100	BK75050
	M43	Charcoal	4330±90	BK75046
Late Shixia Culture	M21	Charred rice	3810 ± 30	Beta-397662

*M79 means the grave No. 79

+ In Lab Number, BK represent Peking University radiocarbon laboratory; Beta means Beta Analytic testing laboratory.

Abundant potsherds, tools made from stone or bone, and wooden ornament were recovered (Li 2000). The popular ceramic vessels at this site are the ring-foot form, round-bottom form, and concave-bottom form, with a small amount of three-foot type, including *fu* cauldrons, *guan* jars, *dou* pedestal cups, and *ding* tripod (Li 2000). The distributions of burials, post holes, pits and shells reveal that this site were well organized, which was planned into three function zones, including graveyard, residential area and garbage area (Li 2000).

There has ever been an opinion that this settlement experienced a significant regression according to the species and quantity changes of recovered shellfishes (Yuan 1995). But after re-identification of those shells, Li et al. (2015) argued that this evidence is not enough to reveal the environment shifts. However, the shellfish unearthed in large numbers indicate that the nearby waters, no matter estuary or epicontinental sea, can provide sufficient resources for fishing of the natives (Li et al. 2015).

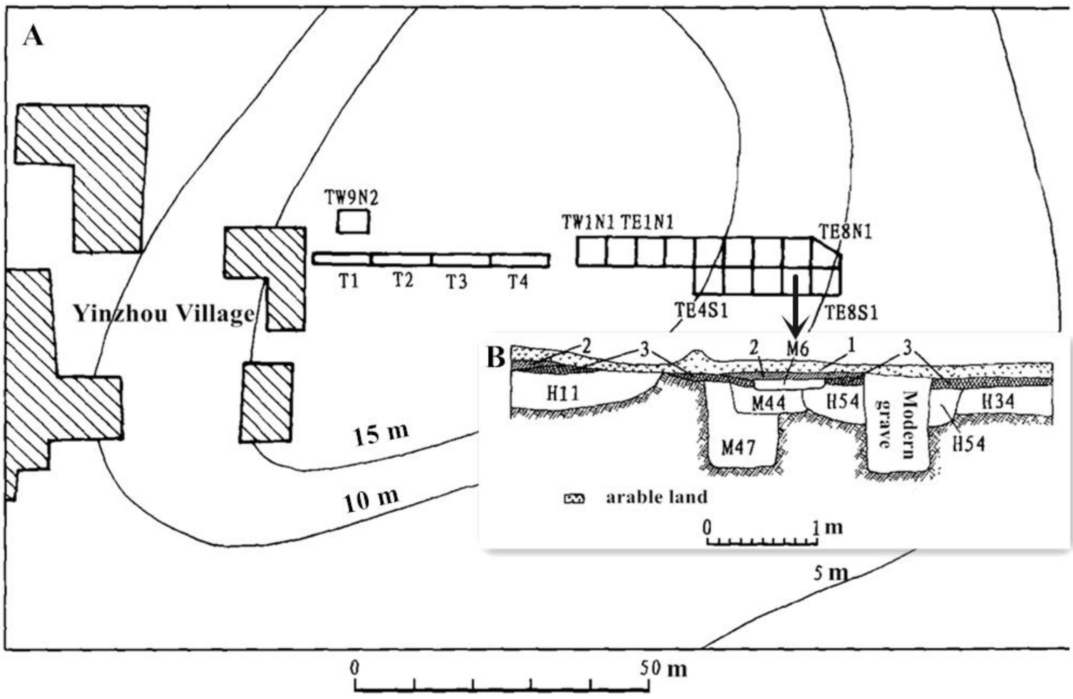

Figure 4. 5 Map of Yinzhou site. A, Location of excavation region of Yinzhou site; B, section image of TE7S1 east side (modified after Figure 2 and Figure 3 in Li 2000). (In the image, M means graves and H means pits).

The cultural sequence of this site is classified into three phases (Li 2000). The first phase bears the features from both the first phase of Youyugang site, which presents the regional cultural features in the Pearl River Delta, and the late phase of Shixia culture in north Guangdong, indicating the interregional communication. The features of the second phase correspond to the second phase of Youyugang site as well, but still under the impacts of Shixia site, revealed by the morphological characters of folded-rim *guan* jars with ring foot. The features of the third phase could be found at Cuntou site and Maogang site as well, while the concave-bottom *guan* jars unearthed from this phase reveal the cultural influence from eastern Guangdong.

4.1.3 Hengling site (c. 4,000 BP)

Hengling Site (Figure 4.1 A), located in the north of Conghua District, Guangzhou city, was excavated in 2012 (Figure 4.6) (Zhang 2014). The excavation region is over 5,000 m^2. Through investigation, except the west of Hengling hill, the similar cultural relics should more widely distribute in an area of 70,000 m^2 (Zhang 2014). It is inferred that the residential region was probably located in the south of Hengling Hill (Zhang 2014). A series of pits and 51 burials, together with hundreds of pottery and stone tools, were unearthed, the date of which is suggested to be around 4,000 years ago (Zhang 2014). The well arranged graveyard uncovered is reported as the most important finding of this site (Zhang 2014).

Figure 4. 6 Aerial image of Hengling site (Zhang 2014).

The cultural deposits are relatively simple, which could be divided into 5 layers, within them, layer 3 is Early Shang Dynasty layer where the unearthed potsherds are mainly decorated by cord- marking, and then zigzag pattern; the layer 4 and 5 are the Late Neolithic deposits, from which the major decoration of potsherds is zigzag pattern, followed by cord-marking and stripe patterns (Zhang 2014).

4.1.4 Haogang site (c. 6,000-4,000 BP)

Haogang site (113°44′E, 22°55′N) (Figure 4.1 A), excavated in 2003, covers an area approximately 600 m^2 and about 10 meters higher than the surrounding area (Li 1998). The excavation area is only 72 m^2 (Figure 4.7). A few recovered shells were selected for ^{14}C dating (Table 4.3), but these dating results were thought to be later than the actual age of the site (Feng 2007). Feng (2007) suggested that the date of Haogang site should range between 6,000 and 4,000 BP.

Table 4. 3 Radiocarbon dates of Haogang Site (data are from Feng 2007).

Sample No.	Sample	^{14}C Dating (yr/BP)	Lab No. (KWG-*)
T0406⑤	Oyster shell	3880±100	1879
T0304③	Oyster shell	2880±90	1882
T0406④	Oyster shell	3670±100	1883
T0304③	Oyster shell	3480±95	1884
T0306⑤	Oyster shell	3630±90	1907
T0306④	Black soil with shells	3210±90	1908

* KWG means that the samples are tested in Guangdong Institute of Geography

The identifiable ceramic vessels include plate with ring foot, *guan* jars, *fu* cauldron, and *bo* bowls. Various stone tools were unearthed, including pointed stone tools (58) (Figure 4.8), axes(15), adzes (27), disc-shape handstones (18), netherstones (3), and pestles (1). Among them, the pointed tools have the largest number, which were presumably used for shellfish opening. Together with the dense shells and fish bones recovered at this site, Feng (2007) suggested that the Haogang site should have an aquatic resource dominant economy. The plant use cannot be ignored as a large number of plant processing tools were unearthed as well. It is inferred that the adzes, axes, and chisels might be used for woodworking, beaters for bark cloth-making and the netherstones and handstones for plant foods processing (Deng 1999; Feng 2007).

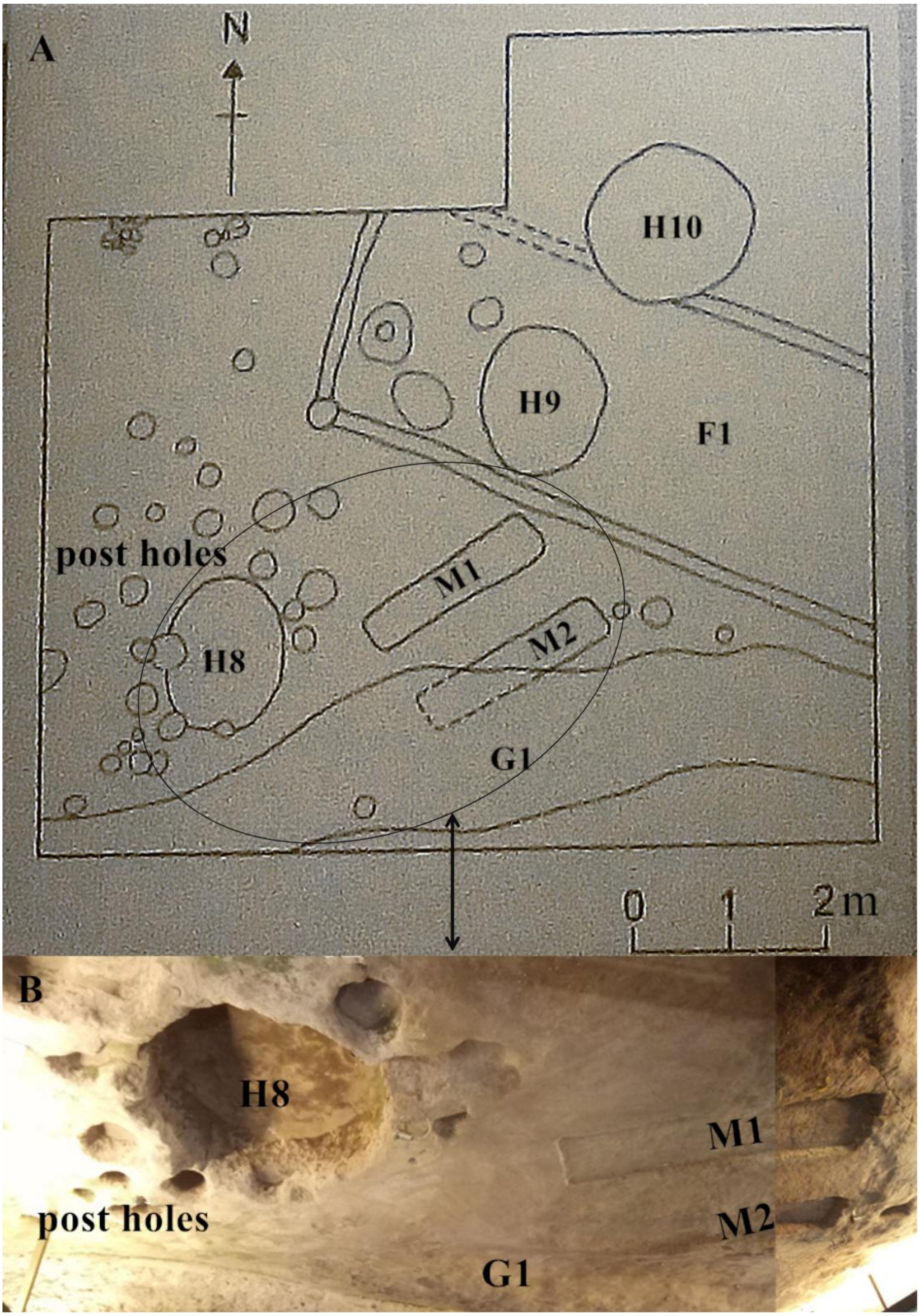

Figure 4. 7 Excavation map of Haogang site. Image A was taken from Dongguan Museum, and Image B was taken in the Haogang Museum when I collected samples in 2017: in these images, M means graves; H means pits; and G means ditch.

Figure 4. 8 Pointed stone tool unearthed at Haogang site, which is displayed in Haogang Museum. (According to visual estimated, this tool is around 5cm in width)

The deposits are divided into 6 layers, in which the layer 2 to layer 6 are Neolithic cultural layers (Feng 2007): layer 2 is grayish brown or reddish-brown clay layer mixed with a small amount of shells; layer 3 to layer 5 are shell layers; and layer 6 is brown sub-clay layer. According to the features of relics, especially pottery, archaeologists argued that Haogang site has three cultural phases (Table 4.4).

Table 4. 4 Phase details of Haogang site (data are from Feng 2007).

Phase	Dating (/BP)	Features
First	6,000-5,500	The unique ceramic vessel is white pottery plates with ring foot and incision decoration; the pottery form is simple, only including ring-foot plates and jars. A small number of stone tools unearthed.
Second	5,500-5,000	The pottery assemblage includes painted pottery and sand-tempered pottery. The popular decoration is cord-marking. Many stone tools were found, including pointed stone tools, handstones, netherstones, stone beaters, adzes and axes.
Third	4,500-4,000	Two features of pottery include the appearance of high-temperature polished clay plates and *bo* bowls with ring foot and disappearance of painted pottery. The decoration patterns are cord-markings, incisions, and shell impressions. The tool kit is similar to the second phase, but the axes and adzes began to have shouldered design.

4.1.5 Yuanzhou site (c. 4,500 BP)

Yuanzhou site (Figure 4.1 A) is found on a hill in southeast of Shipai town, Dongguan city, which is about 4 m above the surrounding fields and more than 350 m^2 in area (Wu 2000). There is no direct dating data of Yuanzhou site, but according to its cultural similarities to Youyugang site, it is suggested that the occupation time of Yuanzhou site was close to that of Youyugang site (Wu 2000). Combined with the radiocarbon dating results of Youyugang site (Table 4.5), human activities at Yuanzhou site should begin at around 4,500 BP.

Table 4. 5 Radiocarbon dates of Youyugang site (data are from Li, Z. and Li, Y. 1997)

Sample source	Phase	Calibrated ^{14}C dating（BP）
F1*	Yououyugang II	3345±150
F1	Yououyugang II	3840±125

*The only information the report mentioned is that they are collected from the No. 1 house remain (F1).

Through excavation in 1998, objects, including a variety of pottery and stone tools, were unearthed; others, including a few high-walled bone rings and some bone tools, were also excavated. The popular pottery forms are *fu* cauldron, *guan* jars, *bo* bowls, and *dou* pedestal cups (Wu 2000). A total of 35 stone tools were uncovered, including adzes, chisels, and grinding tools, which are mainly made from fine sandstone (Wu 2000). Besides shellfish and fish bones, some animal bones are recovered, such as cattle, pigs, and deer (Wu 2000).

According to stratigraphic evidence and recovered remains, director Zhang in Dongguan Museum noted (2017) that Yuanzhou site was possibly located on a hillock, which was one or two meters higher than the surrounding field, where there were shallow waters in the rainy seasons or years and swamp or land at less rainy times.

The deposits could be divided into 4 layers (Figure 4.9 C). Take T0303 as an example (Wu 2000):

Layer 1: modern soil layer, 40 cm;

Layer 2: yellow fine sand layer, no more than 30 cm. the sand is friable, with a small amount of broken shell, pottery, and porcelain;

Layer 3: grey fine sand layer, with dense shell, 5-10 cm;

Layer 4: grey fine sand layer, 10-55 cm.

The remains of Yuanzhou site could be roughly separated into two phases (Wu 2000). The pottery of the early phase is characterized by *fu* cauldron, *guan* jars with ring foot, shallow *bo* bowls with round bottom, and deep *dou* pedestal cups. The popular decorations on vessels at that time are checkered pattern, stripe pattern, and leaf vein pattern. Some similar features are also identified from other sites, such as the first phase of Youyugang site and the first phase of Yinzhou site. The represented pottery of the late phase of Yuanzhou site include *fu* cauldron with cord marking, round-bottom *guan* jars with stand collar, folded shoulder and combined decoration, and shallow *dou* pedestal cups. All the cultural features of this phase correspond to some other sites around delta, such as the second phase of Yinzhou site, and the second phase of Youyuguang site. And the finding of two tripod feet from the early phase indicates the relationship between Yuanzhou site and Shixia site (all the information of this paragraph is referred from Wu 2000).

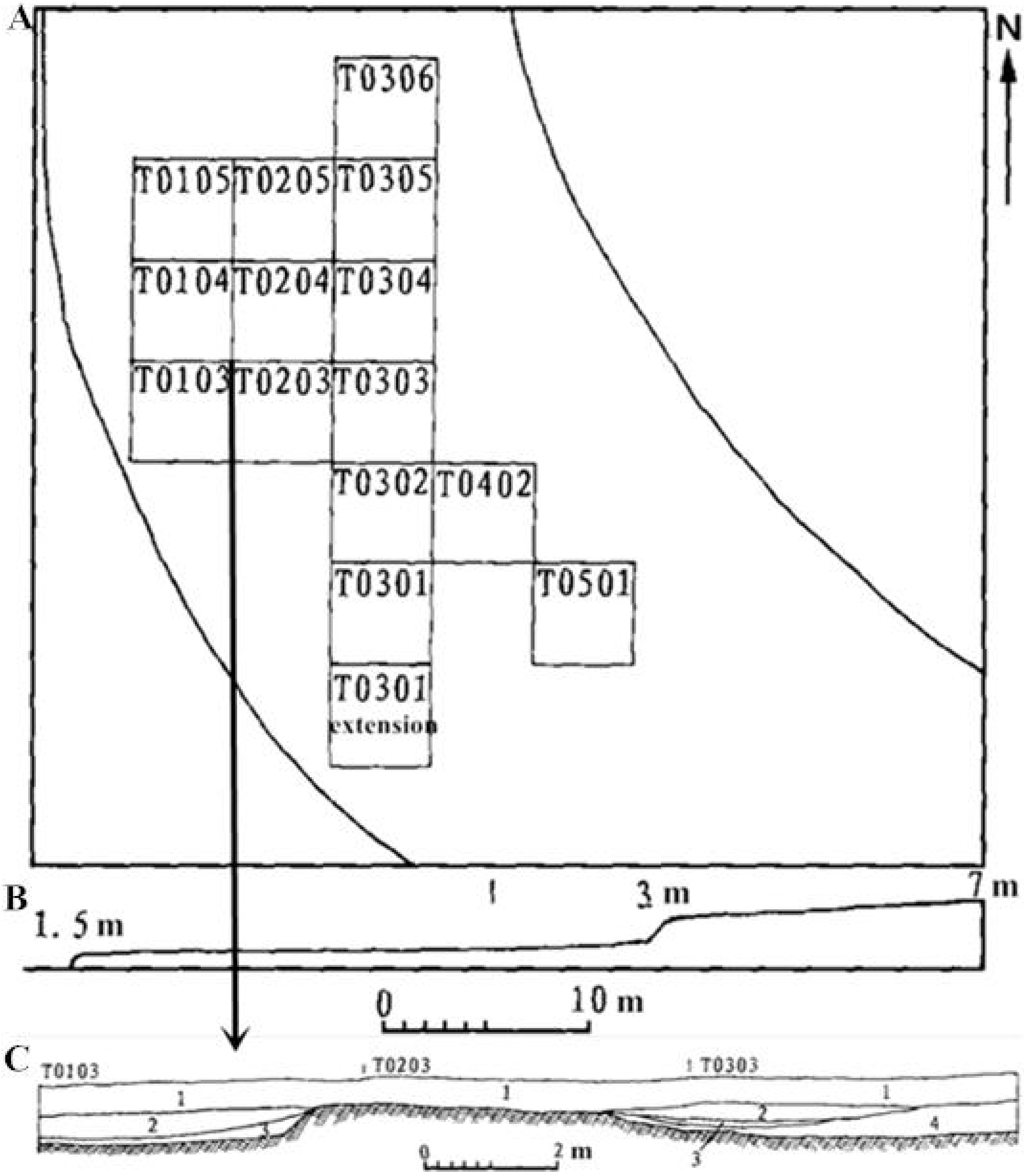

Figure 4. 9 Map of Yuanzhou site. A, excavation area of Yuanzhou site; B, relative surface height; C, profile of T0103, T0203, T0303 from Yuanzhou site (from Wu 2000).

4.1.6 Cuntou site (c. 4,100-3,000 BP)

Cuntou site（22°49′23.1″N, 113°43′04. 1″E）(Figure 4.1 A), located in the southeast of Pearl River Delta, was excavated twice from 1989 to 1993 (Figure 4.10) (Li 2000). The systematic excavations of this site and few radiocarbon data demonstrate that the age of this site is in the range of 4,100 to 3,000 years ago (Table 4.6).

Table 4. 6 Radiocarbon dates of Cuntou site (Peking University radiocarbon laboratory 1996; Excavation report in press).

Sample No.	Samples	Dating (yr/BP)	Lab No.*
89DCH184	Charcoal	3635±70	BK90093
T1406③E	Charcoal	3650±90	KWG-1037

*BK represent Peking University radiocarbon laboratory; KWG are from Guangdong Institute of Geography which will be published in the report of Cuntou site

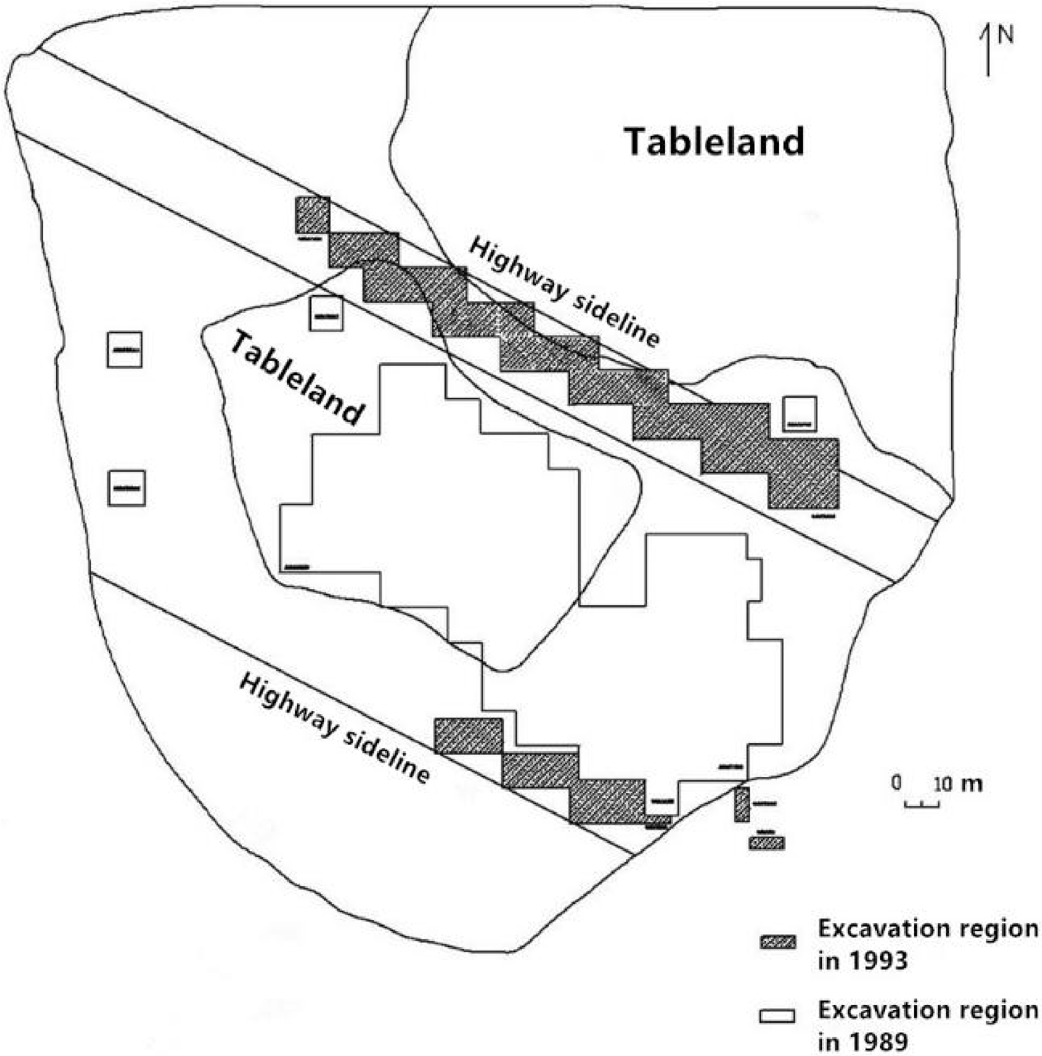

Figure 4. 10 Excavation map of Cuntou site (Provided by Zhang Haicheng in Dongguan Museum).

The diverse forms of ceramic vessels include ring-foot type and concave-bottom type mainly, and in the late phase of this site, the flat-bottom vessels present infrequently (Excavation report of Cuntou site, in press). Their decorations are also various, mainly characterized by geometric stamped patterns, such as cord pattern, water wave pattern, leaf vein pattern and X pattern (Excavation report of Cuntou site, in press; Li 2000). A large number of stone tools were unearthed as well. Besides production tools, such as adzes and grinding slabs, the tool kit unearthed also contains weapons, like spears, arrowheads, and dagger axes, and decorations, for example, rings. The remains, such as houses, pits, and burials indicate that this settlement was well organized, where clear functional zones are identified (Li 2000). Li (2000) described the settlement plan: in the northeast part of this site, the residential area, the houses were arranged in an orderly manner; the south region is possible as a garbage area, from which dense shells were found; and the central part is used for public community activities. The analysis of the settlement plan also revealed that the center of this settlement moved northward gradually, as an adaptation strategy to environmental changes (Li 2000).

Paleoclimate research indicates the surrounding environment of this site transformed from a coastal type to a lakeside type (Table 4.7). The findings of oyster shells, deer, and other wild animal bones in large quantities indicate that hunting and fishing were still the main components of indigenous subsistence practice (Lou and Huang 2009). But domesticated pigs and dogs recovered at this site are suggestive of stability of original agriculture and complex social structure at this site (Huang and Zhang, in press). In archaeobotany, there is no evidence on plant cultivation at this site.

Table 4. 7 Paleogeography and paleoclimate of Cuntou site (data are from Lou and Huang 2009; Excavation report in press).

Layer	Dates (/BP)	Paleogeography	Paleoclimate
5A	c. 5,000	Near the coast. Sea level rose but was still slightly lower than the ground.	Hot and completely moist
mid-4	4,350±440*	Seaside, and the sea water flowed into the site.	Cooler and still moist
4A		Sea level declined slightly, so that the site was far from the sea. Mainly in freshwater environment, but there are still tidal inflowed.	Slightly warmer and dryer than before
3C	3,384±340*	Freshwater dominated, but little different from last period: waters with weak liquidity.	Cooler and dryer
3A	3,160±320*	Sea level rose, and the site was near the sea.	Hot and moist

* These date were tested through thermoluminescence dating of potsherds.

The stratigraphy of Cuntou site showed that it can be divided into 6 layers, while each layer has several sublayers further (Figure 4.11). Within them, the third to fifth layers are the ones where remains of the pre-Qin Dynasty were found (Li 2000).

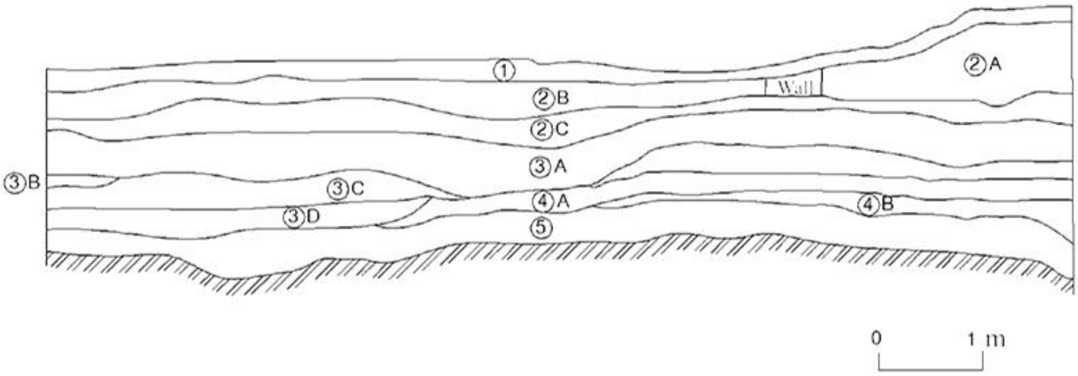

Figure 4. 11 Profile of 89DCT0706 from Cuntou site (Excavation report in press).

The cultural sequences of Cuntou site are classified to four phases in the excavation report (in press) (Table 4.8). The cultural relics, especially ceramic vessel forms and decorations, of the early phase have the local features, similar to the findings from, for example, the second phase of Yinzhou site. But some new features, such as bowl-shaped *dou* pedestal cups, the inflow of concave-bottom ceramic vessels, and the absence of stone dagger-axe indicate that the time of the first phase of Cuntou site should be later than that of the second phase of Yinzhou site. The second and third phases of Cuntou site are closely linked to each other on the aspect of ceramic form changes. The remains unearthed from these two phases are consistent with those from other sites throughout the delta, such as the third phase of Yinzhou site, Maogang site, and Tangxiahuan site. Meanwhile, the stone dagger-axes were unearthed at various sites in the Pearl River Delta, for example, Maogang site. The *yazhang* serrated-edged jade tablet emerged. The ceramic vessels recovered from the fourth phase of Cuntou site are different from those of the third phases and no inheritance relationship is found. The features of this phase were similar to those in the second phase of Wubeiling site (c. 3,600-3,000 BP) in Shenzhen.

Table 4. 8 Culture sequence of Cuntou site (Excavation reports of Cuntou site, in press).

Phase	Features
1	The ring-foot jars have the most abundant patterns during this phase. Besides, there are also other forms, such as high-collar type, concave-bottom type and folded-shoulder type. The flat-bottom vessels and tripods are absent. The decoration includes zigzag pattern, checkered pattern, diamond pattern, raised edge, leaf vein pattern, mat pattern, X-shaped pattern and some combination patterns.
2	In this phase, the vessel forms are continuations of the previous period. But the proportion of concave-bottom vessels increase along with the slight decrease of ring-foot jars.The combination pattern decoration become popular. Meanwhile, the stone dagger-axes, stone scepters and ivory scepters emerge.
3	The ring-foot jars continuously declined at that time, with the increase of concave-bottom vessels. The flat-bottom vessels are present infrequently, for example, small-size flat-bottom jars.The stone dagger-axes, stone scepters and ivory scepters are recovered as well.
4	The typical vessel forms includes *Zun* vat, flat-bottom jars and *dou* pedestal cups.The decoration includes cloud pattern, fine checkered pattern and mat patterns.

4.2 Description of sampled tools

4.2.1 Guye site

Seven sandstone grinding tools of Guye site were sampled for starch grains analysis, including six fragments of netherstones and one complete upper grinder from Neolithic layers (Figure 4.12). The selected grinding stones, which have irregular shapes, were considered typical of the Guye material from the storeroom (Table 4.9). All netherstones were broken fragments and all, except one (TN01W04⑤: 9), had two or three concave ground surfaces, and one narrow ground flat side.

Table 4. 9 Sampled stone artefacts of Guye site.

Type	Raw material	Sample No.	L (cm)	W (cm)	Th (cm)	Observations
Netherstone (broken)	Sandstone	TS10W09④: 38	15	8	4	Netherstone fragment with three used surfaces:two opposing concave surfaces and one ground edge. Its ground edge is also concave with striae. This may be an earlier surface of a much larger grinding stone.
Netherstone (broken)	Sandstone	TN01W04⑤: 9	19	9.5	7	Netherstone fragment with roughly flaked around perimeter. One ground surface smoothed and concave. Zone of central pitting on ground surface.
Netherstone (broken)	Sandstone	TN01W04⑥: 14	25	15	6	Netherstone fragment with oughly flaked around perimeter. Opposing ground surfaces both concave.
Netherstone (broken)	Sandstone	TS02W04⑥: 1	6.5	5.9	2.8	Squared fragment with one flat ground surface and one edge also grounds flat (whetstone?) One edge hammer dressed.
Netherstone (broken)	Sandstone	TS09W08⑥: 8	22.5	13.5	4	Netherstone fragment. Upper surface heavily smoothed and concave. Lower surface convex and roughly smoothed. May have been used as top stone.
Netherstone (broken)	Sandstone	TS09W07⑥: 43	26	13	6.5	Netherstone fragment with roughly flaked around perimeter. Opposing surfaces heavily ground and concave. One edge also ground flat (whetstone?) Upper ground surface with zone of central pitting.
Upper grinder (complete)	Sandstone	TS09W06⑦: 69	11	10	3	Hammer dressed around the perimeter. Extensive smoothing on upper surface. Lower surface used, but with less smoothing and with zone of central pitting.

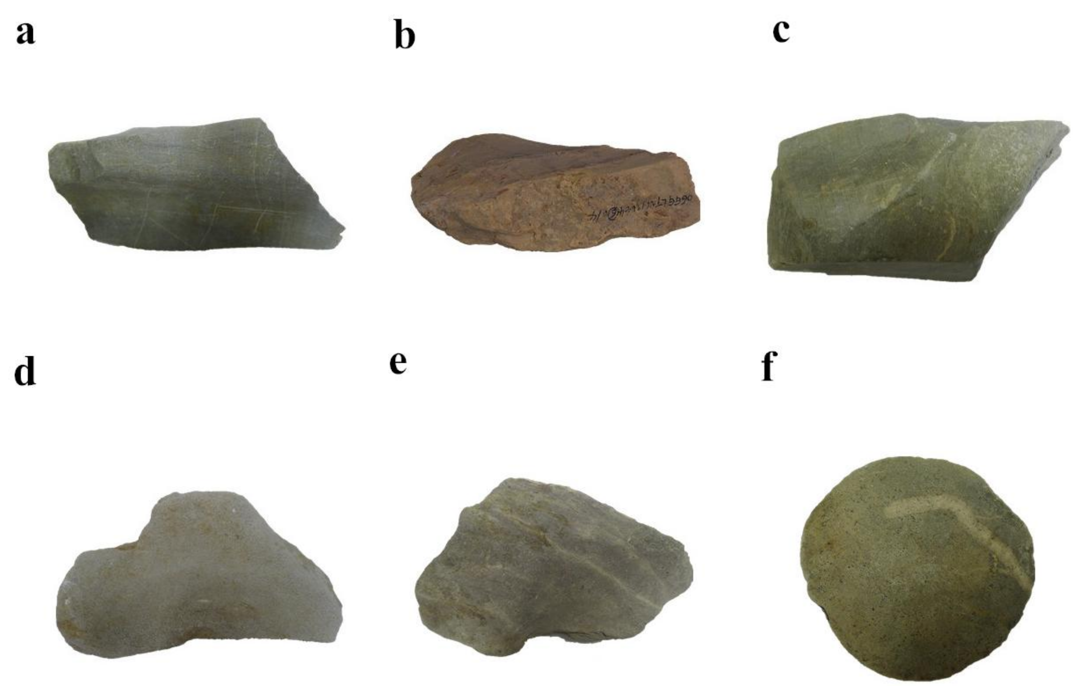

Figure 4. 12 Studied stone tools at Guye site. a, netherstone (TN01W04: 9); b, netherstone (TN01W04: 14); c, netherstone (S10W09: 38); d, netherstone (S09W07: 43); e, netherstone (S09W08: 8); f, upper grinder (TS09W06⑦: 69).

4.2.2 Yinzhou site

Five netherstones unearthed at Yinzhou site were sampled from the storeroom of Sanshui Museum, including four irregular slabs and one rectangular block (Figure 4.13). All these netherstones, except one (metamorphic rock), were made from sandstone. Most of them have two ground surfaces, except one from Pond II, which has three concave use surfaces (Table 4.10).

Table 4. 10 Sampled stone artefacts of Yinzhou site.

Type	**Raw material**	**Sample No.**	**Observation**
Netherstone	Metamorphic	93SDTW5S1④	It is a rectangular block, which has two ground surfaces
Netherstone	Sandstone	93SD Pond II	There are three concave ground surfaces
Netherstone	Sandstone	92SDTE3N1 M23	It is an irregular slab with two ground surfaces
Netherstone	Sandstone	92SDTE3N1 M53	It is an irregular slab with two ground surfaces
Netherstone	Sandstone	92SDE8N1 d7	It is an irregular slab with two ground surfaces

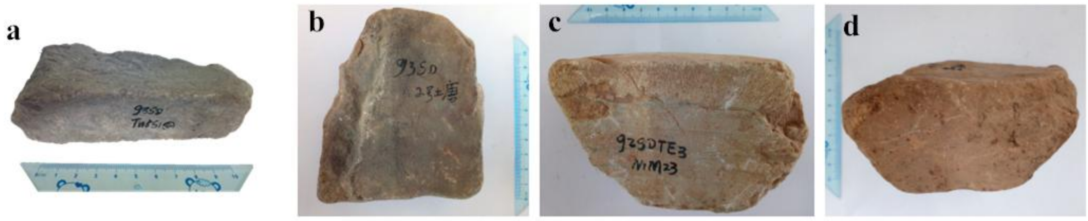

Figure 4. 13 Studied netherstones at Yinzhou site. a, 93SDTW5S1④; b, 93SD Pond II; c, 92SDTE3N1 M23; d, 92SDTE3N1 M53.

4.2.3 Hengling site

Samples for starch analyses at this site were collected from twelve stone artefacts, including four handstones, two netherstones, one pestle, one hammer, and four unmodified tools unearthed from Neolithic layers and Early Shang layer (Figure 4.3.1). Three handstones have elongated shapes and except the broken one (2013CHT2245), the other three all have two ground surface. The raw materials of two netherstones are sandstone and siltstone respectively, and each of them possibly has only one ground surface (Table 4.11). Those natural pebbles were selected as a control group and further to check whether they have the relationship with starch-rich plant processing.

Table 4. 11 Sampled stone artefacts of Hengling site

Sample	Sample No.	Description
Netherstone	2013CHT1624③b	Irregular sandstone block with one concave ground surface
Pestle	2013CHT1937③	Sandstone pestle
Handstone	2013CHT1726③	Two ground surfaces
Handstone	2013CHT1826④	Elongate tool with two ground surfaces
Hammer	2013CHT2346 北隔梁③	
Handstone	2013CHT1826H19	Coarse-grained sandstone elongate tool with two ground surfaces
Netherstone	2013CHT2038④	Unmodiefied siltstone, possible 1 ground surface
Handstone	2013CHT2245 东隔梁④	Elongate tool. Broken
Natural pebble	2013CHT1926⑤-1	Unmodified tool
Natural pebble	2013CHT1926⑤-2	Unmodified tool
Natural pebble	2013CHT1725④	Broken
Natural pebble	2013CHT1624②	Broken, possible have one ground surface

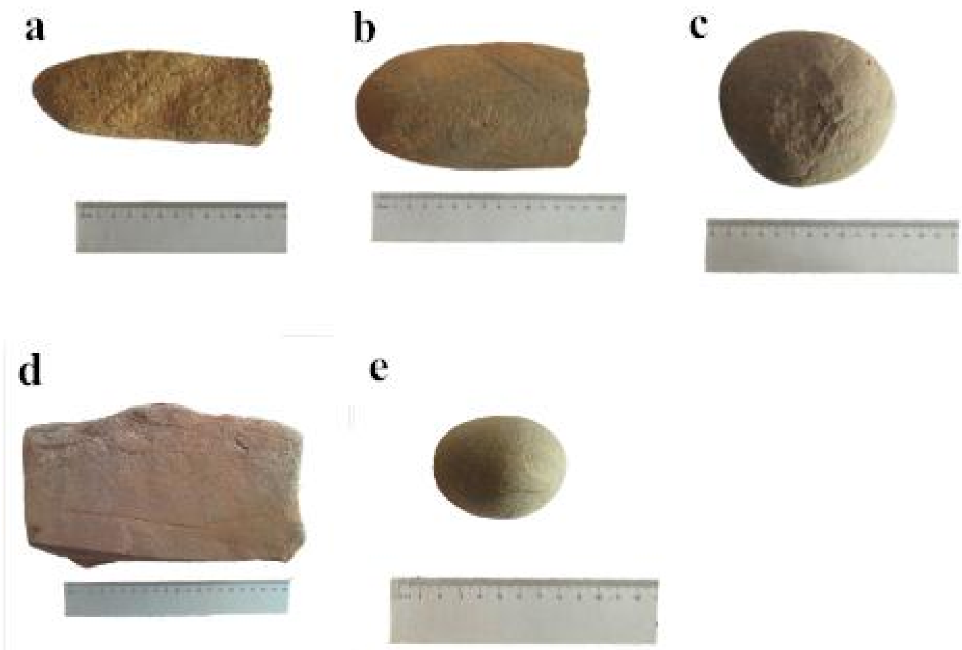

Figure 4. 14 Studied tools at Hengling site. a, handstone (2013CHT1826H19); b, pestle (2013CHT1937③); c, hammerstone (2013CHT2346 北隔梁③); d, netherstone (2013CHT1624③b); e, natural pebble (2013CHT1725④).

4.2.4 Haogang site

A total of 15 stone artefacts were selected from storeroom of Haogang Museum. Within them four disc-shape handstones were selected, which form is typical in the Pearl River Delta, called "饼形器". The netherstones are irregular sandstone slab, which are roughly flatted, and everyone has at least one concave ground surface (Table 4.12).Besides the handstones and netherstones, seven hammerstones, which may be used for acorn process, were included (Figure 4.15).

Table 4. 12 Sampled stone tools at Haogang site.

Type	Raw material	Sample No.	L/W/Th (cms)	Weight (g)	Observation
Handstone	Sandstone	T0305 ⑤:35 northward expansion	9.0x9.0x3.0	383	It is dressed and has disc-shape. There is one knapping to flatten non-use surface
Handstone	Sandstone	03DHT0407⑤: 28	8.0*8.0*3.0	152	It has disc-shape. there are three ground surfaces, including one main used surface
Handstone	Sandstone	T0306⑤: 36	6.0*6.0*3.0	162	Disc-shape handstone, there are three grounded surfaces, including one concave grounded surface
Handstone	Sandstone	03DHT0405②: 2	5.0*5.0*1.5	63	Disc-shape handstone. There are three ground surfaces, including one main used surface
Pestle/handstone	Metamorphic	03DH H6			This is a broken pestle. It has one flat abraded surface and rounded end. It may be multifunctional
Netherstone	Sandstone	03DHT0306⑤: 34 northward expansion	19.0*15.0*3.5	1014	It is an irregular slab and roughly flatted. There are two concave depression surfaces
Netherstone	Sandstone	03DHT0306⑤: 193	14.5*9.0*4.5	724	It is an irregular wedge-shape slab and roughly flatted. There are two ground surfaces
Netherstone	Sandstone	03DHT030⑥: 168	14.0*9.0*3.0	353	It is an irregular slab and roughly flatted. There is one concave ground surface
Stone hammer		layer 2	8.4*6.8*4.4	488	
Stone hammer		layer 2	7.0*5.4*4.6	343	
Stone hammer		03DHT0406②: 13	9.3*7.0*5.0	717	
Stone hammer		03DHT0304②: 2	10.0*6.4*5.7	504	
Stone hammer		03DH H9: 1	7.5*6.6*4.5	387	
Stone hammer		layer 4	8.6*10.0*8.7	806	
Stone hammer		03DHT0407⑤: 24	9.0*7.0*5.0	440	

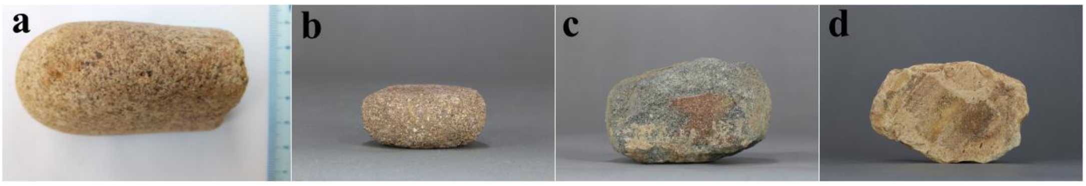

Figure 4. 15 Studied tools at Haogang site. a, pestle/handstone (03DH H6); b, handstone (T0306⑤: 36); c, hammerstone (03DHT0304②: 2); d, netherstone (03DHT0306⑤: 193).

4.2.5 Yuanzhou site

Within the thirty-five unearthed stone tools, the four netherstones may be possibly related to starchy plant food processing (Wu 2000). Therefore, all of them are sampled (Figure 4.16). These irregular slabs, made from slate, sandstone, and metamorphic stone, respectively. All of them have one concave use surface at least. Besides the heaviest one, the other three slabs have another flat use surface as well (Table 4.13).

Table 4. 13 Sampled stone tools at Yuanzhou site.

Type	**Raw material**	**Sample No.**	**L/W/Th (cms)**	**Weight (g)**	**Observation**
Netherstone	Slate	98DSY T0304④: 13	13*(9.6-4.6) *(2.4-1.4)	246.3	Irregular shape netherstone. There are two use surfaces, one is flat, and the other is concave.
Netherstone	Sandstone	98DSYT0304④: 15	13.3*7.0*4.2	539	Irregular shape netherstone, there are two use surfaces. The concave surface may be the main use surface. The other may be used for tool manufacture?
Netherstone	Metamorphic	98DSYT0304③: 14	13.5*10.2*7.4	1211.4	Irregular shape netherstone. There is one concave use surface
Netherstone	Sandstone	98DSYT0105③			Irregular shape netherstone. There are two use surfaces, one is flat, and the other is concave.

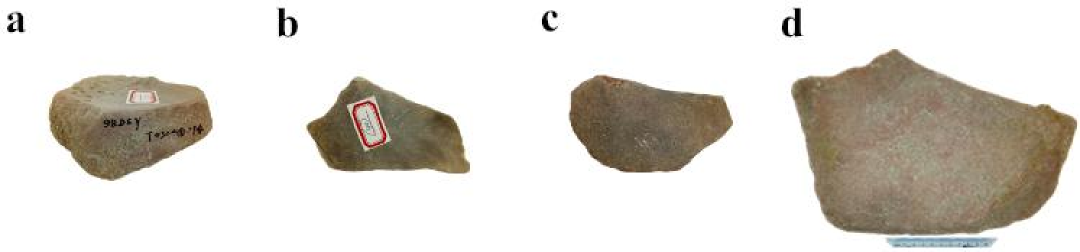

Figure 4. 16 Studied netherstones at Yuanzhou site. a, 98DSYT0304③: 14; b, 98DSY T0304④: 13; c, 98DSYT0304④: 15; d, 98DSYT0105③16.

4.2.6 Cuntou site

Within 839 stone artifacts were unearthed at the Cuntou site (Lou 2012), the tools possibly related to plant food processing mainly include pestles (N=30), handstones (including oval-shaped stone, disc-shaped stone and grinding rod) (N=11), aand netherstones (N=21). Based on a visual assessment, twelve stone tools unearthed from Neolithic layers were selected randomly from the storeroom of Dongguan Museum, including three handstones, three netherstones, two pestles, three hammerstones, and one artefact possibly used for grinding (Figure 4.17 and Table 4.14). A total of 14 samples are collected via an ultrasonic cleaning machine for starch grain analysis.

Table 4. 14 Sampled stone tools of Cuntou site.

Type	Raw material	Sample No.	L/W/Th (cms)	Observation
Handstone	Metamorphic	93DCT1614③B: 6	6.3*4.8*1.9	Unmodified pebble. There is one flat ground surface
Netherstone	Siltstone	89DCT0613③: 6		It is an irregular slab which has one ground surface
Pestle	Metamorphic	89DCT1010③E: 6	7.1*3.4*3.0	
Stone tool		93DCT1615③: 14	6.1*5.1*3.6	Possible ground stone
Hammerstone		93DCT0707③C: 28	8.4*5.7*4.2	
Handstone	Sandstone	93DCT1416④: 10	5.7*5.6*3.4	Disc-shape
Tapered hammer		89DCT1406④C: 7	9.3*3.6*3.3	
Waisted hammer	Metamorphic	93DCT1615④: 19	4.7*4.7*10.6	Cylindrical
Netherstone	Sandstone	93DCT2211F17: 2	10*5.7*2.1	It is a slab with one ground surface
Handstone		89DCT0807 5A： 22	8.5*8.5*4.9	Disc-shape, two used surfaces
Netherstone	Limestone	89DCT1504G6: 2	10.4*6.6-3.3	one concave ground surface
Pestle	Metamorphic	89DCT0712H93: 1	11.7*4.5*3.8	

Figure 4. 17 Studied tools at Cuntou site. a, handstone (93DCT1614③B: 6); b, netherstone (89DCT0613③: 6); c, pestle (89DCT0712H93: 1).

Chapter 5: Starch granule analysis

This chapter is divided into three parts. Part one reviews the biology of modern starch including its formation in plants and granule morphology, and the preservation of starch on the archaeological artefact. Part two describes the variables typically used in the description, classification and identification of starch granules, whether modern or ancient. Part three describes the methods used to prepare modern reference material and the methods used in the extraction of starch from the archaeological sample studies in this thesis.

5.1 Biology of modern starch granules

All plants produce starch as the primary mechanism for the storage of sugars produced during photosynthesis. Starch granules may occur in all parts of a plant, including leaf tissues, stem tissues, epidermal tissues including bark, as well as roots (Bertoft 2017). Diagnostic starch granules are mostly found in specialised storage organs that include underground storage organs (e.g. roots, tubers and corms), seeds (e.g. cereal grains), fruits and nuts (e.g. acorns), and in the stems (pith) of some woody perennials (e.g. sago palms) (Santelia and Lunn 2017). Starch has also been recorded in small quantities in tree resins (Pyatt et al. 2005). Plants produce two different types of starch granules as a product of photosynthesis: transitory starch and storage starch (Messner 2011; Santelia and Lunn 2017) (Figure 5.1). Both are efficient methods for the short and long-term, stable storage of plant sugars (carbohydrate). Transitory starch, is used for the short-term storage of carbohydrates, and is primarily synthesized in in the leaves and stem tissues for the purpose of providing some energy for growth and operation of the leaf stoma (Fernandez et al. 2017; Stitt and Zeeman 2012). They are often very small in size (1-2 microns), with few diagnostic features (e.g. Haslam 2004). As a result, transitory starch granule has little or no diagnostic potential and is normally excluded from starch granule analyses (e.g. Barton 2005).

Storage starch represents a solution to the longer-term storage of carbohydrates and is created by the plant in specialised storage organs. Many plants produce distinguishable storage starch grains with relatively large sizes, up to100 microns, which may be identifiable to genus and species level (e.g. Holst et al. 2007; Torrence and Barton 2006; Yang et al. 2009; 2012). In general, larger-size granules tend to offer greater diagnostic potential than small granules, and often granules smaller than 5 microns are excluded from taxonomic identification (e.g. Barton 2005, Yang et al. 2012), though they may be included in total starch counts. In this thesis, I have also excluded these granules from analyses.

The starch granules vary in shapes, commonly including spheres, ovals, polygons, and irregular forms (Torrence and Barton 2006). In the case of Poaceae, the tribe Triticeae produce two types of granules: the larger A-type is lenticular granule and the small-size B-type is disc-shaped (e.g. Figure 5.2: 24 and 39) (Kim and Huber 2008; Yang and Perry 2013); seeds of foxtail millet and broomcorn millet display basic polyhedral granules (Figure 5.2: 7 and 9) (Yang et al. 2012); while job's tears may have nearly rounded or rounded granules (Figure 5.2: 17) (Ge 2010). Not all granule shapes are highly diagnostic, hence some other properties, like hilum position (Figure 5.1 b), fissure types (Figure 5.1 b), lamellae (Figure 5.1 b), extinction cross (Figure 5.2 40 and Figure 5.4 a), and surface texture, are probably useful for identifying the plant. The hilum is the core of the granule where it starts growing (Torrence and Barton 2006). It is commonly near the central position but can also be situated near one end of the granule, described as an eccentric type (Torrence and Barton 2006). The potato starch granules in Figure 5.1, for example, present one type of eccentric hilum position. At the hilum, some granules have fissures, like cracks outward from the hilum (Figure 5.1 b) (Torrence and Barton 2006), such as the deep fissures on the starch granules of edible legumes (Figure 5.3) (Wan 2012).

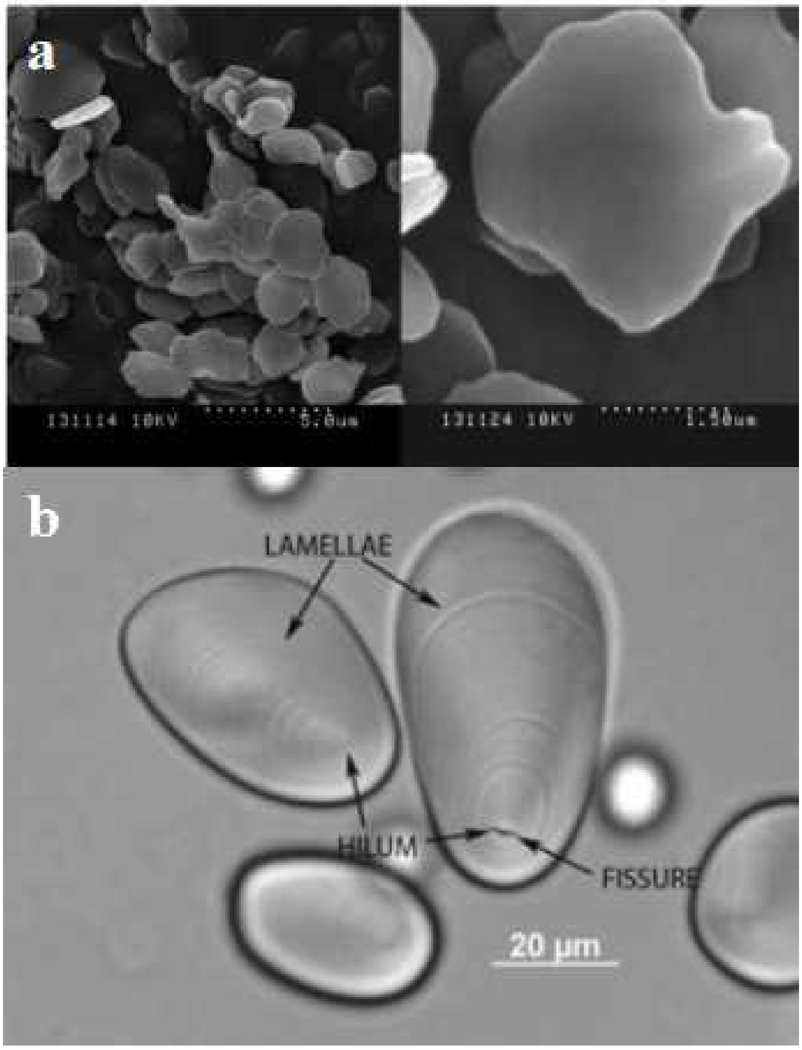

Figure 5. 1 Transitory starch and storage starch. a, scanning electron micrographs of *Arabidopsis* leaf starches collected from end of the day (Scale bar, left: 5µm; right 1.5µm) (Zhu et al. 2015) b, storage starch grains of potato (*Solanum tuberosum*) (Coster and Field 2015).

Figure 5. 2 Characteristic starch grains from the family Poaceae (1-38 are from Fig 1 and 39 is from Figure 2 C in Yang and Perry 2013; 40 is from Liu et al. 2014), 1, *Oryza sativa*; 2, *Oryza rufipogon*; 3, *Zizania caduciflora*; 4, *Sorghum bicolor*; 5, *Eriochloa villosa*; 6, *Echinochloa colonum*; 7, *Panicum miliaceum*; 8, *Panicum bisulcatum*; 9, *Setaria italica*; 10, *Setaria faberil*; 11, *Setaria viridis*; 12, *Setaria pumila*; 13, *Setaria chondrachne*; 14, *Setaria parviflora*; 15, *Setaria plicata*; 16, *Digtaria sanguinalis*; 17, *Coix lacryma-jobi*; 18, *Elymus dahuricu*; 19, *Roegneria kamoji*; 20, *Leymus chinensis*; 21, *Triticum aestivum*; 22, *Hordeum vulgare*; 23, *Hordeum vulgare* var. *coeleste*; 24, *Aegilops tauschi*; 25, *Aegilops speltoides*; 26, *Agropyron criststum*; 27, *Secale cereale*; 28, *Bromus japonica*; 29, *Alopecurus aequalis*; 30, *Lolium perenne*; 31, *Milium effusum*; 32, *Milium effusum*, 33, *Melica scabrosa*; 34, *Poa annua*; 35, *Poa annua;* 36, *Avena nuda*; 37, *Eleusine coracana*; 38, *Eleusine coracana*; 39, side view of *Aegilops tauschi* granule; 40, Z-shaped arm and curved arm on the extinction cross of job's tear. Scale bar, 1-16, 28-38, and 40, 10 µm; others, 20 µm.

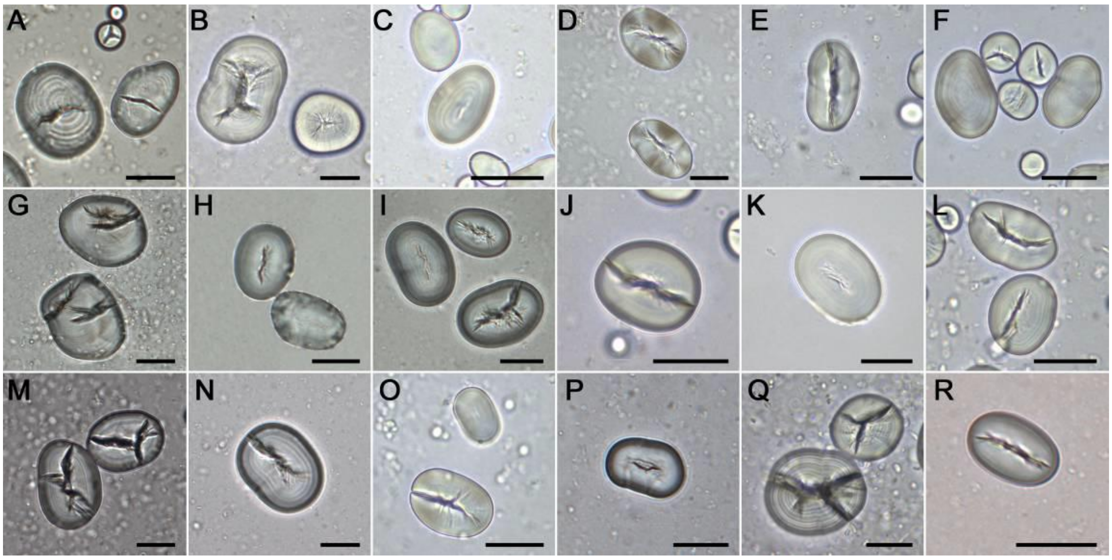

Figure 5. 3 Starch grains of edible legumes (Figure 4.6 in Wan 2012). A, *Cajanus cajan*; B, *Canavalia gladiata*; C, *Cicer arietinum*; D, *Lablab purpureus*; E, *Lathyrus sativus*; F, *Lens culinaris*; G, *Mucuna pruriens*; H, *Phaseolus coccineus*; I, *Phaseolus lunatus*; J, *Phaseolus multiflorus*; K, *Phaseolus vulgaris*; L, *Pisum sativum*: M, *Vicia faba*; N, *Vigna angularis*; O, *Vigna cylindrica*; P, *Vigna radiata*; Q, *Vigna umbellata*; R, *Vigna unguiculata.* Scale bars, 20 µm.

At the molecular level, starch granules are composed of carbohydrates in two related forms: amylose and amylopectin(Figure 5.4) (e.g. Bertoft 2017; Torrence and Barton 2006). The internal properties of starch granules, visible lamellae (the growth layers) (Figure 5.1 b) and birefringence of granules under cross-polarised light (Figure 5.4 a), have relationships with granule microstructure, especially amylopectin (e.g. Bertoft 2017; Torrence and Barton 2006). Birefringence of granules are also characterised by a distinct black cross (an interference pattern caused by the bands of the polarising filter and analyser) (Figure 5.4 a). What helps distinguish starch granules from other birefringent materials, including some that can produce an extinction cross, such as some heavy minerals and fecal spherulites, is that the arms of the cross in starch will move as the analyser is rotated (Coster and Field 2015). Besides, it is also possible that some granules present particular form of extinction arms, like the Z-shaped arm and curved arm on the extinction cross of job's tear granules (Figure 5.2: 40) (Liu et al. 2014).

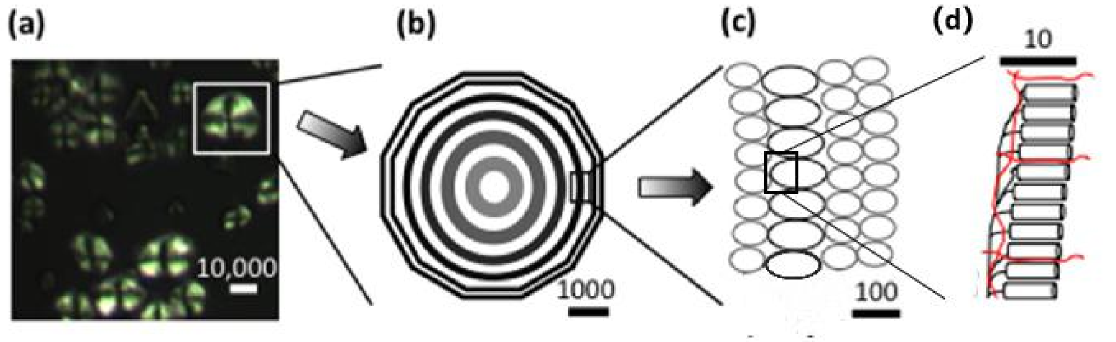

Figure 5. 4 Dimensions in starch: from granules to glucosyl units (modified after Bertoft 2017 Figure 1). (a) Maize starch granules observed under polarised light showing the "Maltese cross", which is indicative of a radial organisation within the starch granule. (b) A hypothetical granule (in this case polyhedral) with growth rings extending from the hilum. (c) Blocklets in semi-crystalline (black) and amorphous (grey) rings. (d) Crystalline and amorphous lamellae formed by double helices (cylinders) and branched segments of amylopectin (black lines), respectively. Amylose molecules (red lines) are interspersed among the amylopectin molecules.

X-ray diffraction can characterize starch granules at the molecular level (e.g. Chen et al. 2010; Pérez and Bertoft 2010). This method can separate granules into three types: A-type, seeds; B-type, most tubers and rhizomes; and C-type, legumes (e.g. Chen et al. 2010; Pérez and Bertoft 2010). However, the method relies on relatively large samples of concentrated starch granules. Typically archaeological samples contain tens of granules, which is too small a sample size for this analysis and other analytical methods used to determine granule microstructures (Ge 2010).

5.2 Archaeological application of starch analysis

Although there are several taphonomic hypotheses of the survival of starch granules adsorbed onto the surfaces of archaeological artefacts, including sorption, enzymatic inaccessibility, microbial modulation, silicification, phosphatisation, and non-enzymatic breakdown, how the starch granules, as organic molecules, can persist on the artefacts for hundreds of thousands of years is still poor understood (see Barton and Matthews 2006; Mercader et al. 2018). No indication suggests the extent to the morphological changes of recovered starch granules during thousands of years of taphonomic processes (Copeland and Hardy 2018). But the processing of starchy foodstuffs through grinding tools may modify the size and morphological features of some granules (e.g. Ma et al. 2019; Wang 2017). For example, grinding the dehusked millet grains to flour, the millet starch granules become up to 1.2 times larger, and 1/4 of them have destroyed surface and reduced clarity of extinction crosses (Ma et al. 2019). But the geophyte granules are less changeable (Wang 2017). Some starch granules will have fine cracks across their hilum after drying, but grinding or pounding 10 minutes will not make morphological changes of most granules in an identifiable manner (Wang 2017). Since few millet granules identified and possible long-lasting horticulture relied on vegetative propagation in southern China, in this thesis I have made the assumption that any starch grains recovered from the surfaces of archaeological artefacts from the Pearl River Delta study sites would be identical in their morphology to modern granules, so the latter could be used to identify the former.

Despite these, the starch granules recovered from stone artefacts, including archived items (e.g. Barton 2007; Barton and Matthews 2006; Barton and Torrence 2015; Hardy et al. 2017; Revedin et al. 2010; Yao et al. 2016), present great potential in exploring food processing technologies, subsistence practices and diet of early humans (see Barton and Torrence 2015; Copeland and Hardy 2018). The particular tool function should be the most direct information available. The starch granules recovered from grindstones from hundreds of sites in China demonstrated their roles of tool function analyses (Table 3.7). Some researches suggest that they were used for crop processing mainly, together with a small amount of wild plants like geophytes (e.g. Li et al. 2019; Ma et al. 2016; Wang et al. 2015; Wu et al. 2018; Yang et al. 2016), while some tend to support the idea that those tools were mainly used for processing wild resources (e.g. Liu et al. 2010; Yao et al. 2016).

The starch residues from the grindstones also provide information on the ancient plant use. Current studies reveal the regional economic plant assemblages in Australia. In the arid Kokatha Country, the economic plant assemblage in the late Holocene (the date estimates based on stone artefact technology) includes Murray lily (*Crinum flaccidum*) and Bulrush/Cumbungi (*Typha domingensis*) (Owen et al. 2019), but in a tropical rainforest region, Northern Queensland, the components were black walnut (*Endiandra palmerstonii*), hairy walnut (*E. insignis),* Whelan's macadamia (*Lasjia whelani*) and yellow walnut (*Beilschmiedia bancroftii*) (Field et al. 2016). Although the starch analyses confirmed that plants, like acorns, tribe Triticeae, job's tears, and yams, were probably consumed widely in northern China and Yangtze River Basin between 28,000 to c. 4,000 BP, the regional difference of plant use between northern and southern China could still be noticed in Table 3.7, in which granules of foxtail millet and broomcorn millet were mainly recovered in northern China, while barnyard, water chestnut, and sago-type granules in southern China (Table 3.7). In addition, these residues also sketch the process of foxtail millet domestication in northern China (Ma et al. 2016; Yang et al. 2012).

5.3 Variables of starch granule description in this thesis

There is no uniform standard on which characteristic assemblages should be selected for classification and identification of starch granules (e.g. Barton 2005; Torrence et al. 2004; Yang et al. 2009). The primary method of granule identification uses a morphometric approach that records overall size and shape in two or three dimensions (e.g. Torrence and Barton 2006). This method has its limitations (e.g. Coster and Field 2015; Fullagar et al. 2008), but over time has proven to be the most reliable method for the taxonomic identification of modern and ancient starch granules (e.g. Arráiz et al. 2016; Mercader et al. 2018; Wan et al. 2011; Yang et al. 2009; 2012).

Shapes of starch grains, especially three-dimensional form, is highlighted as a useful diagnostic feature (e.g. Musaubach et al. 2013; Wang et al. 2018; Yang and Perry 2013; Yang et al. 2012). For example, the lenticular grains are representative of tribe Triticeae (Yang and Perry 2013). To assess the three-dimensional shape of starch grains recovered from archaeological samples, they should be observed at different views under the microscope by pressing the coverslip. Other features, including hilum, fissure, lamellae, and extinction cross, are also used for granule identification (e.g. Torrence and Barton

2006; Yang and Perry 2013; Yang et al. 2012). The hilum positions, used to classified starch grains, are classified to two types mainly (Pearsall et al. 2004; Torrence and Barton 2006). The first group, centric, is that the hilum is centrally located and the second group, eccentric, means that the hilum located an asymmetrical position. The birefringent phenomenon under polarized light is helpful for describing hilum position, which is the intersection of extinction cross is the hilum position. The lamellae can be analogized to the tree rings, however, it may not be visible in all the plant species and even different organs of the same plant. For example, starch grains from lotus roots have clearly visible lamellae, but the lamellae of lotus seed granule is invisible (Piperno and Holst 1998; Wan et al. 2011). Therefore, the visibility of lamellae is used as another diagnostic characteristic of starch grains. The shape of the fissure is another common feature used to describe a starch granule, such as longitudinal, stellate, transverse, and Y-shape (e.g. Holst et al. 2007; Yang et al. 2012; Zarrillo and Kooyman 2006).

Overall, the morphometric features of granules in this thesis I selected to describe both modern and ancient granules includes granule size, shape (2D or 3D if possible), position of hilum (centric or eccentric), presence or absence of lamellae, form of fissures, and surface texture (smooth or rough) (see Torrence and Barton 2006). All the starch grains were observed and photographed in both plane light and cross-polarised light of light microscopy (x400). The size, maximum length, of at least 100 granules from each modern reference materials were measured through Zeiss AxioVision software, and their morphological features were described through the images taken with Zeiss Axiocam. All archaeological starch residues will be measures and recorded in the same way.

5.3.1 Size and shape

All starch granule sizes are available by the length they display on the picture taken with Zeiss AxioCam, through Zeiss AxioVision software. The size of rounded granules is its diameter through hilum (Figure 5.5 a). When the granule has a spherical part like Figure 5.5 b shown, then I measured the underside length of the spherical part, but I selected the height of the bell-shaped granule as its size (Figure 5.5 c). The oval-type granules, including oval granules, spindle-shaped granules, and pestle-shaped granules, were measured the length between two ends as its size (Figure 5.5 d), but if the shape is not regular, then I measured the longest straight distance from one end to the other (Figure 5.5 e). The polyhedral granules and irregular ones were measured with the longest length shown in the image (Figure 5.5 f).

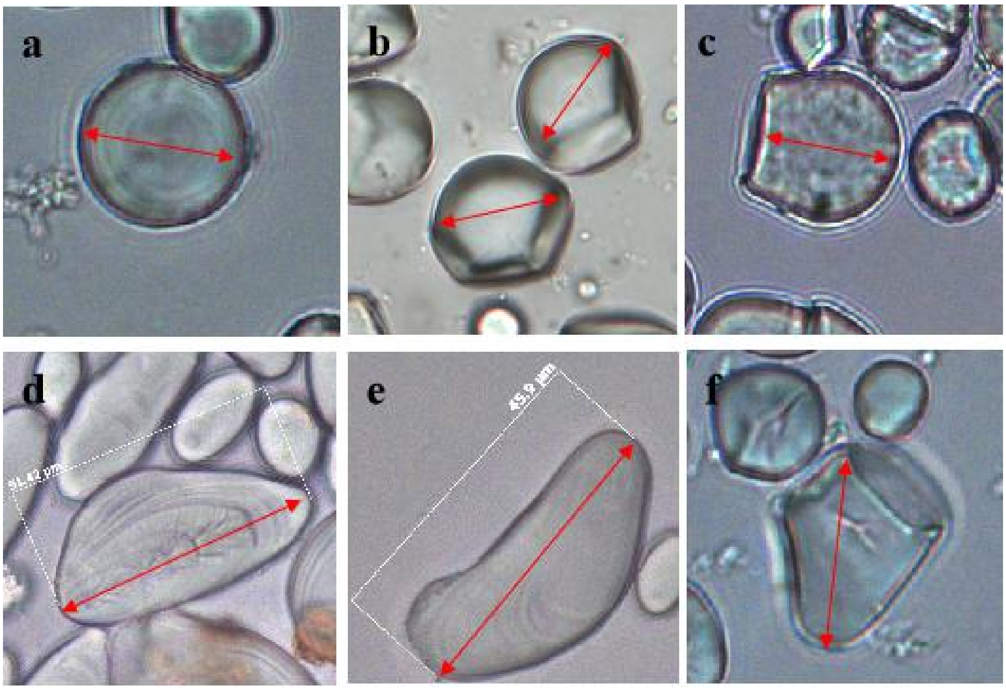

Figure 5. 5 Granule size measurement. The red two-way arrows represent the sizes I measured.

During the observation of modern starch granules, the slides were not touched to make the granules flip, so that in these images, the 2D or 3D figures may coexist. On the other hand, in some slides containing ancient starch grains, it is difficult to make the granules flip also, then only plane figures were observed. Therefore, in this thesis, 2D and 3D figures are mixed to describe the images of starch granules. Totally, I described the granule shapes appearing in the thesis into 16 categories. Except the irregular shapes, others varieties are listed as follows.

1) Bell shape (Figure 5.6 a): It is a solid figure here. Its contour is in outline of vertical section of an inverted cup, but, unlike the real bell, it is without flaring rim and convex crown.

2) Combination shape of spherical cap and polyhedron (CSCP) (Figure 5.6 e): This is a kind of 3D shape, which looks like a polyhedron with a curved surface. The facets are caused by granules abutting each other in the plant cell. The curved areas occur where there was no granule contact.

3) Drop shape (Figure 5.6 b): This is an ovate with one pointed end. It has a wide shoulder at the hilum, tapering toward the distal end.

4) Oval: This is a 3D shape, having a rounded and slightly elongated outline or shape, like that of an egg.

5) Pestle shape (Figure 5.6 c and f): It is a part of ovate which is cut by a plane and has a wide shoulder at the hilum, tapering toward the distal end.

6) Polygon/ rounded polygon. In this thesis, polygon is a 2D shape in plane view with five or more straight sides. If the angle is not sharp, then the shape was called rounded polygon.

7) Polyhedron/irregular polyhedron (Figure 5.6 d): Polyhedron is a typically 3D figure. Geometrically, it has plane polygonal faces (more than six), straight edges and sharp corners. When the granules other features like a concave or convex surface, curved edges, or rounded corners, it was defined as irregular polyhedron in this thesis.

8) Spindle shape (Figure 5.6 g): It is a spindle-like shape. Here I classified the oval granules which are wide in the middle and have two pointed ends in this group.

9) Sphere: It is a round solid 3D figure and this kind of granules looks like balls no matter how it flips.

10) Spherical cap: In geometry, a spherical cap is a portion of a sphere cut off by a plane. The hemisphere was also included in this group, which is a unique spherical cap when the plane passes through the center of the sphere.

11) Triangle/elongate triangle/ rounded triangle (Figure 5.6 h): This is a group of 2D figures based on the basic triangle shape in geometry, which is a polygon with three

edges. If the height was much longer than its corresponding base, then the triangle will be called elongate one in this thesis. And the rounded triangle represents the triangular figures which do not have sharp angles.

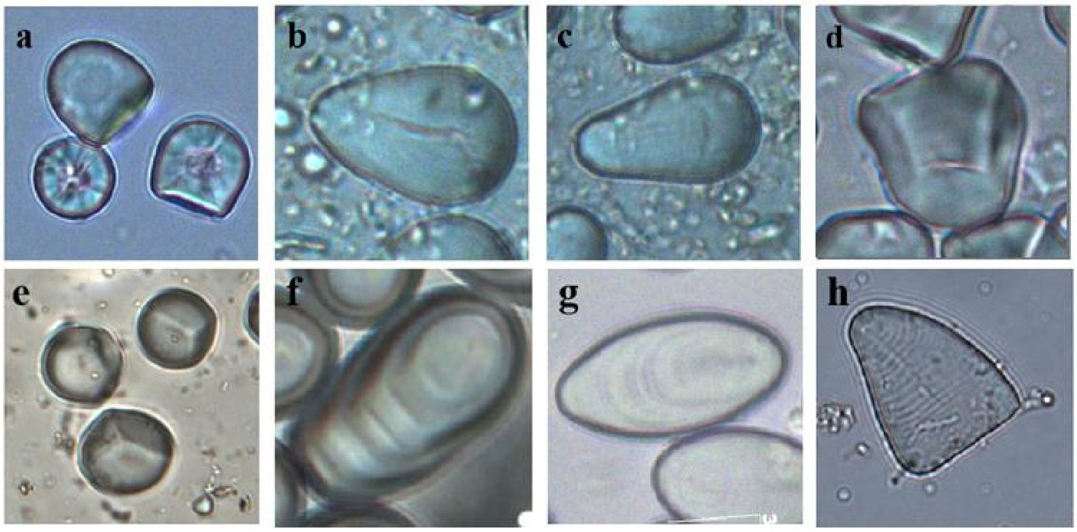

Figure 5. 6 Some shapes of starch granules. a, bell shape granule (*Cyclobalanopsis glauca*); b, drop shape granule (*Quercus cocciferoides*); c, pestle shape granule (*Quercus cocciferoides*); d, irregular polyhedron granule (*Castanopsis hystrix*); e, CSCP shape (*Cycas pectinata*); f, pestle shape (*Caryota urens*); g, spindle shape (*Arenga pinnata*); h, triangle shape (*Dioscorea pentaphylla*).

5.3.2 Other variables

Some of granules bear fissure, which have various forms. In this thesis, I observed seven forms of them, including linear, transverse, longitudinal, Y-shape, V-shape, π shape, and stellate shape (Figure 5.7). There are three straight types. The one is short and light from hilum, which is called linear type; another two are deep and long, within them, the one along the long axis of granule is longitudinal type and the other is transverse.

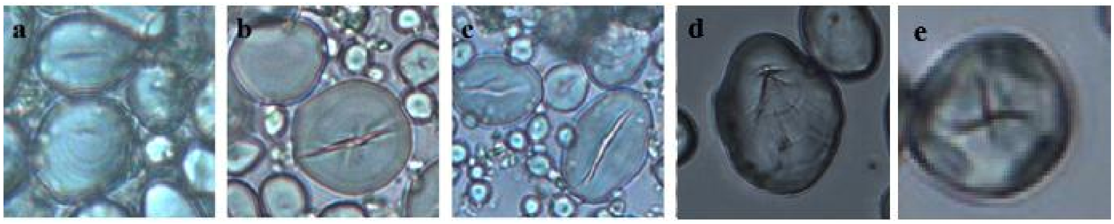

Figure 5. 7 Some fissure forms of starch granules. a, linear shape; b, transverse shape; c, longitudinal shape; d, π shape; e*, stellate shape. (*This image is referred from Yang et al. 2012)

The lamellae was classified into visible type and invisible type. Some granules have clear visible lamellae, like Figure 5.6 f to h, and the others in Figure 5.6 are completely invisible ones. On the aspect of the surface texture, I used 'smooth' and 'rough' to divide the starch granules. The smooth granules have regular surface with no holes, lumps, or areas that rise or fall suddenly, and the rough ones have uneven surfaces which like the ones in Figure 5.5 c.

5.4 Analytical approach of modern reference materials

There have been several attempts to develop an expert method that relied on granule size, mathematical descriptions of shape analysis, and sometimes inclusive of particular features of the granule, such as the shape of the extinction cross, position of the hilum, and the presence/absence of lamellae, to identify the starch granules automatically (Arráiz et al. 2016; Coster and Field 2015; Mercader et al. 2018). The results of these approaches have been mixed, and either provide support for the morphometric approach (e.g. Coster and Field 2015; Liu et al. 2014) or question its reliability (e.g. Copeland and Hardy 2018; Mercader et al. 2018).

In this thesis, I attempted statistical methods to analyze the data of modern reference samples as well, in order to classify the starch granule population as objectively as possible. The size data displayed by box plots, to compare their distributions between species. In terms of morphological features, including shapes, the position of hilum, visibility of lamellae, fissure forms and surface textures, these nominal data were analyzed by multiple correspondence analysis, applied through SPSS v25.0. Multiple correspondence analysis, an effective dimension-reduction tool for variables, is an exploratory method to visualize the large dataset in terms of dependency between rows (Beh and Lombardo 2014; Devaux et al. 1992; Greenacre 2007; Le Roux and Rouanet 2005; Macheridis, 2017). This analysis method presents the categorized data set in the two-dimensional graph (Greenacre 2007; Le Roux and Rouanet 2005).

The interpretation of the multiple correspondence analysis result is relied on the scatter plot with two axes, representing two principal dimensions (Greenacre 2007). In these scatter plots, objects within the same category are close together and objects in different categories are far apart. Franco (2016) explained how to understand these scatter plots: "1) If two or more categories of the same variable appear close to each other, this means that their distribution is similar; If two or more categories of the same variable appear distant in the graph, this means that their distributions are different; 2) If two categories present high coordinates and are close in space, this means that they tend to be directly associated; if two categories present high coordinates but not are close (e.g. they have opposite signs), this means that they tend to be inversely associated".

5.5 Laboratory methods

The laboratory work was performed in the Key Laboratory of Land Surface Pattern and Simulation, the Institute of Geographic Sciences and Natural Resources Research and the School of Archaeology and Ancient History Starch and Residue Laboratory, separately. The preparation and observation of modern reference materials and heavy-liquid extraction of archaeological starch granules were processed in the lab of the Institute of Geographic Sciences and Natural Resources Research. The microscopes and other equipment used for archaeological starch granules observation were located in the School of Archaeology and Ancient History Starch and Residue Laboratory.

The primary approach used to observe starch granules was with the use of an optical microscope with magnifications ranging from x100 to x500 and fitted with filters allowing for cross-polarised illumination (Torrence and Barton 2006). The microscope used for this study was a Zeiss AxioMAT, configured with Epi-Plan objectives ranging from X5 to X100, including oil immersion lenses at X63 and X100. Total magnification ranged from X50 to X1,000, though analysis and description of starch granules were typically undertaken at magnifications of X200 and X500. Images of the starch granules were taken with Zeiss AxioCam and Zeiss AxioVision software.

5.5.1 Preparation of modern reference materials

My modern reference materials came from three sources. The acorns were provided by the Kunming Institute of Botany herbarium; some fresh geophytes were collected in the Xishuangbanna Tropical Botanical Garden or bought from local market in Yunnan; the guanglang flour was purchased online from Guangxi (detailed information in Chapter 6). As the samples were from different sources and in different conditions, their preparation methods varied a little in comparison to previously published methods (e.g. Torrence and Barton 2006; Yang et al. 2009; Wang et al. 2018).

The acorns from herbarium were dried, therefore, I firstly cracked them by hammers for shelling. And then I moved the kernels into a small plastic sealed bag and further pounded with a ceramic mortar and pestle. A small amount of sample was transported in sterile test tubes with distilled water for 24 hours to soak and crushed lightly with a sterilized probe to release starch. The solution of starches were pipetted on clean glass slides, mounted with 50% glycerin solution and covered by a glass slip.

The fresh geophyte collection was first sliced once we returned to the lab in the Institute of Geographic Sciences and Natural Resources Research. And the sliced samples were dried in an oven at around 30 °C overnight. Then a small quantity of the dried samples was scraped and soaked into distilled water in a sterile test tube. The starch grains released through stirring, and then the slides were prepared with a 50% glycerin/water solution.

The fresh palm pith collected from botanical garden were prepared in a same protocol as the fresh geophytes. But the samples of *Arenga* purchased online has already been ground into a fine powder, therefore, the guanglang flour was directly dissolved in distilled water and the solution was made as slides in the same way.

The starch granules were photographed by light microscopy and the morphometric features of at least 100 granules were randomly described including size data and selected morphological features. Besides the samples I collected, images of some geophyte references in Modern Starch Reference Database from the Institute of Geographic Sciences and Natural Resources Research were included and analyzed in the same way. These morphometric characteristics of starch granules were then categorized and discriminated against.

5.5.2 Extraction and preparation of ancient starches

Concerns about the integrity of starch evidence recovered from archaeological contexts has been raised (e.g. Crowther et al. 2014; Haslam 2004; Laurence et al. 2011). In order to control for contamination, a series of methods were taken. Firstly, all the sampled stone tools were handled with disposable gloves. All the experimental supplies were boiled, including slides, coverslips, and test tubes. Before the sample extraction and slide prepared, the table where the materials rested on was cleaned twice with hot water and alcohol, respectively.

The samples of Hengling site were collected by Dr. Zhikun Ma in 2013. I have got permission from him and Professor Yang to analyze these samples. Apart from samples from Hengling site, other samples are obtained from different museum archives, which have ever been washed with water. The first sampling trip took place in August 2015, with Dr. Huw Barton and Professor Xiaoyan Yang. During this trip, the samples from Guye site and Cuntou site were collected from Foshan Museum and Dongguan Museum separately. These sampled stone tools included not only netherstones and handstones, which were related to plant processing in traditional perspective, but also hammerstones and pestles, possibly related to woody starch-rich plant processing. The second trip took place in April 2017, together with Dr. Zhikun Ma. At that time, the stone tools unearthed at Haogang site, Yuanzhou site, and Yinzhou site were sampled from Haogang Museum, Dongguan Museum and Sanshui Museum respectively. The sampled stone tools also included netherstones, handstones, hammerstones and pestles similarly.

Most starch residues were collected with an ultrasonic bath. The stone tools were first rinsed with still water to remove the dust from the surface. And then I put the sample tools in disposable containers, and added still water over the part I planned to sample, such as ground surfaces. The container were placed in the water-filled sink of the ultrasonic cleaner. The machine ran at 40Khz / 250W for five minutes. In this process, the sampling surface was immersed in pure water, and the disposable container was in contact with the water in the sink. When the machine stopped, the solution in the disposable container was transferred to a 50 ml labeled disposable centrifuge tubes.

However, some netherstones are large in size, like the one at Yuanzhou site (98DSYT0105③) and one at Cuntou site (89DCT0613③: 6), which cannot be cleaned by ultrasonic machines. Hence, these netherstones were sampled by pipette. Still water were pipetted to the surface of rinsed stone tools, stirred with a disposable needle, and the remain solution was pipetted to a l.5 ml disposable centrifuge tube. These samples were made into slices directly after shaking when analyzed.

The samples collected through ultrasonic machine were prepared by heavy-liquid extraction in the lab. The protocol is as follows:

1. Soak 50 ml centrifuge tubes boiling water and label them (referred to as experiment tubes below).

2. Top up the sample tubes with distilled H_2O, centrifuge for 5 min at 3000 rpm and decant.

3. Divide samples tubes into 2 parts: part 1 is the clear tubes and part 2 is tubes with precipitate.

4. Top up the part 2 tubes containing the samples with a 5% weight solution of Sodium Hexametaphosphate, shake and leave them overnight.

5. Shake the samples and then centrifuge for 10 min at 1500 rpm and discard the supernatant. Top up with distilled H_2O and repeat this step at least 3 more times (more if the supernatant is still not clear).

6. Add 5ml of solution with a specific gravity (Cesium chloride) of 1.8 g/cm^3 into all

sample tubes, shake and centrifuge of 10 min at 3000rpm.

7. Pipette the floating fraction and transfer to the corresponding experiment tube.

8. Add 5ml of solution with a specific gravity of 1.8 g/cm^3 into sample tubes again, shake and centrifuge of 10 min at 3000rpm, and transfer the floating fraction to the same corresponding experiment tube as in step 7.

9. Top the recovered floating fraction up with distilled H_2O and centrifuge for 10 min at 3000 rpm. Decant pouring just half of the content of the tubes.

10. Top up with distilled H_2O, shake gently and centrifuge for 10 min at 3000 rpm four more times. Do not decant the tubes after the last centrifuge. Instead, pipette out the supernatant leaving about 1 ml in the tube. Samples are ready to be mounted.

11. For part 1 tubes, pipette out the supernatant directly without adding any reagents, leaving about 1 ml solution in the tube.

12. Add a small amount of 50% glycerol/water solution to make slides.

13. Observe and photograph starch granules under the Zeiss biological microscope with polarized light and record their morphological characteristics.

Chapter 6: Starch grains of modern reference materials

This chapter outlines the approach to the collection and analysis of reference materials used as comparators in this thesis. The reference collection has focused on plants argued to have been important in the pre-agricultural diets of southern China (see Chapter 3). Previous starch research in China has focused on a range of plant families, e.g. tribe Triticeae (Wan et al. 2016; Yang and Perry 2013), edible legumes (Wang et al. 2013), millets (Ge et al. 2010; Yang et al. 2012), acorns (Yang et al. 2009), and geophytes (Wan et al. 2011; Wang et al. 2018). Chapter 5 reviewed starch analysis as a technique and reviewed the descriptive criteria used in the morphometric analysis of the reference collection. This Chapter presents the reference collection analysed for this study along with the basic descriptive statistics of each plant group. In an attempt to improve the reliability of ancient starch granule identification in this study, I have analysed the key reference samples using multiple correspondence analysis (MCA). This method is helpful to find better identifications of starch granules that could distinguish plants from each other as much as possible.

6.1 Fieldwork and collation of the reference collection

To help improve the identification of ancient starch granules recovered from the Pearl River Delta sites, I expanded upon the existing reference collections from the Modern Starch Grain Morphological Database in China (Table 6.1), and I also supplement two samples from the collections at the University of Leicester (Table 6.1).

The first fieldwork conducted in the Yunnan provinces in April 2015 to collect geophyte materials, in the guidance of Dr. Huw Barton, Professor Xiaoyan Yang, and Professor Lu Li. At that time, we went to southern Yunnan, including Honghe, Puer, Jinghong, and Xishuangbanna. Some samples were bought from the local market, like the wild yam and cultivated yam (Table 6.1). The stall owners introduced separately that the wild yam, bought from Puer, was collected from the surrounding region of their village in someplace of Puer City, and the cultivated yam from Jinghong was harvested from their private garden. Professor Li preliminary identified these two samples into two species of *Dioscorea*. However, most of the geophyte reference materials listed in Table 6.1 were collected from the edible wild plant garden of Xishuangbanna Tropical Botanical Garden. In this special park, more than 400 species of wild edible plants and relatives of cultivated plants were collected and preserved. Wu Fuchuan, a staff in Xishuangbanna Tropical Botanical Garden, accompanied and helped to check the species name of the reference materials we collected. And in this trip, we also collected the samples of palm pith (Table 6.1) through a dedicated tool used to bore out a thin, pencil-sized core from a living tree. These samples are from the palm garden of Xishuangbanna Tropical Botanical Garden.

The second fieldwork conducted in Kunming, Yunnan provinces in November 2015, in the guidance of Professor Xiaoyan Yang, and Professor Lu Li, which mainly focused on Fagaceae collection. Most samples were provided by Herbarium, Kunming Institute of Botany, CAS, or collected in the Kunming Botanical Garden, CAS (Table 6.1). Besides, some acorn references, for example, *Quercus semecarpifolia*, were also collected in Kunming, and those samples were identified by Professor Li as well.

Table 6. 1 Modern starch reference materials collected for this thesis

Family	Species	Local name/Notes
Fagaceae	*Castanopsis kweichowensis*†	
Fagaceae	*Castanopsis sclerophylla*†	
Fagaceae	*Castanopsis hystrix*†	
Fagaceae	*Castanopsis fleuryi*†	
Fagaceae	*Castanopsis fargesii*†	
Fagaceae	*Castanopsis platyacantha*†	
Fagaceae	*Cyclobalanopsis gambleana*†	
Fagaceae	*Cyclobalanopsis chapensis*†	
Fagaceae	*Cyclobalanopsis glauca*†	
Fagaceae	*Cyclobalanopsis phanera*†	
Fagaceae	*Quercus variabilis*‡	Kunming Botanical Garden, CAS
Fagaceae	*Quercus franchetii*‡	Kunming Botanical Garden, CAS
Fagaceae	*Quercus semecarpifolia*‡	Shuangshao Town, Kunming
Fagaceae	*Quercus cocciferoides*‡	
Fagaceae	*Quercus oxyphylla*‡	
Fagaceae	*Lithocarpus litseifolius*†	
Fagaceae	*Lithocarpus fohaiensis*†	
Fagaceae	*Lithocarpus balansae*†	
Fagaceae	*Lithocarpus chrysocomus*†	
Fagaceae	*Lithocarpus cleistocarpus*†	
Fagaceae	*Lithocarpus corneus*†	
Fagaceae	*Fagus engleriana*†	
Fagaceae	*Fagus longipetiolata*†*	
Fagaceae	*Fagus grandifolia*†	
Fagaceae	*Fagus engleriana**	
Fagaceae	*Fagus lucida**	
Fagaceae	*Fagus orientalis**	
Fagaceae	*Fagus sylvatica**	
Alismataceae	*Alisma plantago-aquatica*#	
Alismataceae	*Sagittaria trifolia*‡	Nanchang local market, Jiangxi Province
Araceae	*Colocasia esculenta*#	Hekou farmers market in Honghe, Yunnan
Araceae	*Colocasia esculenta cv.*#	Xiangyu (香芋): sweet taro
Araceae	*Colocasia esculenta*#	
Araceae	*Amorphophallus xiei*#	
Araceae	*Amorphophallus konjac*#	
Araceae	*Amorphophallus paeoniifolius*#	
Araceae	*Amorphophallus sp.*#	A kind of edible konjac
Cibotiaceae	*Cibotium barometz*#	
Dennstaedtiaceae	*Pteridium aquilinum*#	
Dioscoreaceae	*Dioscorea sp.*‡	Wild yam collected near village /Puer local market, Yunnan

Dioscoreaceae	*Dioscorea sp.*‡	Cultivated yam in private garden/Jinghong local market, Yunan
Dioscoreaceae	*Dioscorea polystachya*#	
Dioscoreaceae	*Dioscorea alata*[1]	Kew Garden ethnobotanical collection
Dioscoreaceae	*Dioscorea bulbifera*#	
Dioscoreaceae	*Dioscorea esculenta var. spinosa*#	
Liliaceae	*Lilium brownii*‡	Nanchang local market, Jiangxi Province
Liliaceae	*Fritillaria cirrhosa*‡	Nanchang local market, Jiangxi Province
Marattiaceae	*Angiopteris yunnanensis*#	
Nelumbonaceae	*Nelumbo nucifera*‡	Fuzhou, Jiangxi Province
Rosaceae	*Potentilla anserina*#	
Smilacaceae	*Smilax glabra*#	
Taccaceae	*Schizocapsa plantaginea*#	
Arecaceae	*Arenga westerhouti* (white)	purchase online from Longzhou, Guangxi
Arecaceae	*Arenga westerhouti* (red)	purchase online from Longzhou, Guangxi
Arecaceae	*Caryota obtuse*#	
Arecaceae	*Caryota urens*#	
Arecaceae	*Caryota mitis*[1]	Field collection, Sarawak, Malaysia
Cycadaceae	*Cycas pectinata*#	
Cycadaceae	*Cycas panzhihuaensis*#	

Collection location: †Herbarium, Kunming Institute of Botany, CAS. ‡Collected in the field with CAS botanists. ∗Herbarium, Institute of Botany, CAS. #Xishuangbanna Tropical Botanical Garden, CAS. 1 got from the University of Leicester

6.2 Starch granule description of modern reference materials

In this section, starch granules from the three categories: acorns, geophytes, and palm pith, were described or reviewed. Then, the obtained data were summarised to form a preliminary overall impression of the starch granules of each category.

6.2.1 Starch grains of acorns

A total of five genera of Fagaceae, *Castanopsis* (six species); *Cyclobalanopsis* (four species); *Fagus* (seven species); *Lithocarpus* (six species); and, *Quercus* (five species), were discussed. Within the genus *Fagus* samples, few starch grains were recovered, except *F. sylvatica,* who produces some tiny granules which are too small (smaller than 5 microns) to be recovered from archaeological samples. This may be related to their oily kernels and possibly low content of starch, according to Flora of China (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). Except *Fagus*, the enough starch granules (more than 100 granules) are extracted from 14 species, belonging to other four genera.

Lithocarpus cleistocarpus **(Figure 6.1)**

A total of 135 grains were observed. The lengths of those granules are from 5.91μm to 15.61μm, and their mean length is 9.24±1.91μm(Table 6.2). Six granule shapes were observed, the major of which are sphere (54%), spherical cap (17%), and polyhedron (17%), with a small amount of oval (7%), irregular (4%), and bell shape (2%) (Table 6.3). Most granules have no fissure (98%), centric hilum (99%) and invisible lamellae (98%) (Table 6.4). Only 2% of them have linear fissure. And the proportion of granules with smooth surfaces is 47% (Table 6.4).

Lithocarpus litseifolius **(Figure 6.1)**

Sample capacity of this species is 100 starch granules. The size range of those granules is from 5.54μm to 17.69μm, and their mean length is 10.49±2.31μm, little larger than *Lithocarpus cleistocarpus* (Table 6.2). The observed granule shapes include sphere (40%), oval (26%), irregular polyhedron (8%), spherical cap (8%), triangle (5%), irregular shape (3%), and bell shape (2%) (Table 6.3). Same as *Lithocarpus cleistocarpus,* Most granules have a centric hilum (99%) but do not bear fissure (98%) (Table 6.4). The proportion of rough granules is 57%. However, the probability of observing lamellae is relatively high, which is 24% of the total (Table 6.4).

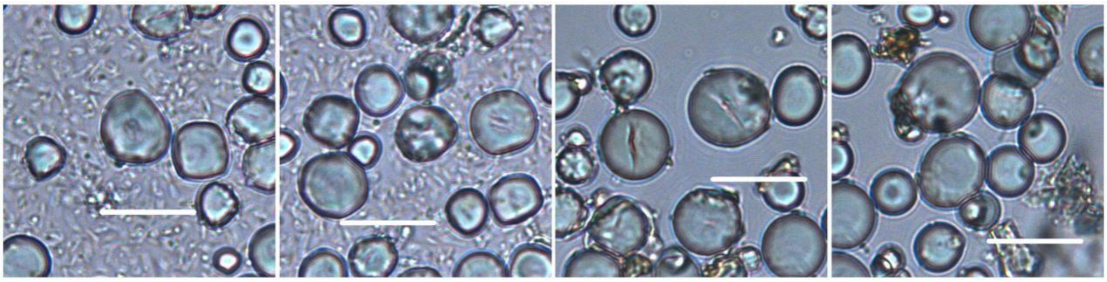

Figure 6. 1 Starch grains from *Lithocarpus*. a and b, *Lithocarpus litseifolius*; c and d, *Lithocarpus cleistocarpus.* Scale, 20μm.

***Quercus cocciferoides* (Figure 6.2)**

A total of 121 starch grains were examined. Their sizes are from 5.01μm to 28.46μm and the average size is 13.09±4.01μm (Table 6.2). The shapes of those granules are diverse, mainly including drop shape (27%), oval (17%), irregular (16%), sphere (14%), pestle shape (12%), with a small proportion of triangle (7%), spindle shape (4%), and spherical cap (2%) (Table 6.3). The proportion of rough granules accounts for 55% of the total, and 83% observed granules have a eccentric hilum (Table 6.4). However, only 9% of 121 granules have visible lamellae, and 6% bear fissures, including linear type (4%) and longitudinal type (2%).

***Quercus oxyphylla* (Figure 6.2)**

A total of 107 starch grains were examined. The size range is from 5.07μm to 21.58μm and the average size is 10.07±3.01μm (Table 6.2). The major granule shapes of this species include oval (27%), irregular (27%), drop shape (19%), and triangle (10%), with minor groups, such as sphere (9%), spindle shape (5%), irregular polyhedron (1%), and spherical cap (1%) (Table 6.3). The proportion of fissure-bearing granules is relatively high (31%) (Table 6.4). And those fissure types include linear (17%), transverse (7%), Y-type (5%), stellate-type (2%), and V-type (1%) (Table 6.4). The percentage of granules with centric hilum is 63%, and that of granules with visible lamellae is still low (6%) (Table 6.4). The percentages of smooth granules and rough granules are 51% and 49%, respectively (Table 6.4).

***Quercus variabilis* (Figure 6.2)**

A total of 116 starch grains were examined. The size range is from 5.07μm to 21.17μm and the average size is 10.19±2.65μm (Table 6.2). The largest group of the observed granules is the irregular ones, accounting for 28% of the total, followed by oval ones (22%), drop shape ones (20%), and triangle ones (17%). There are also some small groups, including pestle shape (5%), spindle shape (4%), and sphere (2%) (Table 6.3). Only 2% granules have fisssures, including linear type (11%), transverse (6%), longitudinal (3%), and V-type (1%) (Table 6.4). The granules with eccentric hilum accounts for 62%, and those with visible lamellae are 13% (Table 6.4). Besides, the smooth granules are common, which proportion is 76% of the total (Table 6.4).

***Quercus franchetii* (Figure 6.2)**

A total of 111 starch grains were examined. The size range is from 5.13μm to 24.93μm and the average size is 10.00±3.30μm (Table 6.2). The drop shaped oval grain is the most common type of this species, accounting for 44% of the total, followed by oval ones (22%) and triangle ones (10%), with a small number of irregular ones (7%), sphere ones (5%), pestle shape ones (3%), spherical cap ones (2%), bell shape ones (2%), and irregular polyhedron one (1%) (Table 6.3). The granules of this species commonly have smooth textures, accounting for 91% of the total, but no granule bears fissure (Table 6.4). The percentage of granules with centric hilum is 38%, and that with visible lamellae is only 3% (Table 6.4).

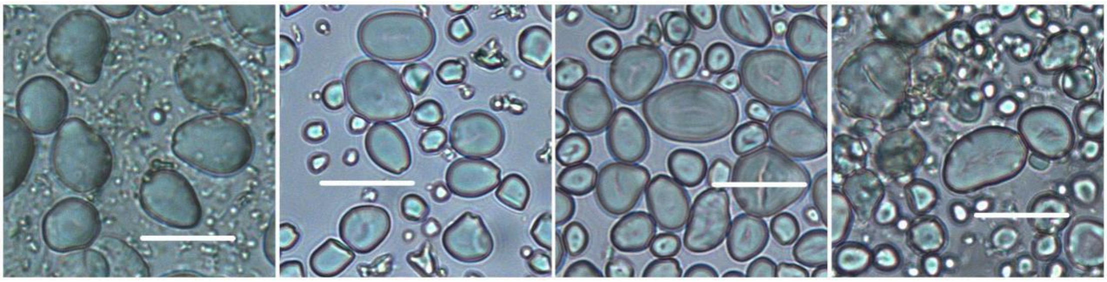

Figure 6. 2 Starch grains from *Quercus*. a, *Quercus cocciferoides*, b, *Quercus franchetii*, c, *Quercus variabilis*, d, *Quercus oxyphylla.* Scale, 20μm.

***Cyclobalanopsis glauca* (Figure 6.3)**

A total of 122 starch grains were examined. The length range is from 7.63μm to 22.48μm and the mean length is 14.61±2.58μm (Table 6.2). The bell-shaped granules are the majority, accounting for 56% of the total (Table 6.3). Every proportion of other granule shapes is lower than 15%, including combination shape of spherical cap and polyhedron (14%), irregular polyhedron (11%), sphere (7%), polygon (5%), oval (3%), irregular (2%), and triangle(2%) (Table 6.3). Only 5% granules have linear fissures (Table 6.4). The granules are mainly have centric hilum (98%) and without visible lamellae (99%) (Table 6.4). But, the proportion of rough granules is up to 79% of the total (Table 6.4).

***Cyclobalanopsis chapensis*(Figure 6.3)**

A total of 117 starch grains were examined. The length range is from 6.29μm to 20.83μm and the mean length is 13.01±2.54μm (Table 6.2). The oval shaped grains make up 52% of the total, followed by bell shaped ones (16%), and sphere ones (15%) (Table 6.3). And the minor populations include irregular ones (8%), triangle ones (3%), drop shaped ones (2%), polygon ones (2%), polyhedron ones (2%), and spindle shaped ones (1%) (Table 6.3). No granule of this species bears fissure (Table 6.4). The population is more likely to contain granules with eccentric hilum (82%) and invisible lamellae (98%) (Table 6.4). The proportion of rough granules is high as well, accounting for 78% of the total (Table 6.2).

***Cyclobalanopsis gambleana* (Figure 6.3)**

A total of 110 starch grains were examined. The length range is from 7.69μm to 24.88μm and the mean length is 14.73±3.62μm (Table 6.2). The major group of this population is the sphere granules, which proportion is 36%, followed by bell shaped granules (28%), and oval granules (17%) (Table 6.3). The minorities include irregular (8%), polyhedron (6%), drop shape (2%), and triangle (2%) (Table 6.3). The granules with rough surface form the major type of this species, accounting for the 79% of the total (Table 6.4). The proportion of fissure-bearing granules is higher, including linear type (11%), V-type (2%), and stellate-type (3%) (Table 6.4). Most granules, 88% of the total, have centric hilum, but none of them has visible lamellae (Table 6.4).

***Cyclobalanopsis phanera* (Figure 6.3)**

A total of 110 starch grains were examined. The length range is from 6.84μm to 19.88μm and the mean length is 11.49±2.53μm (Table 6.2). The major shape types of this species are oval (32%), bell shape (23%), triangle (16%), and sphere (15%), with a small proportion of irregular (8%), drop shape (3%), and spindle shape (3%). This species also produce a large number of rough granules, which percentage is 68% of the total. Only one granule has V-type fissure and 15% of them have visible lamellae. Totally, 68% of this population have a eccentric hilum.

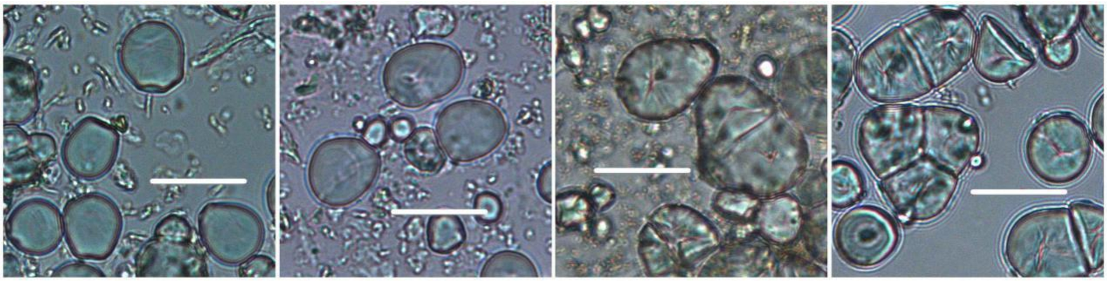

Figure 6. 3 Starch grains from *Cyclobalanopsis*. a, *Cyclobalanopsis chapensis*, b, *Cyclobalanopsis phanera*; c, *Cyclobalanopsis gambleana*, d, *Cyclobalanopsis glauca.* Scale, 20μm.

***Castanopsis platyacantha* (Figure 6.4)**

A total of 113 starch grains were observed. The length range is from 8.27μm to 19.16μm and the mean length is 12.48±2.01μm (Table 6.2). The common shape of these granules is sphere, making up 37% of the population, followed by oval (28%), bell shape (14%), and irregular polyhedron (10%), with small groups including irregular ones (8%), polygonal ones (1%), spindle shape ones (1%), and triangular ones (1%) (Table 6.3). There are 16% granules bearing fissures, including linear type (11%), transverse type (3%), V-type (2%), and Y-type (1%). Three quarters of them have centric hilum. Only 3% have visible lamellae. Besides, the proportion of smooth granules is 41% of the total.

***Castanopsis hystrix* (Figure 6.4)**

A total of 105 starch grains were examined. The length range is from 6.06μm to 28.66μm and the mean length is 14.29±4.05μm (Table 6.2). The shapes of this population are diverse, including polyhedron (26%), polygon (18%), irregular polyhedron (17%), triangle (14%), oval (11%), irregular (7%), and sphere (5%) (Table 6.3). 15% of them bear fissures, including four types: linear (9%), transverse (4%), Y-type (2%), and π-type (1%) (Table 6.4). The granules with centric hilum and eccentric are almost fifty and fifty, and the smooth granules accounts for 74% of the total (Table 6.4). No visible lamellae was observed(Table 6.4).

***Castanopsis fargesii* (Figure 6.4)**

A total of 101 starch grains were examined. The length range is from 6.63μm to 19.45μm and the mean length is 12.02±2.18μm (Table 6.2). The shapes of this population include oval (18%), polygon (16%), irregular polyhedron (15%), triangle (13%), polyhedron (12%), irregular (12%), bell shape (10%), and sphere (5%) (Table 6.3). Only one granule has linear fissure, and three have visible lamellae (Table 6.4). The percentages of granules with centric hilum and smooth granules are same, which are 57% of the total (Table 6.4).

***Castanopsis sclerophylla* (Figure 6.4)**

A total of 101 starch grains were examined. The length range is from 6.52μm to 22.08μm and the mean length is 12.97±3.01μm (Table 6.2). The major shapes of this population are sphere (35%) and oval (32%), with small groups of irregular (11%), triangle (9%), spindle shape (7%), bell shape (4%), and irregular polyhedron (2%). There are six granules with fissures, including linear type (5) and transverse type (1) (Table 6.4). More than half of this population are granules with centric hilum (59%) or smooth granules (52%) (Table 6.4). And 29% of the total have visible lamellae (Table 6.4).

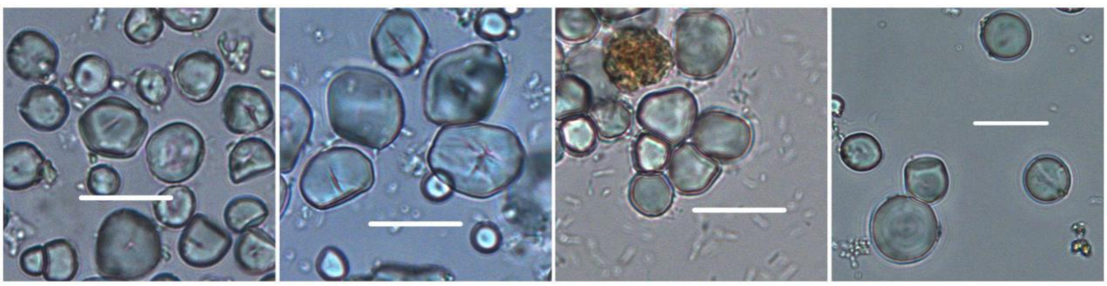

Figure 6. 4 Starch grains from *Castanopsis*. a, *Castanopsis platyacantha*; b, *Castanopsis hystrix*, c, *Castanopsis fargesii;* d, *Castanopsis sclerophylla.* Scale, 20μm.

Table 6. 2 Length range and mean length of the examined nuts

Species	Length Range/μm	Mean length/μm	Granule number
Lithocarpus cleistocarpus	5.91 -15.61	9.24±1.91	135
Lithocarpus litseifolius	5.54-17.69	10.49±2.31	100
Quercus cocciferoides	5.01-28.46	13.09±4.01	121
Quercus oxyphylla	5.07-21.58	10.07±3.01	107
Quercus variabilis	5.07-21.17	10.19±2.65	116
Quercus franchetii	5.13-24.93	10.00±3.30	111
Cyclobalanopsis glauca	7.63-22.48	14.61±2.58	122
Cyclobalanopsis chapensis	6.29-20.83	13.01±2.54	117
Cyclobalanopsis gambleana	7.69-24.88	14.73±3.62	110
Cyclobalanopsis phanera	6.84-19.88	11.49±2.53	110
Castanopsis platyacantha	8.27-19.16	12.48±2.01	113
Castanopsis hystrix	6.06-28.66	14.29±4.05	105
Castanopsis fargesii	6.63-19.45	12.02±2.18	101
Castanopsis sclerophylla	6.52-22.08	12.97±3.01	101

Table 6. 3 Shape distribution of acorn starch granules

	Lithocarpus cleistocarpus	***Lithocarpus litseifolius***	***Quercus cocciferoides***	***Quercus oxyphylla***	***Quercus variabilis***	***Quercus franchetii***	***Cyclobalanopsis glauca***	***Cyclobalanopsis chapensis***	***Cyclobalanopsis gambleana***	***Cyclobalanopsis phanera***	***Castanopsis platyacantha***	***Castanopsis hystrix***	***Castanopsis fargesii***	***Castanopsis sclerophylla***
Granule number	135	100	121	107	116	111	122	117	110	110	113	105	101	101
Bell shape	2%	2%	0%	0%	0%	2%	56%	16%	28%	23%	14%	2%	10%	4%
CSCP*	0%	0%	0%	0%	0%	0%	14%	0%	0%	0%	0%	0%	0%	0%
Drop shape	0%	0%	27%	19%	20%	44%	0%	2%	2%	3%	0%	0%	0%	0%
Irregular	4%	3%	16%	27%	28%	7%	2%	8%	8%	8%	8%	7%	12%	11%
Irregular polyhedron	0%	8%	0%	1%	0%	1%	11%	0%	0%	0%	10%	17%	15%	2%
Oval	7%	26%	17%	27%	22%	25%	3%	52%	17%	32%	28%	11%	18%	32%
Pestle shape	0%	0%	12%	0%	5%	3%	0%	0%	0%	0%	0%	0%	0%	0%
Polygon	0%	0%	0%	0%	0%	0%	5%	2%	0%	0%	1%	18%	16%	0%
Polyhedron	17%	6%	0%	0%	0%	0%	0%	2%	6%	0%	0%	26%	12%	0%
Sphere	54%	40%	14%	9%	2%	5%	7%	15%	36%	15%	37%	5%	5%	35%
Spherical cap	17%	8%	2%	1%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%
Spindle shape	0%	0%	4%	5%	4%	0%	0%	1%	0%	3%	1%	0%	0%	7%
Triangle	0%	5%	7%	10%	17%	10%	2%	3%	2%	16%	1%	14%	13%	9%

*Combination shape of spherical cap and polyhedron

Table 6. 4 Other features of acorn starch granules

			Lithocarpus cleistocarpus	*Lithocarpus litseifolius*	*Quercus cocciferoides*	*Quercus oxyphylla*	*Quercus variabilis*	*Quercus franchetii*	*Cyclobalanopsis glauca*	*Cyclobalanopsis chapensis*	*Cyclobalanopsis gambleana*	*Cyclobalanopsis phanera*	*Castanopsis platyacantha*	*Castanopsis hystrix*	*Castanopsis fargesii*	*Castanopsis sclerophylla*
Granule number			135	100	121	107	116	111	122	117	110	110	113	105	101	101
Fissure	Fissure type	Linear	2%	2%	4%	17%	11%	0%	5%	0%	11%	0%	11%	9%	1%	5%
		V-type	0%	0%	0%	1%	1%	0%	0%	0%	2%	0%	2%	0%	0%	0%
		Y-type	0%	0%	0%	5%	0%	0%	0%	0%	0%	1%	1%	2%	0%	0%
		π-type	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%
		Transverse	0%	0%	0%	7%	6%	0%	0%	0%	0%	0%	3%	4%	0%	1%
		Stellate	0%	0%	0%	2%	0%	0%	0%	0%	3%	0%	0%	0%	0%	0%
		Longitudinal	0%	0%	2%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Non-fissure		98%	98%	94%	69%	78%	100%	95%	100%	84%	99%	84%	85%	99%	94%
Hilum position	Centric		99%	99%	17%	63%	38%	32%	98%	18%	88%	32%	75%	51%	57%	59%
	Eccentric		1%	1%	83%	37%	62%	68%	2%	82%	12%	68%	25%	49%	43%	41%
Visibility of lamellae	Visible		2%	24%	9%	6%	13%	3%	1%	2%	0%	15%	3%	0%	3%	29%
	Invisible		98%	76%	91%	94%	87%	97%	99%	98%	100%	85%	97%	100%	97%	71%
Surface texture	Smooth		47%	43%	45%	51%	76%	91%	21%	22%	21%	32%	41%	74%	57%	52%
	rough		53%	57%	55%	49%	24%	9%	79%	78%	79%	68%	59%	26%	43%	48%

Summary

The size range and mean length of Fagaceae starch granules are shown in Table 6.2. The box-plot (Figure 6.5) reflects the size distribution of those starch granules. The starch granules from examined species of Fagaceae have their upper limit, which is no larger than 29μm (Table 6.2), while most grains are smaller than 25μm. The slight interspecies differences make it difficult to identify the Fagaceae starch grains by granule size independently.

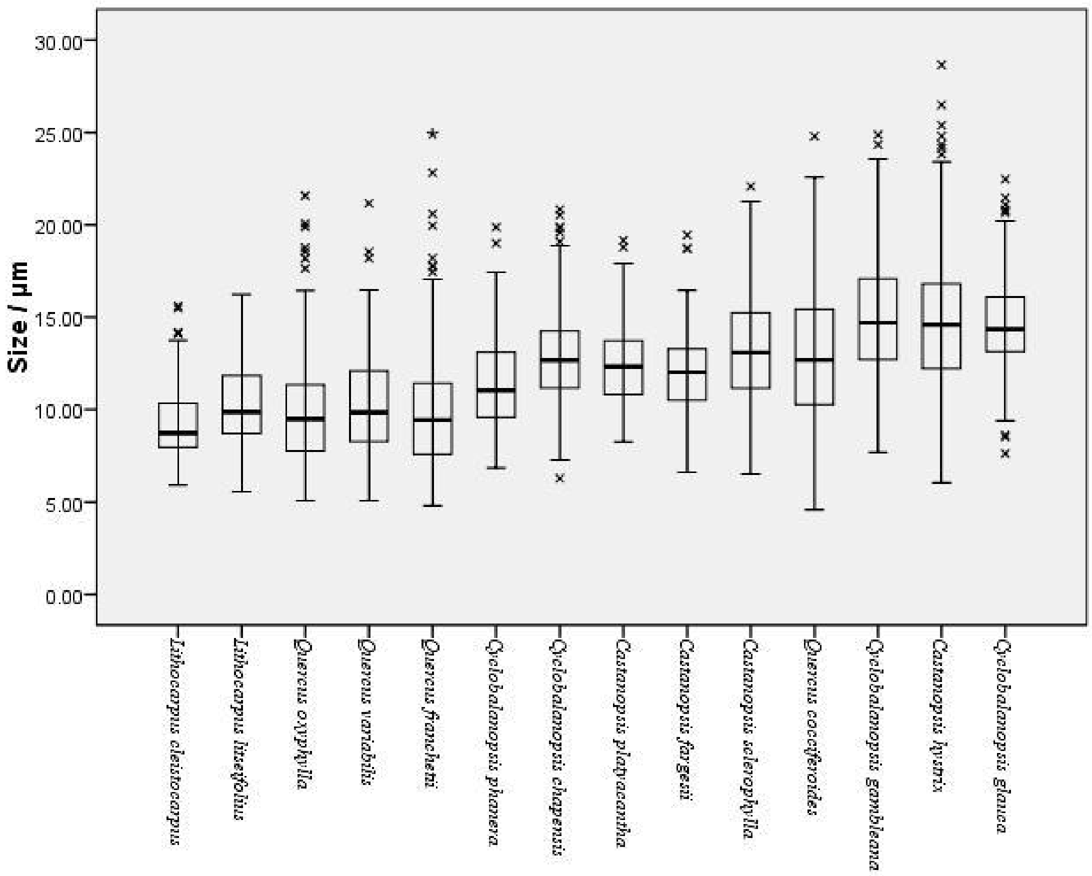

Figure 6. 5 Box-plot of mean length of starch grains from Fagaceae

The most common shapes of all acorn starch granules are sphere and oval (Table 6.3). But the shape distribution table reveals the identifiable shape features of each genus, like the drop shape granules in *Quercus*, bell shape granules in *Cyclobalanopsis*, and polygonal granules in *Castanopsis* (Table 6.3). The proportion of fissure-bearing granules from Fagaceae is not high, so is that of visible lamellae. Other features are helpful to distinguished these genera, for example, *Cyclobalanopsis* have the highest possibility to produce rough granules.

At species level, the difference between *L. litseifolius*, and *L. cleistocarpus* is the presence of lamellae. The proportion of grains with lamellae of *L. litseifolius* is 24%, much higher than 2% of *L. cleistocarpus* (Table 6.4). Interspecies difference between *Quercus* is mainly from fissures. Except *Q. franchetii*, other species all produce some starch granules with different kinds of fissures, and the proportion of this kind of granules is up to 31% in *Q. oxyphylla*, which is the highest among these four species (Table 6.4). In the case of *Cyclobalanosis*, the most popular shape of *C. glauca* is bell shape, which is different from the other three species, which major shapes are oval and sphere. *C. chapensis* do not have fissures, and *C. gamblean*a does not have visible lamellae (Table 6.4).

The starch grains of *Castanopsis* could be mainly divided into two groups, the geometric group (*C. hystrix* and *C. fargesii*) and the round group (*C. platyacantha* and *C. sclerophylla*). Within the geometric group, the percentage of starch granules with fissures of *C. hystrix* is much higher than that of *C. fargesii*, which is 15% and 1% separately. In the round group, the differences between *C. platyacantha* and *C. sclerophylla* are from fissures and lamellae. The granules of *C. platyacantha* have 16% of possible to bear fissures, higher than 6% of *C. sclerophylla* (Table 6.4). In contrast, the proportion of starch granules with visible lamellae in *C. platyacantha* is 3%, much lower than 29% of *C. sclerophylla*.

6.2.2 Starch granules of geophytes

As most underground storage organs of geophyte plants are rich in starch, starch granules analysis contributed to providing direct evidence for their ancient use. The morphological features of these starch populations, such as *Dioscorea* and *Colocasia*, were briefly described in some studies on the food industry or medicine because of their edible or medicinal values (Table 6.5) (e.g. Andrade et al. 2017; Hang et al. 2006; Lertphanich et al. 2013; Rincón-Aguirre et al. 2018; Zhu et al. 2015). But these studies did not focus on their identifiability.

Table 6. 5 Previous descriptions of starch granules from taros and yams

Latin name	Size range (μm)	Morphology	Reference
Dioscorea alata	28–40.25 (average)	Round, triangular, oval	Otegbayo et al. 2014
	10–40	Oval or angular	Huang et al. 2006
	16 - 55	Oval, pear shape or elongated shape	Hang et al. 2006
Dioscorea bulbifera	33–49 (average)	Triangular	Otegbayo et al. 2014
	10–60	Irregular flat cake	Jiang et al. 2012
	27-34	irregular oval, elongated shape	Hang et al. 2006
Dioscorea esculenta	1–3		Riley et al. 2004
	5.8–6.2	Polygonal	Amani et al. 2004
	4–10	Polygonal	Jayakody et al. 2007
	1.5-3	Polygonal	Hang et al. 2006
Dioscorea polystachya	20.17–26.34	Round, oval, or irregular	Zhou et al. 2012
	18 - 48	Oval, elongated oval, or shell shape	Hang et al. 2006
Colocasia esculenta	0.6-6	Polyhedral	Rincón-Aguirre et al. 2018
	2.0 (average)	Polygonal shape	Lertphanich et al. 2013
	2.273-3.986	Polyhedral with both circular and irregular shapes	Andrade et al. 2017
	1.0-5.0	Mixture of shapes such as spherical or dome-shaped and split, oval, polygonal, and irregular	Agama-Acevedo et al. 2011

In this part, a total of 24 modern reference samples from geophytes were described or reviewed. The samples include taro, yam, konjac, lotus, arrowroot, lily, and ferns, which may have vital values in native economies in southern China. Besides samples collected Xishuangbanna Tropical Botanical Garden or purchased from the local market in Yunnan Province, some data also referred to Modern Starch Grain Morphological Database. Additionally, the grain descriptions of *Dioscorea* japonica (Hang 2006) and *Smilax china* (Hong 2012), which were consumed widely in South China, were also supplemented in this section.

Taros (*Colocasia esculenta*)

This species is cultivated widely in China, and it has wide variations possibly owing to cultivation selections, escapes, naturalizations, and re-domestications (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). Previous studies showed that taros have small polyhedral grains with bare surfaces which are widely agglomerated (e.g. Agama-Acevedo et al. 2011; Andrade et al. 2017; Lertphanich et al. 2013; Rincón-Aguirre et al. 2018) (Table 6.5). Three varieties of this species are chosen as supplements in this thesis, including one cultivated type, and one purple-colored type. The starch grains from this species also have agglomerated groups and are characterized by polyhedron with sizes smaller than 5 μm. They have centric hila without lamellae and fissures. Because those grains are too small to be observed even at 400X, it is difficult to be identified them from archaeological samples, unless the agglomerated starch groups are found.

Lesser yams (*Dioscorea esculenta* var. *spinosa*)

Based on previous research on starch grains from lesser yam, those starch granules have polygonal shapes which are smaller than 10μm (Hang et al. 2006; Reliy et al. 2004; Zhu, et al. 2015) (Table 6.5). This small size also makes it difficult to be observed from archaeological samples, like taros. Its variety with thorny roots (*D. esculenta* var. *spinosa*) were collected as a supplementary reference. As previous study indicated, the polyhedral starch grains from this variety are also agglomerated. The sizes of them are from 2.95 μm to 7.91 μm, and the mean size is 5.44±1.08 μm. Although it is slightly larger than those of taros, the size still limited its identification from archaeological samples.

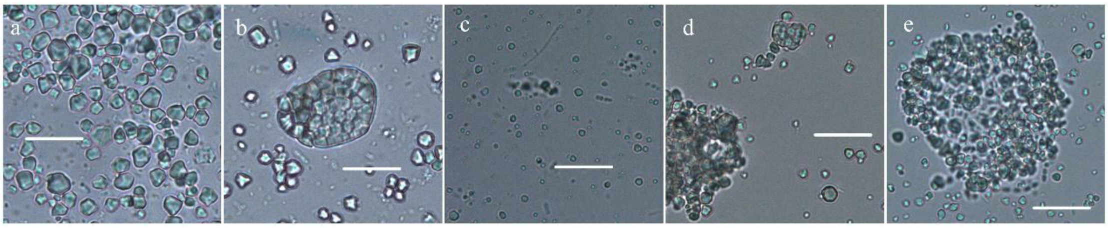

Figure 6. 6 Starch granules of geophytes smaller than 5 microns. a, lesser yam (*D. esculenta* var. *spinosa*); b, compound group from lesser yam (*D. esculenta* var. *spinosa*); c, taro (*C. esculenta*); d, taro (purple) (*C. esculenta*); e, taro (*C. esculenta* cv.). Scale: 20μm.

Air potato (*Dioscorea bulbifera*)

Totally, 75 starch granules of this species were counted. The starch granules from air potato are from 12.8μm to 51.63μm, and their mean size is 34.25±8.71μm (Table 6.6). The most identifiable shape of this species is the triangle, accounting for 84% of the total (Table 6.7). The proportions of other shapes are relatively low, including polyhedron (8%), irregular (5%), and oval (3%) (Table 6.7). All granules have eccentric hilum without fissure, and 88% of them have visible lamellae (Table 6.8).

Water yam (*Dioscorea alata*)

A total of 105 starch granules were observed. The sizes of those granules from water yam are from 8.63 μm to 62.38 μm, and their mean size is 32.84±12.14 μm (Table 6.6). The common granules are oval ones, accounting 47% of the total (Table 6.7). And 37 oval granules are larger than 30 microns. The following types are combination shape of spherical cap and polyhedron ones (16%) and bell shape ones(10%), which are smaller than 30 microns (Table 6.7). There are also other granule shapes, including irregular (9%), rounded polygon (6%), polyhedron (5%), irregular polyhedron (2%), sphere (2%), spherical cap (2%), drop shape (1%), and rounded triangle (1%) (Table 6.7). Only few granules have fissures, including four linear types, and one V-shape (Table 6.8). All the granules have eccentric hilum and 18% of them have visible lamellae (Table 6.8).

Chinese yam (*Dioscorea polystrachya*)

A total of 111 granules were observed. The size range of those grains is from 15.81 μm to 54.22 μm and their average size is 33.77±8.23 μm (Table 6.6). More than one third of them are irregular type (37%) (Table 6.7). Others include oval (25%), polyhedron (11%), elongate triangle (8%), rounded triangle (7%), elongate oval (6%), triangle (4%), combination shape of spherical cap and polyhedron (1%), and spindle (1%) (Table 6.7). All the granules are without fissure, and most of them have eccentric hilum (99%) and visible lamellae (98%) (Table 6.8).

Wild yam (*Dioscorea* sp.) and cultivated yam (*Dioscorea* sp.)

A total of 102 starch granules from cultivated yam were counted. The size range of those single grains is from 6.82 μm to 63.8 μm, while their mean size is 31.23±9.68 μm (Table 6.6). Those grains have oval shapes mainly, accounting for 71% of the total, followed by irregular shape (18%) (Table 6.7). There are also some minor groups, including elongate oval (4%), rounded triangle (3%), sphere (2%), and spindle (1%) (Table 6.7). No granules have fissures, and only two of them have centric hilum (Table 6.8). However, more than half of them granules, 54% of the total, have visible lamellae (Table 6.8).

102 granules from wild yam were observed. The size of those single granules is from 11.6μm to 104.16μm, and their average size is 39.48±15.78μm, larger than the cultivated ones (Table 6.7). The oval shape granules are the majority, including the normal oval ones (38%) and elongate ones (34%) (Table 6.7). There are also other type granules, including elongate triangle (13%), irregular (7%), drop shape (4%), polyhedron (2%), rounded triangle (1%), and sphere (1%) (Table 6.7). All the granules have eccentric hilum without any fissure (Table 6.8). The percentage of those with visible lamellae is higher than the cultivated ones, which could be up to 97% of the total (Table 6.8).

Glutinous yam (*Dioscorea japonica*) is also widely cultivated in China. As Hang et al. (2006) introduced, the starch granules of this species have elongated oval shape or oblong shape, with the size from 17 μm to 52 μm (Table 6.6). Some of them have a eccentric hilum, and clear visible lamellae.

Figure 6. 7 Starch granules of sampled *Dioscorea*. a, wild yam (*Dioscorea* sp.); b, compound granules from wild yam (*Dioscorea* sp.); c, cultivated yam (*Dioscorea* sp.); d, Chinese yam (*D. polystachya)*; e, water yam (*D. alata*); f, air potato (*D. bulbifera*). Scale: 20 μm.

Amorphophallus xiei

This new endemic species is cultivated as a food crop in Yunnan (Li and Dao 2006). The starch grains of this species have small size, from 0.77 μm to 2.82 μm. The common granule has polygonal shape, centric hilum, but no fissures and lamellae. In addition, crystals of calcium oxalate could be observed together with those granules, which in length are around 40 μm.

Amorphophallus konjac

A total of 103 granules were observed. The size range of starch granules from this species is from 6.1 μm to 31.12 μm, and their average size is 15.42±5.55 μm (Table 6.6). The common shape of these granules is combination shape of spherical cap and polyhedron (52%), followed by spherical cap (14%) (Table 6.7). There are also some other forms of granules, including irregular polyhedron (8%), irregular (7%), polyhedron (7%), sphere (6%), oval (3%), and bell shape (2%) (Table 6.7). All of them have centric hilum without fissures, and only 3 granules have visible lamellae (Table 6.8).

Amorphophallus paeoniifolius

A total of 104 granules were observed. The size range of those starch granules is from 4.48 to 15.17 μm, and the mean size of them is 8.57±2.23 μm (Table 6.6). The polygonal granules are the most common ones, accounting for 36% of the total, followed by combination shape of spherical cap and polyhedron type (26%) (Table 6.7). There are also some irregular granules (10%), sphere (9%), oval (7%), irregular polyhedron (5%), spindle shape (5%), spherical cap (2%), triangle (1%), and bell shape (1%) (Table 6.7). All the granules have centric hilum, without any visible lamellae and fissures (Table 6.8).

***Amorphophallus* sp.**

A total of 116 granules were examined. The granule sizes of this species are from 6.58 μm to 24.25 μm, and their mean size is 12.26±3.62 μm (Table 6.6). The major shape of these granules is combination shape of spherical cap and polyhedron (59%), followed by sphere (12%), spherical cap (10%), irregular (7%), oval (7%), polygon (3%) and triangle (2%) (Table 6.7). All the starch granules have centric hilum without any fissures (Table 6.8). And only one granule have visible lamellae (Table 6.8).

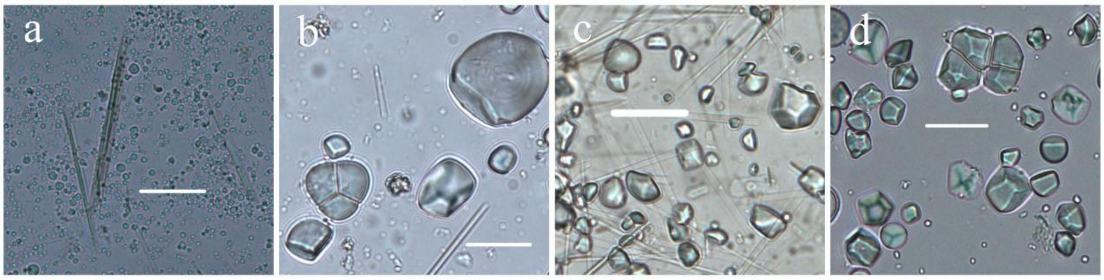

Figure 6. 8 Starch grains from sampled *Amorphophallus.* a, *Amorphophallus xiei*; b, *Amorphophallus konjac*; c, *Amorphophallus paeoniifolius*; d, *Amorphophallus* sp. Scale: 20 μm

Lotus roots (*Nelumbo nucifera*)

As a food of high value, several studies of food industry focused on the starch grains form lotus roots in different growing periods and from different sorts. Although those researches showed that their morphological features have slight differences, the overall features of those starch granules include elongate oval shape, elongate or irregular flat shape and a small group of spherical shape, with the sizes from 6 μm to 80 μm (Qian et al. 2012; Song et al. 2009). Furthermore, the oval shape is relatively larger than the spherical ones (Lu et al. 2017; Tian et al. 2008), for example, Tian et al. (2008) showed their sizes are 61.48 μm and 14.30 μm separately.

A total of 114 starch granules from the reference database in this thesis were observed. The mean size is relative larger, 46.03±12.56 μm, ranging from 16.95 to 68.63 μm (Here, only 50 granule sizes were counted) (Table 6.6). The oval granules are composed of the majority of this population, including elongate ones (39%) and normal ones (25%) (Table 6.7). The other types include irregular (12%), rounded triangle (10%), sphere (5%), spindle (5%), polyhedron (3%), bell shape (1%), and spherical cap (1%) (Table 6.7). All the granules have eccentric hilum (Table 6.8). Only one of them bear linear fissure, and another one granules do not have visisble lamellae.

Lotus seed (*Nelumbo nucifera*)

Starch is the main ingredient of lotus seeds, which accounts for 50% at least (Qian et al. 2007; Yin and Peng 2013; Zeng et al. 2007). The previous study showed that the smooth starch granules from lotus seeds have oval shape mainly without any lamellae and fissures (Qian et al. 2007; Yin and Peng 2013; Zeng et al. 2007). Those granules have centric hilum, but the extinction is weakened in the central part of those particles (Qian et al. 2007; Yin and Peng 2013; Zeng et al. 2007). And the sizes of the granules are from 4 to 30 μm and the average size is around 12 μm (Qian et al. 2007; Zeng et al. 2007).

A total of 141 starch granules from my reference database were counted. The average size of them is 12.74±3.53 μm, which range is from 3.69 to 24.58 μm (Table 6.7). The features are similar as the previous study. What is different is that the granules are not smooth (Figure 6.9: b).

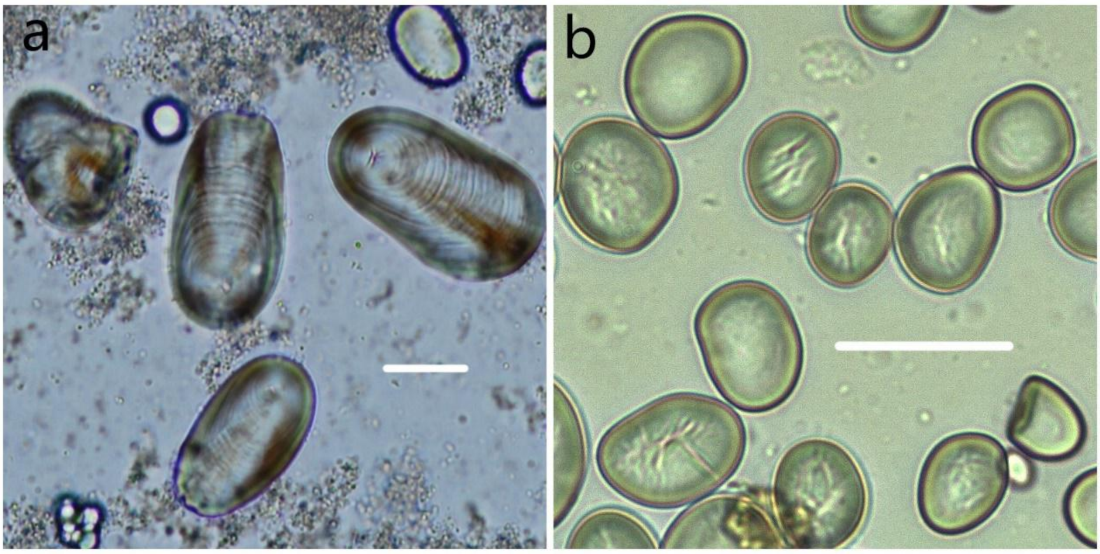

Figure 6. 9 Starch grains of Lotus (*Nelumbo nucifera*) roots and seeds. a,root; b, seed. Scale, 20μm

Alisma plantago-aquatica

The sizes of those particles are from 6.61μm to 15.75μm and their mean size is 9.62±1.69μm (Table 6.6). The starch granules from *Alisma plantago-aquatica* seem to have cluster constructions. A total of 38% of 120 granules have combination shape of spherical cap and polyhedron, followed by sphere (21%), and spherical cap (18%) (Table 6.7). There are also some minor groups, including irregular (9%), polyhedron (9%), oval (3%), and bell shape (1%) (Table 6.7). Every granule has a centric hilum but no visible lamellae and fissures (Table 6.8).

Sagittaria trifolia

A total of 107 granules were observed. The size range of them is from 11.80 to 27.58 μm and the average size is 19.13±3.52 μm (Table 6.6). Most granules of this species have oval shape (45%) or rounded triangular shape (35%) (Table 6.6). Other granule shapes include sphere (11%), irregular (7%), polyhedron (2%), and spindle shape (1%) (Table 6.7). Most granules have eccentric hilum, accounting for 98% of the total, and 24% of this population have visible lamellae (Table 6.8). There are 38% granules bearing different-form fissures, including linear (14%), V-shape (13%), Y-shape (8%), stellate-type (2%), and transverse (1%) (Table 6.8).

Lilium brownii

A total of 104 granules were observed. The sizes of them are relatively large, which is from 5.75 μm to 64.94 μm, and the mean size is 28.15±13.01 μm (Table 6.5). The diverse granules shapes include oval (34%), rounded triangle (24%), spindle (13%), and sphere (12%), with a low proportion of drop shape (3%), elongate oval (1%) and polyhedron (1%) (Table 6.7). No granule has visible lamellae and fissures (Table 6.8). And 89% of the total have eccentric hilum (Table 6.8).

***Smilax* spp.**

A total of 111 *Smilax glabra* granules were tested. The sizes of those starch granules are from 7.68 μm to 21.44 μm, and the averaged size is 13.31±2.61 μm (Table 6.6). The diverse shapes of this population include combination shape of spherical cap and polyhedron (36%), spherical cap (22%), sphere (19%), irregular (14%), oval (5%), and polyhedron (5%) (Table 6.7). All the granules have centric hilum (Table 6.8). 12% of the granules bear fissures, including linear type (10%), transverse type (1%), and Y-shape (1%), and 11% of them have visible lamellae (Table 6.8).

Smilax glaucochina and *Smilax china* are also important starch plants of this genus. *Smilax china* could be found in north Guangdong, which have similar medicinal value with *Smilax glabra*. The previous study (Hong 2012) showed the starch granules from *Smilax china* have spherical shape with the size from 5 μm to 30 μm. Most of them are single granules with linear or V shape fissures. And some compound groups contain 2 to 4 granules as well. *Smilax glaucochina* is also have starchy rhizomes, however, there is no research on its starch grains.

Fritillaria cirrhosa

A total of 103 granules were observed. The sizes of those granules are relatively large, which is from 3.12 μm to 46.19 μm and the mean size is 23.06±11.88 μm (Table 6.6). The oval granule is the largest component of this population, which percentage is 68%, followed by rounded triangle granules (12%) and sphere granules(10%) (Table 6.7). Other granules may have drop shape (5%), combination shape of spherical cap and polyhedron (2%), or spherical cap (2%) (Table 6.7). The majority of granules have centric hilum (86%) and visible lamellae (74%) (Table 6.8). There are also a high proportion of granules bearing fissures (68%), including stellate-type (46%), π-shape (28%), transverse (5%), linear (2%), V-shape (1%), and Y-shape (1%) (Table 6.8).

Schizocapsa plantaginea

The granule size of this plant is 5.09-12.4 μm, which mean size is 8.7±1.69μm. The shapes of those granules include sphere, combination shape of spherical cap and polyhedron and polyhedron, and bell shape. All the starch grains have centric hilum without any fissures and lamellae.

Pueraria montana* var. *lobata

The size range of starch granules of this species is from 5.78 to 14.23 μm, which mean size is 9.5±2.02 μm. Most granules are combination shape of spherical cap and polyhedron type, which seem to come from an agglomerated group. Every granule has a centric hilum and smooth surface, but none of them bear any visible lamellae or fissure.

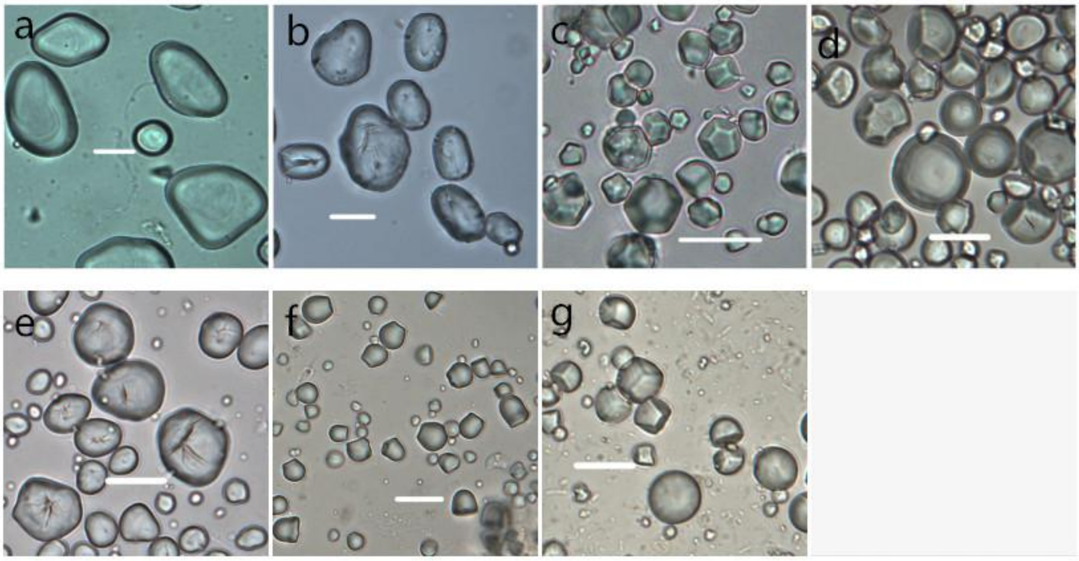

Figure 6. 10 Starch grains from some medicinal geophytes. a, *Lilium brownii;* b, *Fritillaria cirrhosa;* c, *Pueraria montana* var. *lobate*; d, *Smilax glabra;* e, *Sagittaria trifolia*; f, *Schizocapsa plantaginea; g, Alisma plantago-aquatica*. Scale, 20 μm

Angiopteris yunnanensis

A total of 82 starch granules were observed. These granules have relatively large size, which is from 8.27 μm to 143.34 μm, and their average size is 32.58±3.18 μm. The oval granules (41%) and spindle shape granules (21%) are composed of the majority of this population (Table 6.7). The others are irregular granules (10%), sphere granules (10%), elongate oval granules (6%), polyhedron granules (2%), rounded triangle granules (2%), and triangle granules (1%) (Table 6.7). Only three granules have fissures: two are linear types and one is transverse type (Table 6.8). One fifth of this population has visible lamellae, and 35% of the total have a centric hilum (Table 6.8).

Potentilla anserina

A total of 111 granules were observed. The size range of these granules is from 4.4 µm to 20 µm, with the average size 8.5±3.09 µm (Table 6.6). The common shape of these grains is rounded triangle, accounting for 50% of total, followed by oval (30%), drop shape (15%), and spindle shape (5%) (Table 6.7). Every granule has a centric hilum, and none of them has fissure or visible laemllae (Table 6.8).

Cibotium barometz

Starch granules from this species have the small size from 2.64 µm to 7.6 µm, and their average size is 4.8±1.07 µm. The common shape of them are oval, and almost every granule have smooth surface and a centric hilum, however, none of them has visible lamellae and fissure.

Pteridium aquilinum

The study of Du et al. (2016) made up the lack of our modern starch database. The samples of their research were harvested in Chongqing, and their result showed that the starch granules from this fern rhizomes were most smooth oval in shape, with few spheres and polygons. No fissures and visible lamellae were observed. Most of them have a centric hilum with vertical or X-shape extinction crosses. The size of those granules ranged from 10.23 to 26.14 µm, with the average size of 19.09 µm.

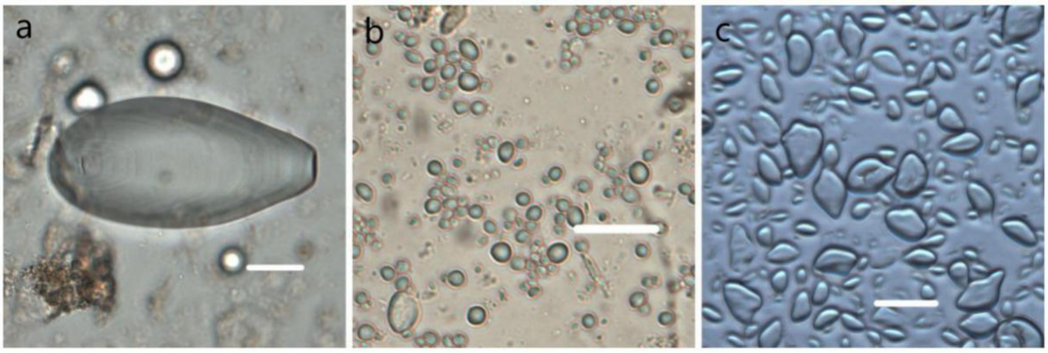

Figure 6. 11 Starch granules of some ferns. *a, Angiopteris yunnanensis; b, Cibotium barometz*; c, *Potentilla anserine.* Scale, 20 µm.

Table 6. 6 Size range and mean size of geophyte starch granules

Species name	Size range	Mean size	Granule number	Reference
Amorphophallus xiei	0.77-2.82	1.73±0.37	100	
Colocasia esculenta	1.17-3.33	1.96±0.41	100	
Colocasia esculenta cv.	1.33-4.15	2.61±0.61	100	
Colocasia esculenta （purple）	1.48-6.25	3.07±0.87	100	
Cibotium baromet	2.64 -7.6	4.8±1.07	100	
Dioscorea esculenta var. spinosa	2.95-7.91	5.44±1.08	100	
Potentilla anserina	4.4 -20	8.5±3.09	111	
Amorphophallus paeoniifolius	4.48 -15.17	8.57±2.23	104	
Schizocapsa plantaginea	5.09-12.4	8.7±1.69	126	
Pueraria montana var. *lobata*	5.78 - 14.23	9.5±2.02	100	
Alisma plantago-aquatica	6.61-15.75	9.62±1.69	120	
Amorphophallus sp	6.58 - 24.25	12.26±3.62	116	
Nelumbo nucifera （seed）	3.69-24.58	12.74±3.53	141	
Smilax glabra	7.68 -21.44	13.31±2.61	111	
Amorphophallus konjac	6.1 -31.12	15.42±5.55	103	
Sagittaria trifolia	11.80 - 27.58	19.13±3.52	107	
Fritillaria cirrhosa	8.21-48.99	33.19±8.21	103	
Lilium brownii	5.75 - 64.94	28.15±13.01	104	
Dioscorea sp.(cultivated)	6.82-63.8	31.23±9.68	82	
Angiopteris yunnanensis	8.27-143.34	32.58±3.18	105	
Dioscorea alata	8.63-62.38	32.84±12.14	111	
Dioscorea polystarchya	15.81-54.22	33.77±8.23	75	
Dioscorea bulbifera	12.8-51.63	34.25±8.71	110	
Nelumbo nucifera (roots)	16.95-68.63	46.03±12.56	50	
Dioscorea sp.(wild)	11.6-104.16	39.48±15.78	102	
Pteridium aquilinum	7 -28	14		Du et al. 2016
Smilax china	5-30.0			Hong 2012
Dioscorea japonica	17-52			Hang et al. 2006

Table 6. 7 Shape distribution of geophyte starch granules

	Bell shape	CSCP*	Drop shape	Elongate oval	Elongate triangle	Irregular	Irregular polyhedron	Oval	Polyhedron	Rounded polygon	Rounded triangle	Sphere	Spherical cap	Spindle	Triangle	Granule number
Potentilla anserina	0%	0%	15%	0%	0%	0%	0%	30%	0%	0%	50%	0%	0%	5%	0%	111
Amorphophallus paeoniifolius	1%	26%	0%	0%	0%	10%	5%	7%	36%	0%	0%	9%	2%	5%	1%	104
Schizocapsa plantaginea	53%	27%	0%	0%	0%	4%	0%	3%	0%	0%	0%	16%	4%	0%	0%	126
Alisma plantago-aquatica	1%	38%	0%	0%	0%	9%	0%	3%	9%	0%	0%	21%	18%	0%	0%	120
Amorphophallus sp	0%	59%	0%	0%	0%	7%	0%	7%	3%	0%	0%	12%	10%	0%	2%	116
Smilax glabra	0%	36%	0%	0%	0%	14%	0%	5%	5%	0%	0%	19%	22%	0%	0%	111
Amorphophallus konjac	2%	52%	0%	0%	0%	7%	8%	3%	7%	0%	0%	6%	14%	0%	2%	103
Sagittaria trifolia	0%	0%	0%	0%	0%	7%	0%	45%	2%	0%	35%	11%	0%	1%	0%	107
Fritillaria cirrhosa	0%	2%	5%	0%	0%	2%	0%	68%	0%	0%	12%	10%	2%	0%	0%	103
Lilium brownii	0%	0%	3%	1%	0%	13%	0%	34%	1%	0%	24%	12%	0%	13%	0%	104
Dioscorea sp.(cultivated)	0%	0%	0%	4%	0%	18%	0%	71%	1%	0%	3%	2%	0%	1%	1%	102
Angiopteris yunnanensis	6%	0%	0%	6%	0%	10%	0%	41%	2%	0%	2%	10%	0%	21%	1%	82
Dioscorea alata	10%	16%	1%	0%	0%	9%	2%	47%	5%	6%	1%	2%	2%	0%	0%	105
Dioscorea polystarchya	0%	1%	0%	6%	8%	37%	0%	25%	11%	0%	7%	0%	0%	1%	4%	111
Dioscorea bulbifera	0%	0%	0%	0%	0%	5%	0%	3%	8%	0%	0%	0%	0%	0%	84%	75
Nelumbo nucifera (roots)	1%	0%	0%	39%	0%	12%	0%	25%	3%	0%	10%	5%	1%	5%	0%	110
Dioscorea sp.(wild)	0%	0%	4%	34%	13%	7%	0%	38%	2%	0%	1%	1%	0%	0%	0%	102

*Combination shape of spherical cap and polyhedron

Table 6. 8 Other features of geophyte starch granules

	Fissure							Visibility of lamellae		Position of hilum		Granule number
	Absence	Linear	Stellate	Transverse	V-shape	Y-shape	π-shape	Invisible	Visible	Centric	Eccentric	
Potentilla anserina	100%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%	111
Amorphophallus paeoniifolius	100%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%	104
Schizocapsa plantaginea	100%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%	126
Alisma plantago-aquatica	100%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%	120
Amorphophallus sp	100%	0%	0%	0%	0%	0%	0%	99%	1%	100%	0%	116
Smilax glabra	88%	10%	0%	1%	0%	1%	0%	89%	11%	100%	0%	111
Amorphophallus konjac	100%	0%	0%	0%	0%	0%	0%	97%	3%	100%	0%	103
Sagittaria trifolia	62%	14%	2%	1%	13%	8%	0%	76%	24%	2%	98%	107
Fritillaria cirrhosa	37%	2%	46%	5%	1%	1%	28%	19%	74%	7%	86%	103
Lilium brownii	100%	0%	0%	0%	0%	0%	0%	0%	100%	11%	89%	104
Dioscorea sp.(cultivated)	100%	0%	0%	0%	0%	0%	0%	46%	54%	2%	98%	102
Angiopteris yunnanensis	96%	2%	0%	1%	0%	0%	0%	80%	20%	35%	65%	82
Dioscorea alata	95%	4%	0%	0%	1%	0%	0%	82%	18%	0%	100%	105
Dioscorea polystarchya	100%	0%	0%	0%	0%	0%	0%	2%	98%	1%	99%	111
Dioscorea bulbifera	100%	0%	0%	0%	0%	0%	0%	12%	88%	0%	100%	75
Nelumbo nucifera (roots)	99%	1%	0%	0%	0%	0%	0%	1%	99%	0%	100%	110
Dioscorea sp.(wild)	100%	0%	0%	0%	0%	0%	0%	3%	97%	0%	100%	102

Summary

There are six samples in which sizes are smaller or around five microns, including *Amorphophallus xiei*, three varieties of *Colocasia esculenta, Cibotium baromet, Dioscorea esculenta* var. *spinosa* (Table 6.6). Other size data are displayed in the box-plot, which are divided into two groups further (Figure 6.12). The first group contains the granules which size are mainly smaller than 20μmm, including ten samples: *Potentilla anserine, Amorphophallus paeoniifolius, Schizocapsa plantaginea, Pueraria montana* var. *lobata, Alisma plantago-aquatica, Amorphophallus konjac, Amorphophallus* sp., *Smilax glabra,* and *Sagittaria trifolia* (Figure 6.12). And the large-size group contains another nine samples (Figure 6.12).

In the small-size group, five of them, including *Amorphophallus paeoniifolius, Pueraria montana* var. *lobata, Alisma plantago-aquatica, Amorphophallus konjac, Amorphophallus* sp., and *Smilax glabra* have a large number of the combination shape of spherical cap and polyhedron, sphere, and spherical cap granules (Table 6.7), and most of them have centric hilum, invisible lamellae, and no fissure (Table 6.8). Only *Smilax glabra* has a 12% possibility to bear fissures and 11% possibility to have visible lamellae (Table 6.8). *Potentilla anserine* and *Sagittaria trifolia* are more like to produce rounded triangle granules (Table 6.7). But they are easily to be distinguished. All the granules of *Potentilla anserine* have centric hilum without fissure and visible lamellae (Table 6.8) and are relatively smaller than those from *Sagittaria trifolia* (Figure 6.12). Besides, *Schizocapsa plantaginea* has a large number of smooth bell-shape granules (Table 6.7).

In the large-size group, the eccentric hilum and visible lamellae are common (Table 6.8). Most of them do not have fissures, except *Fritillaria cirrhosa* (Table 6.8). Among the diverse fissures observed on the granules from *Fritillaria cirrhosa*, the π-shape one is distinguishable. In terms of the granule shapes, the *Dioscorea bulbifera* is easily recognizable due to its large proportion of triangle granules (Table 6.7).

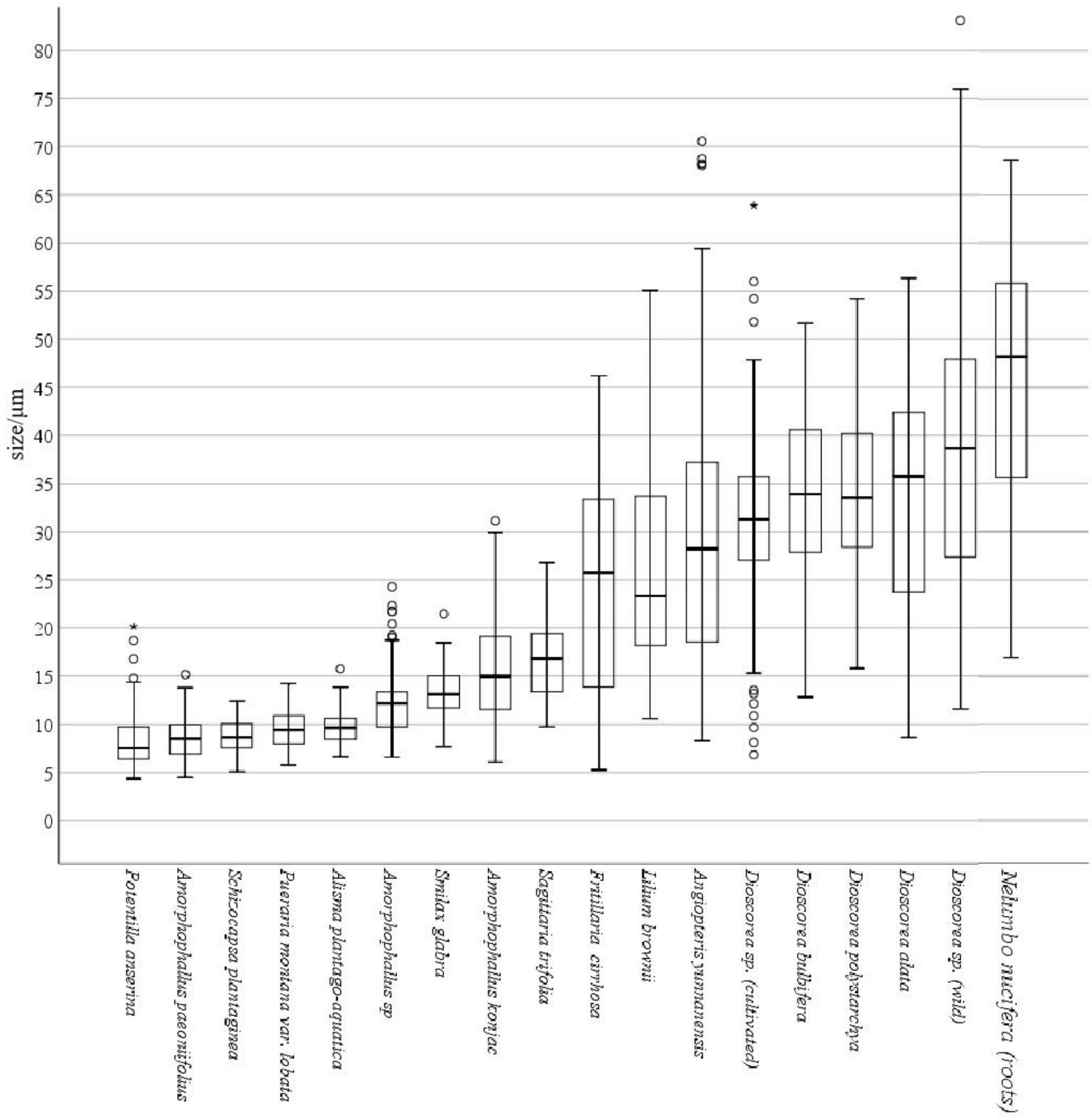

Figure 6. 12 Box-plot of geophyte granule size. (In this figure, four outliers are exclude, which are from *Angiopteris yunnanensis* and wild yam separately).

6.2.3 Starch grains from palm pith

A total of seven samples of sago-type palms are described in this section, including *Caryota* (three species), *Arenga* (two samples), and *Cycas* (two species).

Caryota mittis and *Caryota monostarchya*

The starch grains from *Caryota mittis* are sparse. 27 observed granules are typically oval shape, and pestle shape. The sizes of them are from 3.22 μm to 10.35 μm, with the mean length of 5.97±1.64 μm. The morphology of *Caryota monostarchya* are similar with *Caryota mittis*, which size is smaller than 5μm.

Caryota obtusa

A total of 105 starch granules were observed. The maximum lengths of them are from 8.01 μm to 47.32 μm, which mean length is 18.07±8.16 μm (Table 6.9). The major granules are the oval ones, accounting for 54% of the total (Table 6.10). And the second group is the pestle granules, which percentage is 28% (Table 6.10). There are also some granules which have irregular shape (10%), spherical shape (6%), polyhedron (2%), and spherical cap (1%) (Table 6.10). Only two granules have linear fissures and three of them have centric hilum (Table 6.10). And 92% of them have visible lamellae (Table 6.10).

***Arenga westerhoutii* (white)**

A total of 100 granules were observed. Their sizes are from 7.39 μm to 52.03 μm, which mean length is 26.40±11.33 μm (Table 6.9). The oval granules (58%), irregular granules (17%), and spindle granules (10%) occupy the majority, followed by some seven rounded polygonal ones, seven pestle ones and one sphere granule (Table 6.10). All of them have eccentric hilum, and only one of them have linear fissure (Table 6.10). And a total of 70 granules have visible lamellae.

***Arenga westerhoutii* (red)**

A total of 116 granules were observed. These starch grains are from 11.73 μm to 65.82 μm in size, with the mean length of 29.51±11.29 μm (Table 6.9). The morphological features of this population are similar as those of the white flour of *Arenga westerhoutii*. The oval granules (58%), irregular granules (13%) and spindle granules (14%) are the common types, with a small proportion of pestle ones (7%), sphere (4%), triangle (3%), and polyhedron (1%) (Table 6.10). Five granules of the total have linear fissures, and there are another three granules which have centric hilum (Table 6.10). And the proportion of visible hilum is also 70%.

Cycas pectinata

A total of 112 granules were observed, which sizes are from 5.26 µm to 30.29 µm and the mean length is 14.12±4.78 µm (Table 6.9). The granule morphological features of this species are like some small-size geophyte populations. The combination shape of spherical cap and polyhedron granules (46%), and spherical cap granules (17%) are composed the majority of this population (Table 6.10). And the others include irregular ones (16%), sphere ones (14%), bell shape ones (2%), oval (1%) and triangle (1%) (Table 6.10). Every granule has a centric hilum, and only five of them bear linear fissures (Table 6.10). And most of them (98%) do not have visible lamellae (Table 6.10).

Cycas panzhihuaensis

A total of 113 granules were examined. The sizes of them are from 11.66 µm to 36.96 µm, and their mean length is 20.63±4.86 µm (Table 6.9). The major shapes of these granules are still combination shape of spherical cap and polyhedron (56%) and spherical cap (6%), and the total proportion of these two granule shapes are close to that of *Cycas pectinata* (Table 6.10). The following groups include irregular (16%), sphere (12%), polyhedron (7%), triangle (2%), bell shape (1%) and oval (1%) (Table 6.10). No granule has fissure and visible lamellae, and everyone has a centric hilum (Table 6.10).

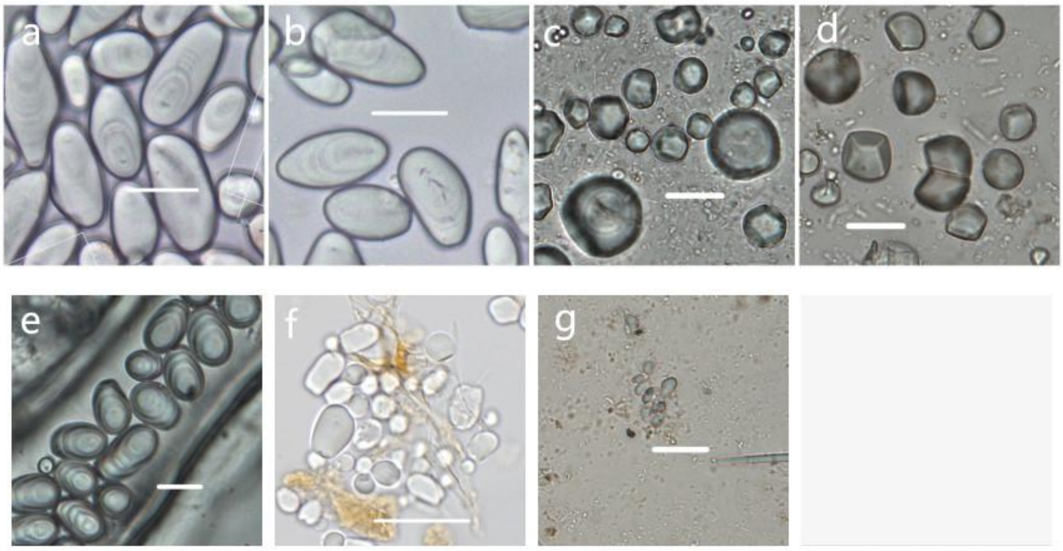

Figure 6. 13 Starch grains from woody starchy pith. a, *Arenga westerhoutii* (red); b, *Arenga weterhoutii* (white); c, *Cycas pectinata;* d, *Cycas panzhihuaensis*; e, *Caryota obtusa*; f, *Caryota mitis*; g, *Caryota monostarchya.* Scale, 20 μm.

Table 6. 9 Size range and mean size of starch granules from sampled starchy pith

	Size range/μm	Mean length/μm	Granule number
Arenga westerhouti (white)	7.39 - 52.03	26.40±11.33	100
Arenga westerhouti (red)	11.73 - 65.82	29.51±11.29	116
Caryota obtusa	8.01 - 47.32	18.07±8.16	105
Cycas pectinata	5.26 - 30.29	14.12±4.78	112
Cycas panzhihuaensis	11.16 - 36.96	20.63±4.86	113

Table 6. 10 Morphological features of starch granules from sampled starchy pith

		***Arenga westerhouti* (white)**	***Arenga westerhouti* (red)**	***Caryota obtusa***	***Cycas pectinata***	***Cycas panzhihuaensis***
Gruanule number		100	116	105	112	113
Shapes	Bell shape	0%	0%	0%	2%	1%
	CSCP*	0%	0%	0%	46%	56%
	Irregular	17%	13%	10%	16%	16%
	Oval	58%	58%	54%	1%	1%
	Pestle	7%	7%	28%	0%	0%
	Polyhedron	0%	1%	2%	4%	7%
	Rounded polygon	7%	0%	0%	0%	0%
	Sphere	1%	4%	6%	14%	12%
	Spherical cap	0%	0%	1%	17%	6%
	Spindle	10%	14%	0%	0%	0%
	Triangle	0%	3%	0%	1%	2%
Fissures	Linear	1%	4%	2%	4%	0%
	Absence	99%	96%	98%	96%	100%
Lamellae	Visible	70%	70%	92%	2%	0%
	Inivsible	30%	30%	8%	98%	100%
Position of hilum	Centric	0%	3%	3%	100%	100%
	Eccentric	100%	97%	97%	0%	0%

* Combination shape of spherical cap and polyhedron

Summary

The most starch grains from starch pith have large sizes. The box plot of those starch granules (Figure 6.14) indicates that the granule size of *Arenga westerhoutii* is quite larger than the other three samples. While between it two varieties, the starch granules of red guanglang flour are slightly larger than those of white ones. The granules of the other three species, *Caryota obtusa, Cycas pectinata*, and *Cycas panzhihuaensis*, are smaller than 40μm. In the size of the two species of *Cycas*, the granules from *Cycas panzhihuaensis* are larger than those from *Cycas pectinata*.

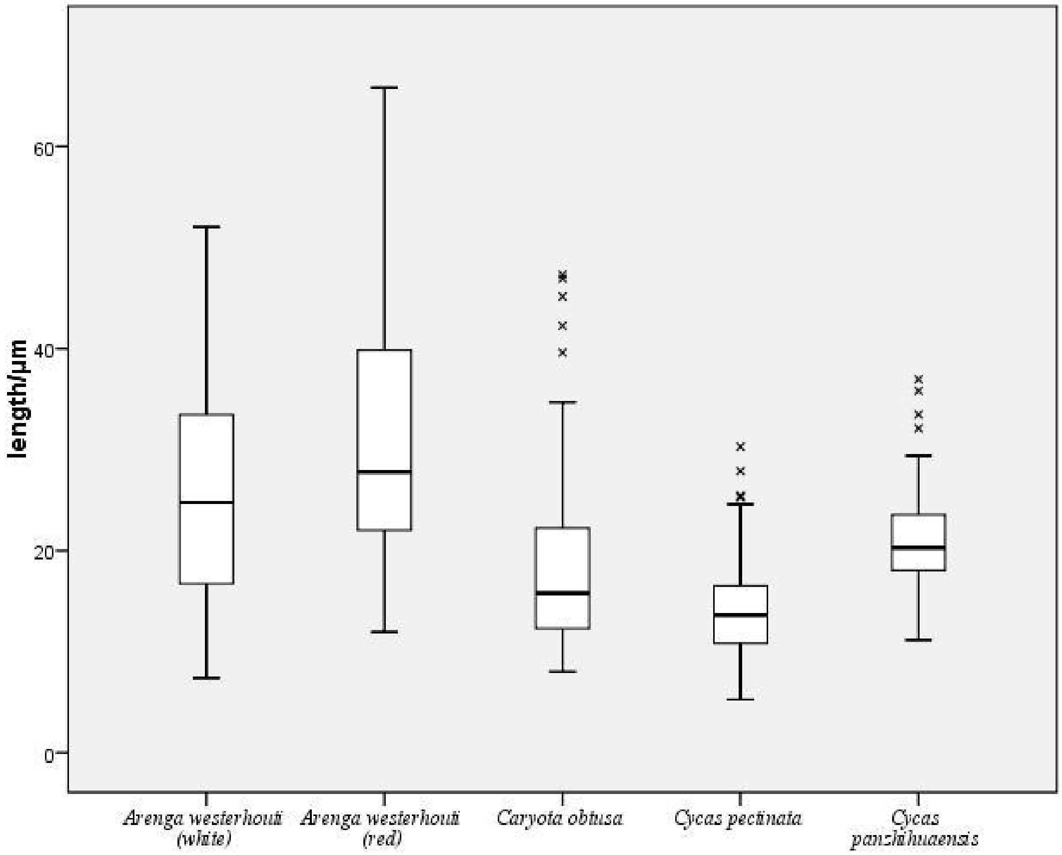

Figure 6. 14 Box-plot of starch granules from starchy pith.

On the aspect of morphological features, the starch granules from these samples are probably distinguished at the genus level. The *Cycas* granules mainly produced combination shape of spherical cap and polyhedron and spherical cap granules, which have centric hilum but without fissure and visible lamellae (Table 6.10). The spindle granules from *Arenga* are identifiable, which have eccentric hilum, visible lamellae, but no fissure (Table 6.10). And the starch from *Caryota obtusa* is characterized by the pestle granules, with visible lamellae, eccentric hilum, and no fissures (Table 6.10).

6.3 Multiple correspondence analysis of starch granules

When the starch granules of each category were described, the box-plots (Figure 6.5, Figure 6.12, and Figure 6.14) revealed that the granule size ranges always overlap partly, especially that smaller than 20 microns. Only some granules from geophytes and palm pith have relatively large sizes (Figure 6.12 and Figure 6.14). Therefore it is difficult to identify most of the starch granules solely through size data.

In this section, I used the multiple correspondence analysis to reflect the morphological features of the starch granules, trying to reveal the relationship between these features and the plant and pick up the identifiable features of each plant further. However, it should be noted that the results reflect the difference between the proportion of different categories and the average level, not their original frequency (Zhang 2013). The multiple correspondence analyses were performed by SPSS v 25.0.

6.3.1 Multiple correspondence analysis results of Fagaceae starch

The morphological features of Fagaceae starch were first analyzed as a case study.

Results at genus level

Firstly, all the data, including shapes, hilum position, fissure type, lamellae visibility, and surface texture, were input. The model summary (Table 6.11) showed that the first dimension explained 33.6% of the principal inertia, the second explained 25.8%.

Table 6. 11 Model summary of multiple correspondence analysis of Fagaceae at genus level

Dimension	Cronbach's Alpha	Variance Accounted For		
		Total (Eigen value)	Inertia	Percentage of variance
1	0.605	2.018	0.336	33.629
2	0.424	1.546	0.258	25.774
Total		3.564	0.594	
Mean	0.527[a]	1.782	0.297	29.702

a Mean Cronbach's Alpha is based on the mean Eigen value

But the plot of discrimination measures (Figure 6.15) of this analysis indicated that the the variable fissure types and lamellae visibility, located very close to the origin, did not discriminate at all in these two dimensions. Therefore, I temporarily deleted these two variables and analyzed the remaining variables again.

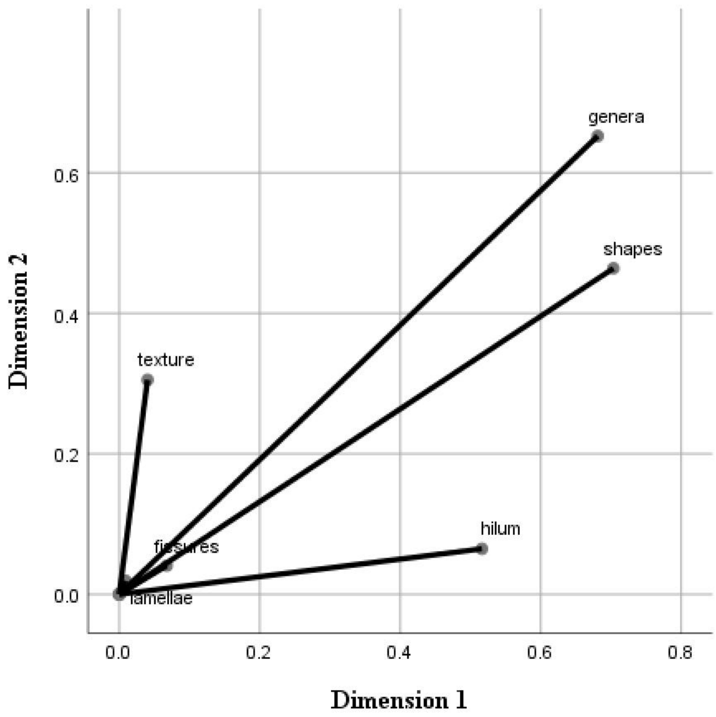

Figure 6. 15 Plot of discrimination measures of whole acorn starch data at genus level

The model summary of the second analysis (Table 6.12) shows that the first dimension explained 49.5% of the principal inertia, the second explained 38.2%.

Table 6. 12 Second model summary of multiple correspondence analysis of Fagaceae starch at genus level

Dimension	Cronbach's Alpha	Variance Accounted For		
		Total (Eigen value)	Inertia	Percentage of variance
1	0.660	1.979	0.495	49.474
2	0.460	1.526	0.382	38.161
Total		3.505	0.876	
Mean	0.573[a]	1.753	0.438	43.818

a Mean Cronbach's Alpha is based on the mean Eigen value

The discrimination measures plot of the second analysis (Figure 6.16) shows that the variables hilum position is related to the first dimension, which has large discrimination measures on the first dimension but small on the second dimension. Hence, the hilum position is mainly distinguished along the first dimension. In contrast, the surface texture is closest to the second dimension, indicating that the second dimension seems to separate the smooth or rough granules. Plant genus and the granule shapes have relatively large values on both dimensions, indicating discrimination in both the first and second dimensions.

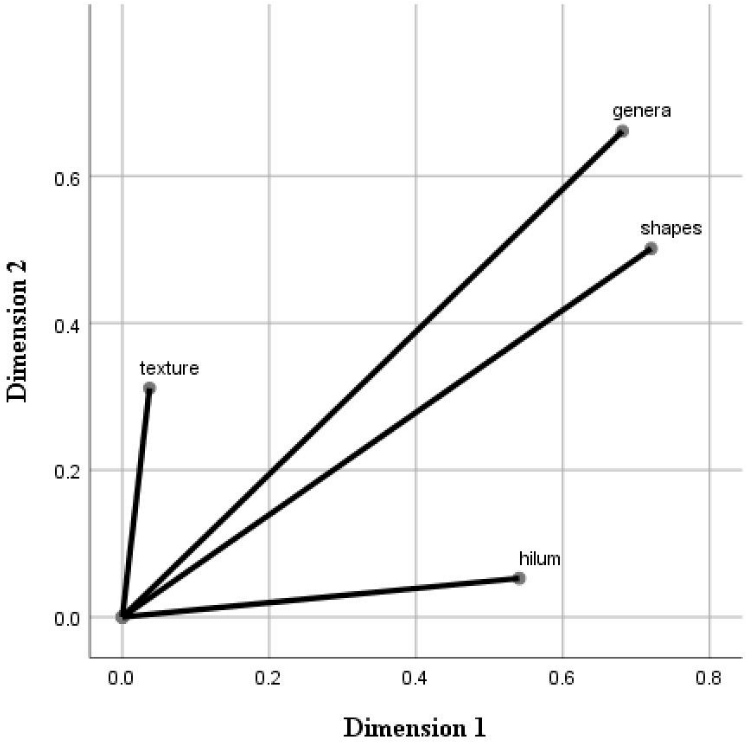

Figure 6. 16 Second plot of discrimination measures of acorn starch data (shapes, hilum position, and surface texture) at genus level

The category quantification plot (Figure 6.17) displays the coordinates of each category on each dimension. Thus, the similarity for each category is noticed. In terms of hilum position, which has large discrimination measures on the first dimension (Figure 6.16), the *Quercus* granule has a higher possibility of having eccentric hilum than other three genera. And on the aspect of surface texture, Figure 6.16 also indicates that the granules from *Cyclobalanopsis* are more likely to have rough surfaces. These results are similar to what I observed.

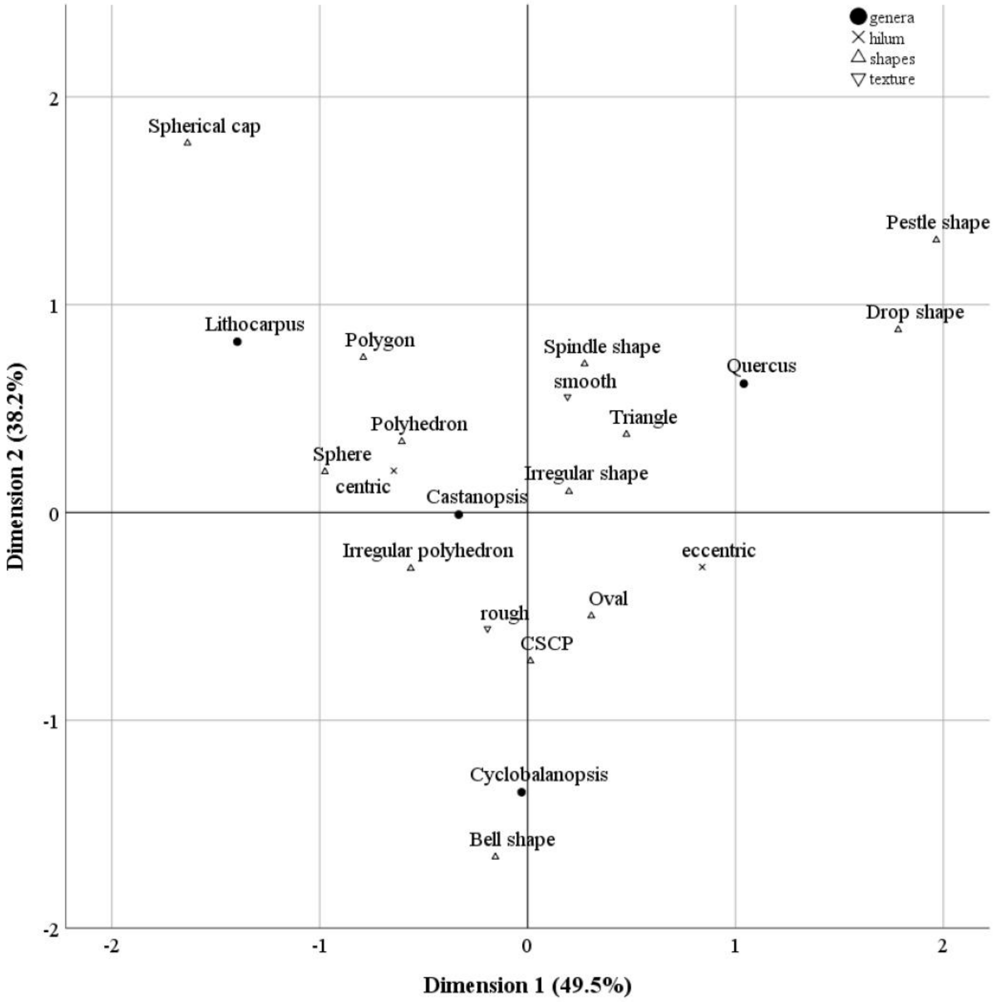

Figure 6. 17 Multiple correspondence analysis result of Fagaceae starch at genus level.

In terms of granule shapes, the pestle-shaped granules and drop-shaped granules are more likely to appear in the *Quercus* populations. And the bell shape point is close to *Cyclobalanopsis*, demonstrating that the frequency of bell-shaped granules in this genus. The polyhedron granules, no matter normal ones or irregular ones, seem to have a close relationship with *Castanopsis*. The spherical cap granules may probably from *Lithocarpus*.

In summary, these four genera are distinguished at genus level:

1) *Quercus* have the smooth drop-shaped or pestle-shaped granules which have eccentric hilum.

2) *Cyclobalanopsis* are more likely to produced the rough bell-shaped granules granules with centric hilum.

3) The identifiable features of *Castanopsis* granules include polyhedron shape (however, based on observation, the irregular polyhedron ones are more distinguish), centric hilum, and smooth surface.

4) *Lithocarpus* may have smooth spherical cap granules with centric hilum.

Results at species level

After find some identifiable features at genus level, I examined whether those granules could be further distinguished at species level. Firstly, all the data were input as well. The plot of discrimination measures (Figure 6.18) of this analysis also indicated that the the variables of fissure types and lamellae visibility did not discriminate at all in these two dimensions. Therefore, I also deleted these two variables and analyzed other variables for the second time.

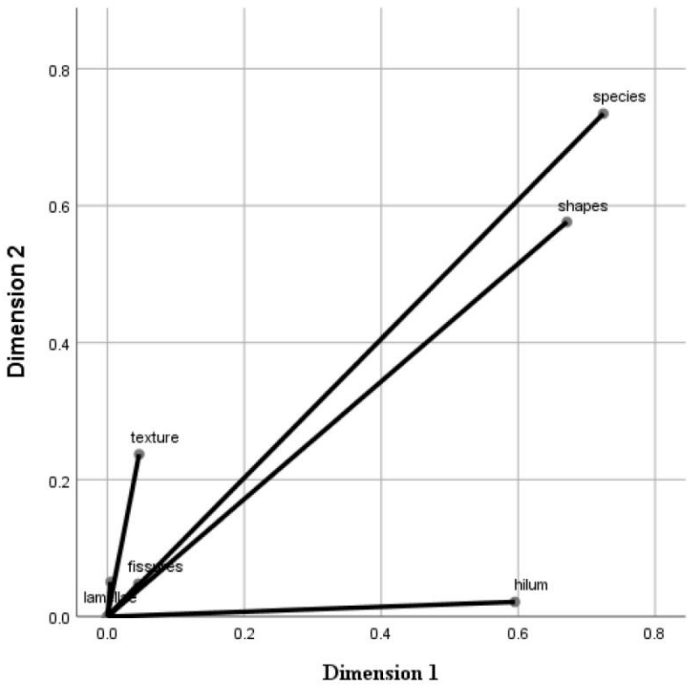

Figure 6. 18 Plot of discrimination measures of whole acorn starch data at species level

The model summary of the second analysis at species level (Table 6.13) shows that the first dimension explained 51.5% of the principal inertia, the second explained 41.0%.

Table 6. 13 Model summary of multiple correspondence analysis of Fagaceae starch at species level

Dimension	Cronbach's Alpha	Variance Accounted For		
		Total (Eigen value)	Inertia	Percentage of variance
1	0.687	2.062	0.515	51.540
2	0.521	1.641	0.410	41.021
Total		3.702	0.926	
Mean	0.613[a]	1.851	0.463	46.281

a Mean Cronbach's Alpha is based on the mean Eigen value

The discrimination measures plot of the second analysis at species level (Figure 6.19) looks similar to that at genus level (Figure 6.16). It shows that the variables hilum position is mainly distinguished along the first dimension, but the surface texture is closest to the second dimension. Plant species and the granule shapes have relatively large values on both dimensions, indicating discrimination in both the first and second dimensions.

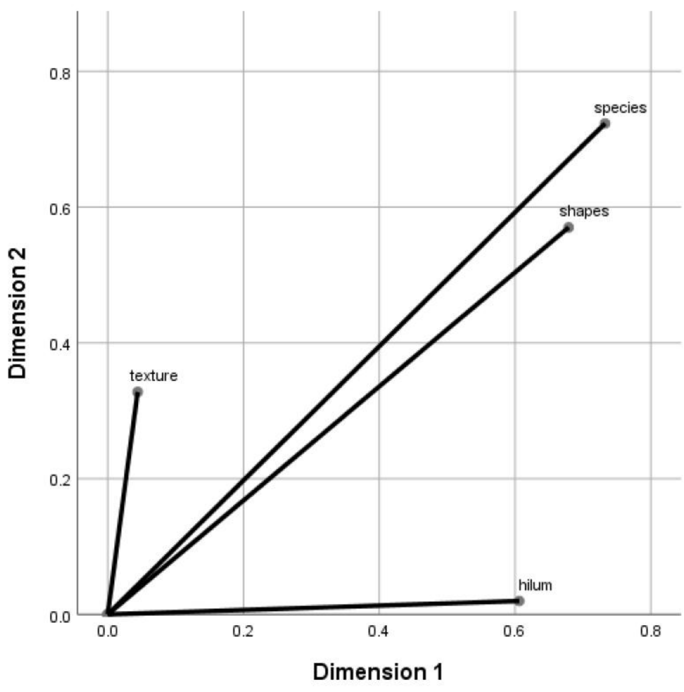

Figure 6. 19 Second plot of discrimination measures of acorn starch data (shapes, hilum position, and surface texture) at species level.

The similarities for each category are noticed in Figure 6.20. Hilum position, which has large discrimination measures on the first dimension (Figure 6.19), are useful to distinguish species 3, 4, 5, 6, 8, and 10, that is, the granules from *Quercus cocciferoides, Quercus oxyphylla, Quercus variabilis, Quercus franchetii, and Cyclobalanopsis chapensis* and, *Cyclobalanopsis phanera* have higher possibilities of having a eccentric hilum than other species. In terms of granule textures, species 1, 5, 6, 12, and 13, namely *Lithocarpus cleistocarpus, Quercus variabilis Quercus franchetii, Castanopsis hystrix*, and *Castanopsis fargesii* , are more likely to have rough surfaces.

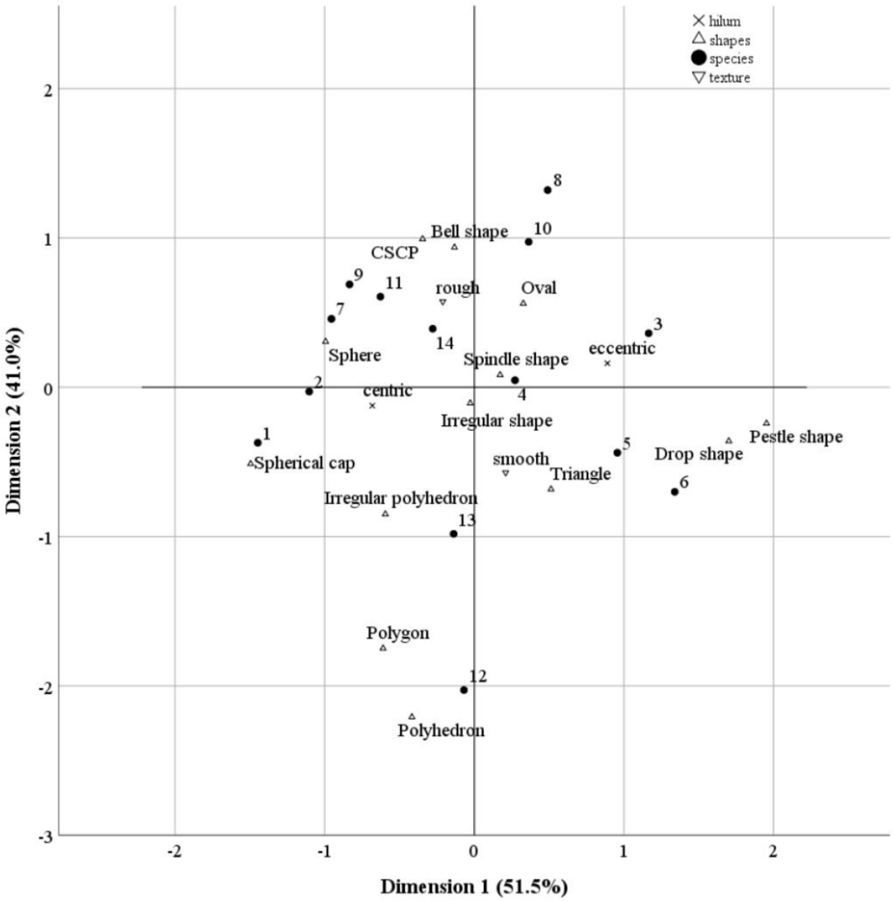

Figure 6. 20 Map of multiple correspondence analysis result of Fagaceae granules at species level. Species: 1, *Lithocarpus cleistocarpus*; 2, *Lithocarpus litseifolius*; 3, *Quercus cocciferoides*; 4, *Quercus oxyphylla*; 5, *Quercus variabilis*; 6, *Quercus franchetii*; 7, *Cyclobalanopsis glauca*; 8, *Cyclobalanopsis chapensis*; 9, *Cyclobalanopsis gambleana*; 10, *Cyclobalanopsis phanera*; 11, *Castanopsis platyacantha*; 12, *Castanopsis hystrix*; 13, *Castanopsis fargesii*; 14, *Castanopsis sclerophylla*

In terms of the granule shapes, the oval granules and spindle-shaped granules in the first quadrant may have the closest relationships with species 3, 4, 8, and 10. As the oval granules are common through observation of all samples, it cannot apply for starch granule identification. However, the species 4, *Quercus oxyphylla,* may have a higher possibility to have spindle shapes. The species 7, 9, 11, and 14 may produce bell-shaped granules, combination shape of spherical cap and polyhedron granules or spherical granules. In the third quadrant, the four species seem to be distinguished further. The species 1 and 2 may have spherical cap granules, while 12 and 13 tend to produce the polygonal granules, including normal ones and irregular ones. And the species 5 and 6, *Quercus variabilis* and *Quercus franchetii,* may be identifiable by the pestle-shaped granules, drop-shaped granules, and triangular granules.

This result reflect some inter-species differences between each species of Fagaceae. Combined to the observations, the identification of Fagaceae granules at species level can be summarized as follows:

1) *Quercus variabilis* and *Quercus franchetii* are more likely to have smooth pestle-shaped or drop-shaped granules, which have eccentric hilum.
2) *Quercus oxyphylla* tend to have spindle-shaped granules which have eccentric hilum.
3) The granule from *Lithocarpus cleistocarpus* and *Lithocarpus litseifolius* seem to be spherical cap type, with smooth surface and centric hilum. This is same as the genus features, therefore, it may not be identified at species level.
4) The morphological features of *Castanopsis hystrix* and *Castanopsis fargesii* include polygonal shapes, such as the 2D polygon ones and 3D normal or irregular polyhedron ones.

6.3.2 Multiple correspondence analysis of geophyte granules

Besides *Dioscorea* and *Amorphophallus*, only one sample was collected from each genus (Table 6.1). Therefore, I directly analyzed the geophyte granules at species level. The model summary of this analysis (Table 6.14) shows that the first dimension explained 64.5% of the principal inertia, the second explained 39.1%.

Table 6. 14 Model summary of multiple correspondence analysis of geophyte starch granules

		Variance Accounted For		
Dimension	**Cronbach's Alpha**	**Total (Eigen value)**	**Inertia**	**Percentage of variance**
1	0.862	3.225	0.645	64.492
2	0.610	1.954	0.391	39.073
Total		5.178	1.036	
Mean	.767[a]	2.589	0.518	51.782

a Mean Cronbach's Alpha is based on the mean Eigen value

The discrimination measures plot of geophyte granule data (Figure 6.21) shows that all the variables have a large discrimination. The variables lamellae visibility and hilum position are related to the first dimension, indicating they are mainly distinguished along the first dimension. And the fissure type has a large discrimination measures on the second dimension but small on the first. Plant species and the granule shapes have relatively large values on both dimensions, indicating discrimination in both the first and second dimensions.

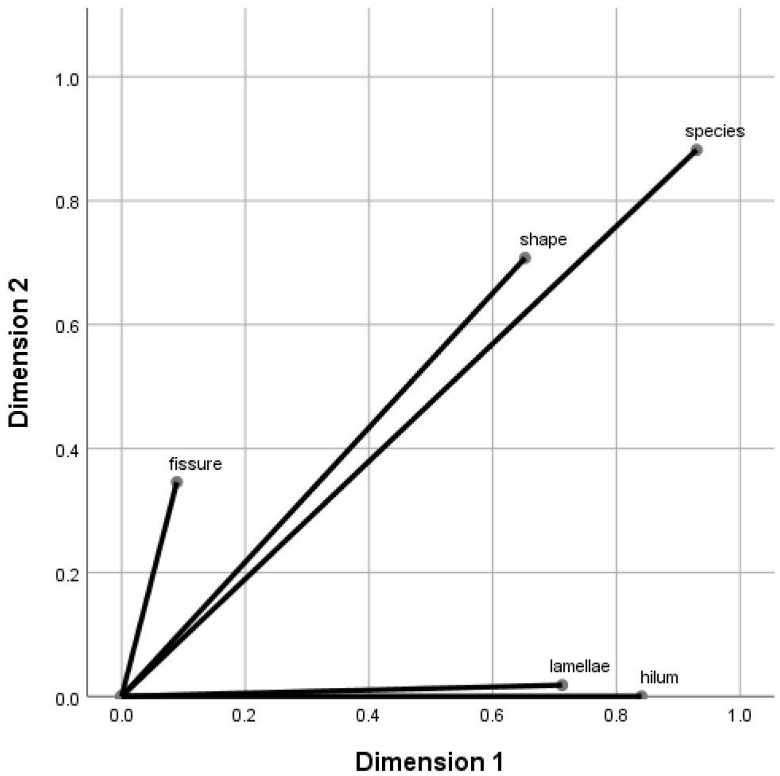

Figure 6. 21 Plot of discrimination measures of geophyte starch data at species level.

In the result of multiple corresponding analysis, these geophyte starch grains are distinguished (Figure 6.22). The first noteworthy thing is that two groups of points are relatively isolated from others. The first group is the species 15, *Dioscorea bulbifera*, closed to the triangular granules on the top of Figure 6.22. Another group is located at the bottom of Figure 6.22. This group contains *Fritillaria cirrhosa* and diverse fissure type, suggesting that comparing to other geophyte samples, this species is more likely to bear fissures that have multiple types.

For other species, firstly, in the terms of fissure types, the species 2 to 6, 10, and 14 to 17, do not have fissures. In dimension one, the lamellae visibility and hilum position are distinguished. Seven species (1 to 6 and 17) tend to produce granule with a centric hilum and invisible lamellae, while others have granule with a eccentric hilum and visible lamellae.

On the aspects of granule shapes, there is a cluster in the positive direction of the first dimension, containing *Amorphophallus paeoniifolius, Alisma plantago-aquatica,* *Amorphophallus* sp., *Smilax glabra, Amorphophallus konjac*, and *Schizocapsa plantaginea*. This group probably has identifiable combination shape of spherical cap and polyhedron, spherical cap, or bell-shaped granules. And the species 1, *Potentilla anserine*, in the fourth quadrant, may have spherical granules, which is too common to be identified. In the second quadrant, besides *Dioscorea bulbifera,* the other three species, *Dioscorea* sp. (wild), *Dioscorea polystarchya*, and *Nelumbo nucifera* (roots), are possibly distinguished by elongate oval or triangle granules and polyhedron granules. In the third quadrant, the *Sagittaria trifolia* is separated from others, whose granule shapes include irregular polyhedron, rounded triangle, and drop shape. Others, including *Lilium brownii*, *Dioscorea* sp. (cultivated), *Angiopteris yunnanensis*, and *Dioscorea alata*, may produce spindle-shaped granules or polygonal granules.

Finally, the homogeneity of some granules are summarized:

1) The starch granules from *Amorphophallus paeoniifolius, Alisma plantago-aquatica, Amorphophallus* sp., *Smilax glabra, Amorphophallus konjac,* and *Schizocapsa plantaginea*, have great commonalities, including similar identifiable shapes (combination shape of spherical cap and polyhedron type, spherical cap type or bell shape type), centric hilum and invisible lamellae.
2) Starch granules from *Sagittaria trifolia* produce some geometric granules, like irregular polyhedron and rounded triangles.
3) The triangle granule with clear visible lamellae, eccentric hilum, and no fissure should come from *Dioscorea bulbifera.*
4) Granules of *Fritillaria cirrhosa* have the highest possibility to bear fissures, which may also have visible lamellae and eccentric hilum. .
5) Granules of *Dioscorea polystarchya,* wild yam (*Dioscorea* sp.) and lotus roots (*Nelumbo nucifera*) look similar. This group is likely to have elongate granules (oval or triangle) with visible lamellae and eccentric hilum.
6) *Lilium brownii, Dioscorea* sp. (cultivated), *Angiopteris yunnanensis*, and *Dioscorea alata*, may produce spindle-shaped granules or polygonal granules, which have eccentric hilum, visible lamellae, and linear fissure.

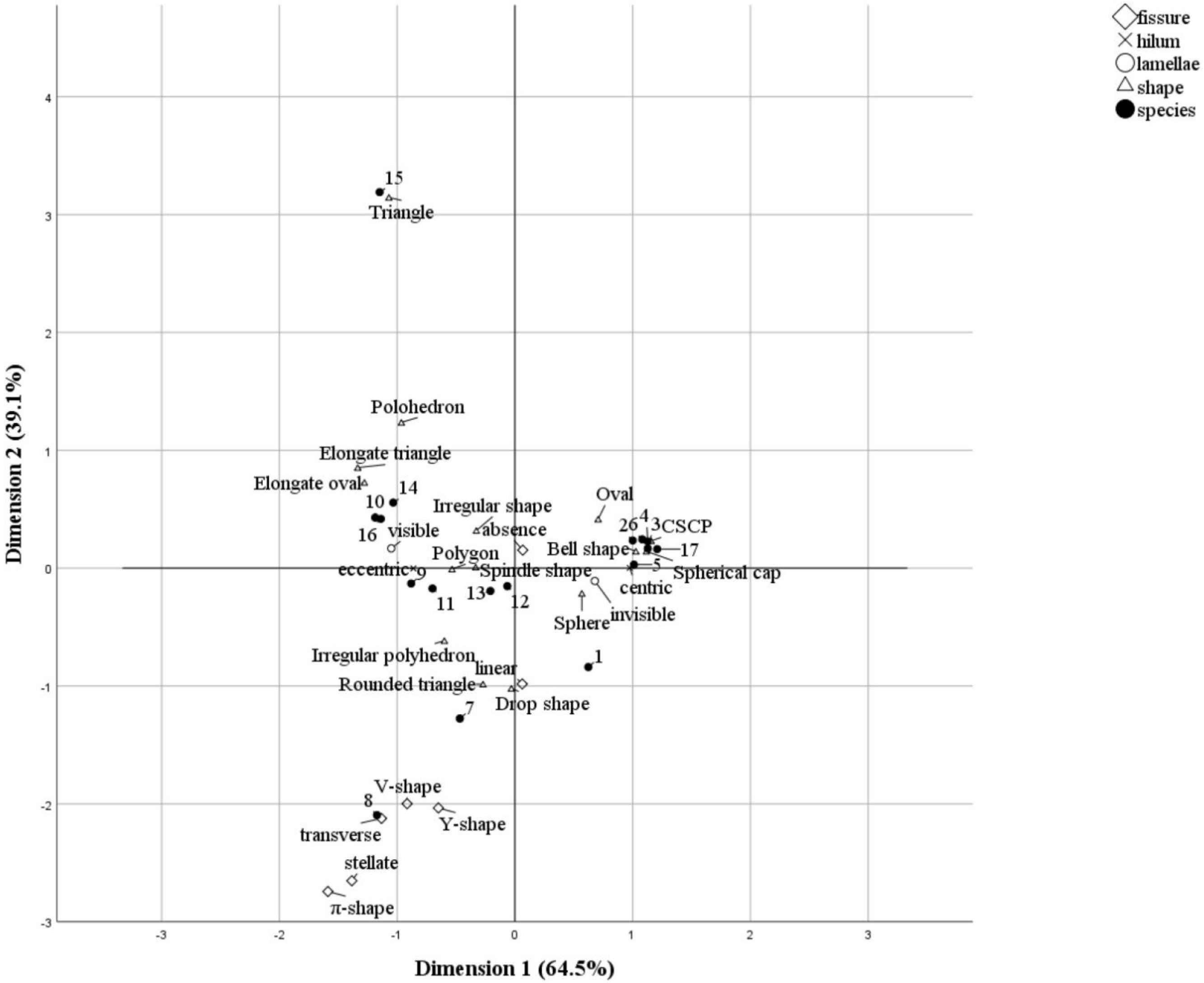

Figure 6. 22 Multiple correspondence analysis result of geophyte grains.

1, *Potentilla anserine*;

2, *Amorphophallus paeoniifolius*;

3, *Alisma plantago-aquatica*;

4, *Amorphophallus* sp.;

5, *Smilax glabra*;

6, *Amorphophallus konjac*;

7, *Sagittaria trifolia*;

8, *Fritillaria cirrhosa;*

9, *Lilium brownii*;

10, *Dioscorea* sp. (wild);

11, *Dioscorea* sp. (cultivated);

12, *Angiopteris yunnanensis*;

13, *Dioscorea alata*;

14, *Dioscorea polystarchya*;

15, *Dioscorea bulbifera*;

16, *Nelumbo nucifera* (roots);

17, *Schizocapsa plantaginea.*

6.3.3 Multiple correspondence analysis of starch granules from palm pith

Like the other two plant categories, I also input all the data of palm pith granules first. However, the plot of discrimination measures (Figure 6.23) indicates that the variable 'fissure type' has a relatively low degree of discrimination, although it is close to the second dimension. Therefore I deleted this variable and analyzed the data second time.

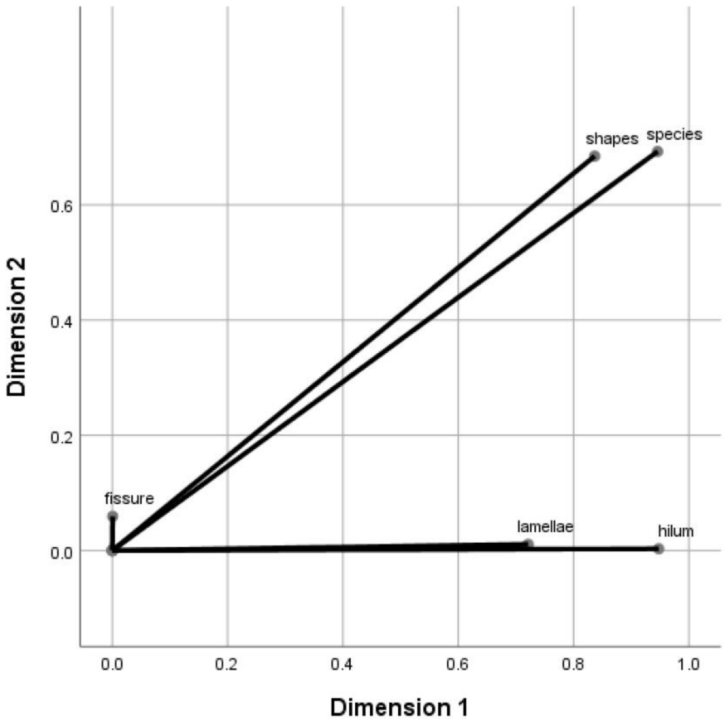

Figure 6. 23 Plot of discrimination measures of the whole starchy pith starch data

The model summary of the second analysis (Table 6.15) shows that the variance in the data is accounted for 86.3% by the first dimension and 35.9% by the second.

Table 6. 15 Model summary of multiple correspondence analysis of starchy pith granules

		Variance Accounted For		
Dimension	**Cronbach's Alpha**	**Total (Eigen value)**	**Inertia**	**Percentage of variance**
1	0.947	3.451	0.863	86.283
2	0.406	1.438	0.359	35.948
Total		4.889	1.222	
Mean	.788[a]	2.445	0.611	61.115

a Mean Cronbach's Alpha is based on the mean Eigen value

The second plot of discrimination measures (Figure 6.24) indicates that the variables lamellae visibility and hilum position have close relationships with the first dimension. Therefore, the categories of these two variables could be distinguished along the first dimension only. The granule shapes and plant species have relatively large values on both dimensions, indicating discrimination in both the first and second dimensions.

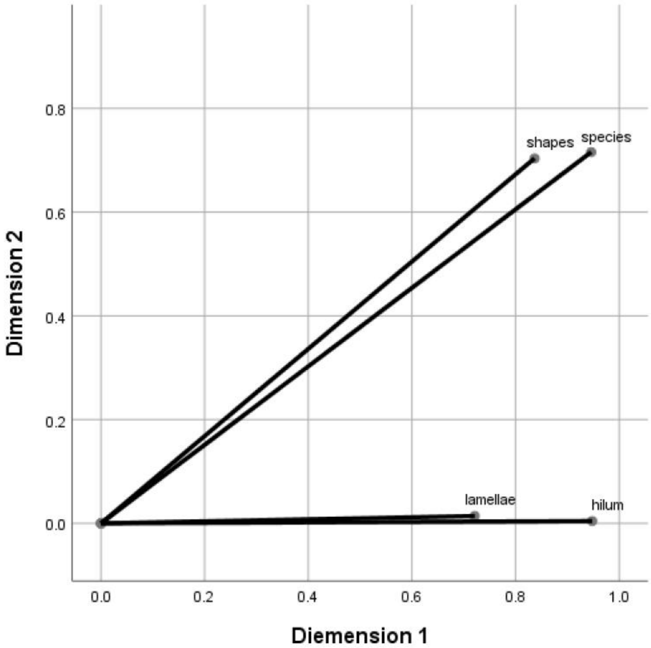

Figure 6. 24 Plot of discrimination measures of palm pith starch data, except the fissure type.

For the lamellae visibility and hilum position, what is shown in Figure 6.25 is that granules from *Cycas pectinata* and *Cycas panzhihuaensis* have centric hilum and invisible lamellae, distinguished against granules with visible lamellae and eccentric hilum from *Arenga westerhoutii* and *Caryota obtusa*.

On the aspects of granule shapes, the two species of *Cycas*, clustered in the positive direction of the first dimension, presumably produce combination shape of spherical cap and polyhedron type, spherical cap type, or bell-shaped type granules. This cluster suggests that it is difficult to identify them at the species level. The pestle-shaped granules may have high relevance to *Caryota obtusa*. The white *Arenga westerhoutii* samples, close to the polygonal granules and oval granules, seem not too recognizable. But the spindle-shaped, triangle-shaped, or elongate oval granules are the identifiable bases of red *Arenga westerhoutii* identification.

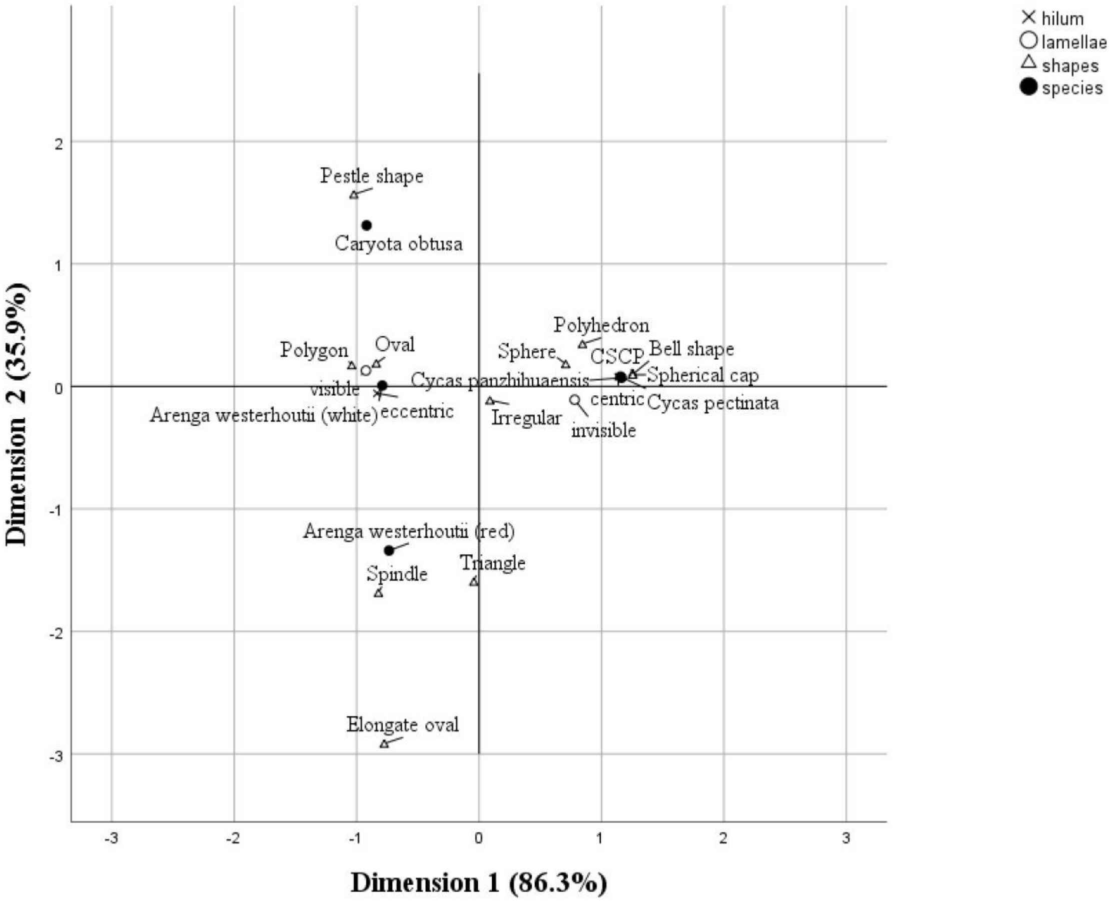

Figure 6. 25 Multiple correspondence analysis results of starchy pith starch.

To sum up, the starch granules from palm pith are distinguishable to some extent.

1) The granules from two species of *Cycas* are almost the same in morphology. They may have bell shape, combination shape of spherical cap and polyhedron, sphere, or spherical cap with centric hilum, but without any visible lamellae.
2) The red guanglang sample (*Arenga westerhoutii*) is more likely to produce elongate oval, spindle or triangle granules. And those granules probably have eccentric hilum and visible lamellae.

3) *Caryota obtusa* granules could be identified by the pestle-shaped granules with eccentric hilum and clear visible lamellae.

6.3 Identification of all the samples

According to the above observation and analysis, in the case of known plant types, some starch granules from them have the same characteristics or can even be identified to the genus. In this section, I analyzed the whole modern reference database collected in this thesis, trying to find the similarities and differences of these starch granules without knowing the plant categories.

6.3.1 Species level

First, based on the granule size data (Table 6.2, Table 6.6, and Table 6.9), I ordered the box plot (Figure 6.26) by their mean size. This plot does not include granules smaller than 5 microns. According to Figure 6.26, most granules are difficult to be identified by their size independently, as their size range have overlap more or less. However, the granules larger than 30 microns can be preliminarily identified as some geophytes (e.g. *Dioscorea* or *Angiopteris*) or palm pith (*Caryota* or *Arenga*).

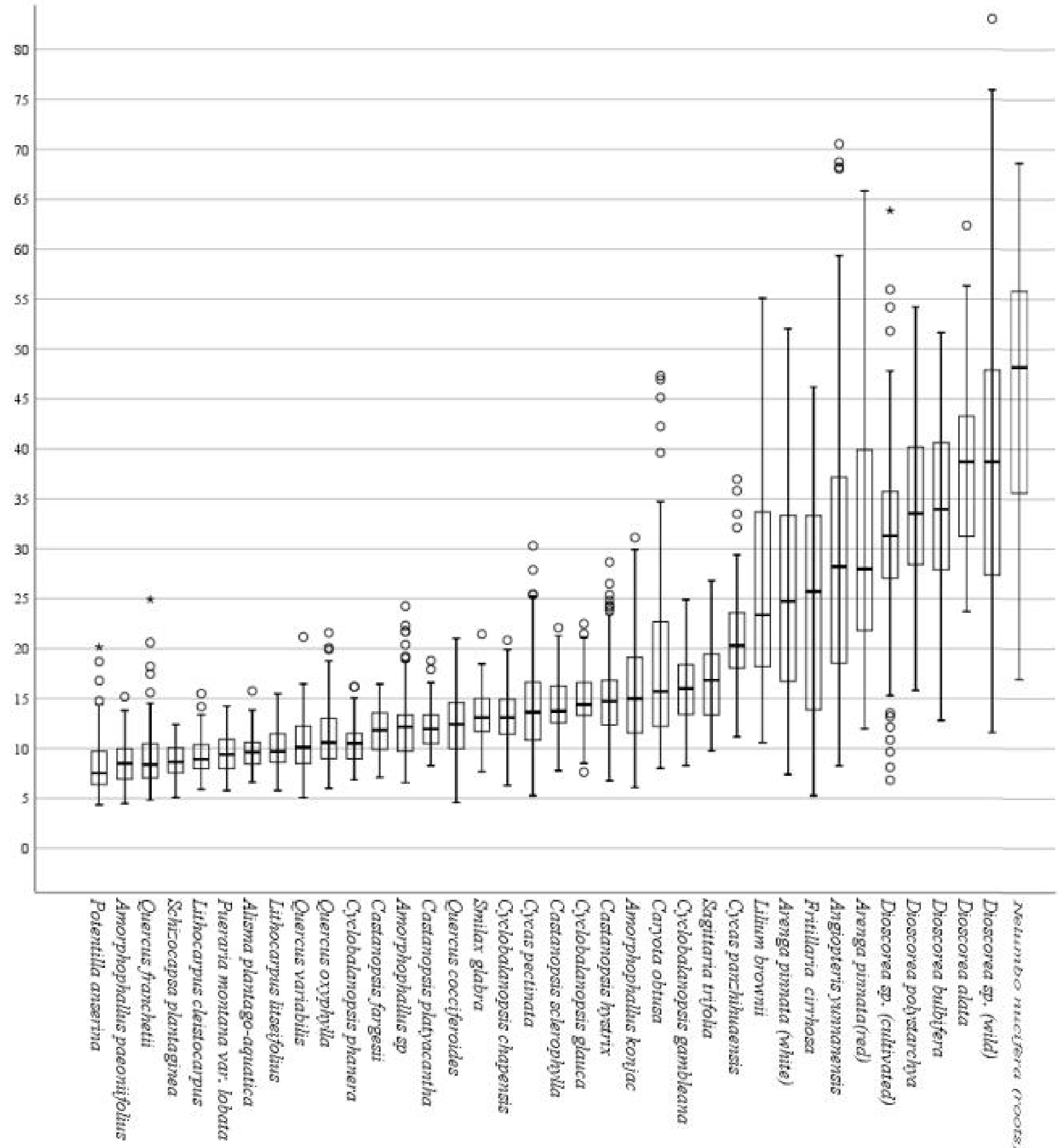

Figure 6. 26 Box-plot of granule size (larger than 5 microns) of modern references collected in this thesis. (The measured granule number of lotus roots is 50, others are 100. This figure also exclude four outliers larger than 80 microns, from *Angiopteris yunnanensis* and wild yam separately)

The second step was the analysis of morphological features. It was also relied on multiple correspondence analysis, being performed by SPSS v 25.0. The model summary of this analysis (Table 6.16) shows that the variance in the data is accounted for 58.0% by the first dimension and 35.5% by the second.

Table 6. 16 Model summary of multiple correspondence analysis of all samples

		Variance Accounted For		
Dimension	**Cronbach's Alpha**	**Total (Eigen value)**	**Inertia**	**Percentage of variance**
1	0.819	2.900	0.580	57.999
2	0.546	1.776	0.355	35.511
Total		4.675	0.935	
Mean	.715[a]	2.338	0.468	46.755

a Mean Cronbach's Alpha is based on the mean Eigen value

The plot of discrimination measures (Figure 6.27) indicates that the variables lamellae visibility and hilum position are close to the first dimension but have small discrimination measures on the second dimension. And the variable fissure types has a large value on the second dimension but a small value on the first dimension. Therefore, the categories of these two variables could be distinguished along the first dimension only. The granule shapes and plant species have relatively large values on both dimensions, indicating discrimination in both the first and second dimensions.

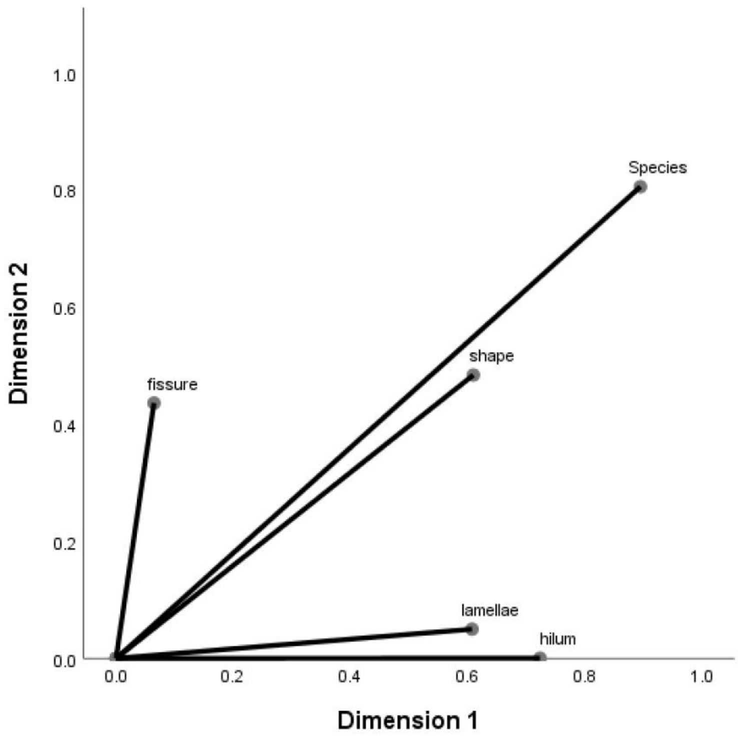

Figure 6. 27 Plot of discrimination measures of all modern samples, except the fissure type.

The granules from species 21 and 22, *Sagittaria trifolia* and *Fritillaria cirrhosa*, may have the most fissure types, as shown in the second quadrant of Figure 6.28. In terms of the lamellae visibility and hilum position, the species located in the right part of Figure 6.28 are more likely to have centric hilum and invisible lamellae, while those in the left are probably with eccentric hilum and visible lamellae.

The distributions of granule shapes and species are more complex. Some granules gather in the right bottom part of this figure, including species16 to 20, 31, 35, and 36. This group is close to the spherical cap granules and combination shape of spherical cap and polyhedron granules, reflecting their relationships. The species 1 and 7, near this cluster, are close to the bell shape granules.

Along the positive direction of the second dimension, the species 9, 11, and 12 tend to have relationships with irregular polyhedron granules and spherical granules. The species 3 to 6 have a higher proportion of oval and drop-shaped granules than the average level. And the triangular granules are probably from species 15, 21, and 22, especially species 21.

In the third quadrant, there are nine species (23, 24, 25, 28, 29, 30, 32, 33, 34) and six granule shapes (triangle, polygon, irregular shape, pestle shape, elongate oval, and elongate triangle). But in terms of proximity, the species 33 and 34 probably have pestle-shaped granules, and 24, 30, and 28 tend to produce elongated ones, including oval or triangular types.

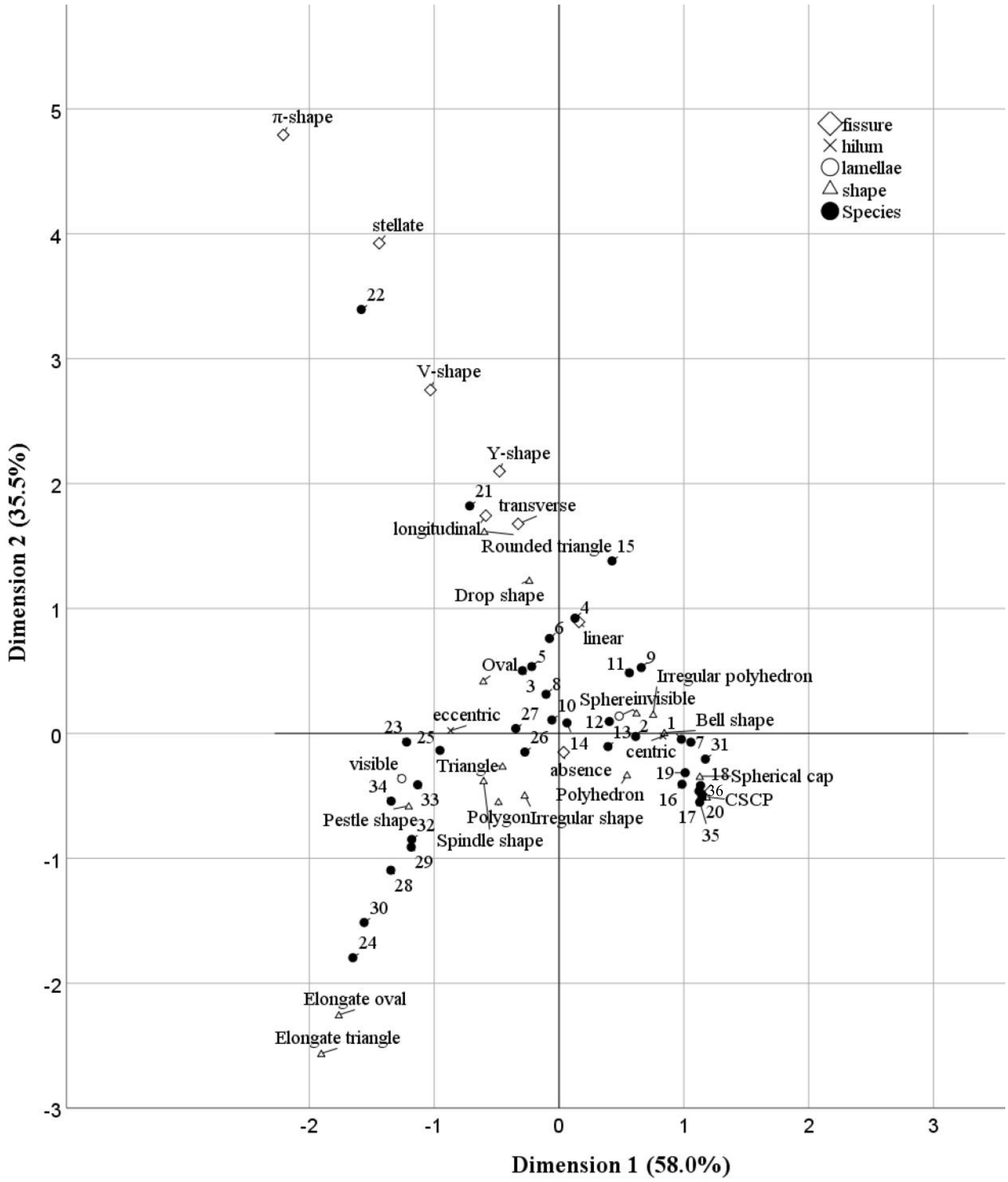

Figure 6. 28 Multiple correspondence analysis results of all the modern samples at species level. Species: 1, *Lithocarpus cleistocarpus*; 2, *Lithocarpus litseifolius*; 3, *Quercus cocciferoides*; 4, *Quercus oxyphylla*; 5, *Quercus variabilis*; 6, *Quercus franchetii*; 7, *Cyclobalanopsis glauca*; 8, *Cyclobalanopsis chapensis*; 9, *Cyclobalanopsis gambleana*; 10, *Cyclobalanopsis phanera*; 11, *Castanopsis platyacantha*; 12, *Castanopsis hystrix*; 13, *Castanopsis fargesii;* 14, *Castanopsis sclerophylla*; 15, *Potentilla anserine*; 16, *Amorphophallus paeoniifolius*; 17, *Alisma plantago-aquatica*; 18, *Amorphophallus* sp.; 19, *Smilax glabra*; 20, *Amorphophallus konjac;* 21, *Sagittaria trifolia*; 22, *Fritillaria cirrhosa*; 23, *Lilium brownii*; 24, *Dioscorea* sp.(wild); 25, *Dioscorea* sp. (cultivated); 26, *Angiopteris yunnanensis*; 27, *Dioscorea alata*; 28, *Dioscorea polystarchya*; 29, *Dioscorea bulbifera*; 30, *Nelumbo nucifera* (roots); 31, *Schizocapsa plantaginea*; 32, *Arenga westerhoutii* (red); 33, *Arenga westerhoutii* (white); 34, *Caryota obtusa*; 35, *Cycas panzhihuaensis*; 36, *Cycas pectinata.*

Combined the size data and morphological features of all examined starch granules, some of them could be identified:

1) Spherical cap granules and combination shape of spherical cap and polyhedron granules with a centric hilum and invisible lamellae are probably from the same group, including *Alisma plantago-aquatica, Amorphophallus sp., Smilax glabra, Amorphophallus konjac, Cycas pectinata*, and *Cycas panzhihuaensis*. Although it is difficult to identify them at species or genus level, all these species are geophytes or cycad. At this group, the granule size helps to identify them further. The granules larger than 20 microns are more likely to be from *Cycas panzhihuaensis*.
2) The pestle-shaped granules are more likely to be from *Arenga westerhoutii* and *Caryota obtusa*, which have eccentric hilum and clear visible lamellae.
3) The wild yam (*Dioscorea* sp.), Chinese yam (*Dioscorea polystarchya*), and lotus roots (*Nelumbo nucifera*) have higher possibilities to produce elongate oval granules or triangular granules. And those granules have large size, visible lamellae, and eccentric hilum.
4) The bell-shaped granules, with centric hilum and invisible lamellae, are possibly from *Lithocarpus cleistocarpus* and *Cyclobalanopsis glauca*. What is different is that the granule size *Cyclobalanopsis glauca* is sightly larger than that of *Lithocarpus cleistocarpus.* And *Cyclobalanopsis glauca* produces more rough granules.
5) *Cyclobalanopsis gambleana*, *Castanopsis platyacantha*, and *Castanopsis hystrix* are inclined to have irregular polyhedron granules, with centric hilum and invisible lamellae.
6) The oval granules and drop-shaped granules have close relationships with *Quercus.* However, according to the observation, the oval shape is common in most samples. Thus, the drop-shaped granules should be the most identifiable features of *Quercus.*

6.3.2 Category level

Sometimes, it is not necessary to identify the ancient starch residues to a specific species or genus.Identifying the recovered granules to different plant categories also helpful for us to understand the ancient plant diet. Therefore, I summarized the data into four categories: acorns, geophytes, palm pith and cycad pith, and then input the data in to the software SPSS v. 25.0. The plot of discrimination measures (Figure 6.29) indicates that the variable ‘fissure type’ has a relatively low degree of discrimination, although it close to the second dimension. Therefore I deleted this variable and analyzed the data second time.

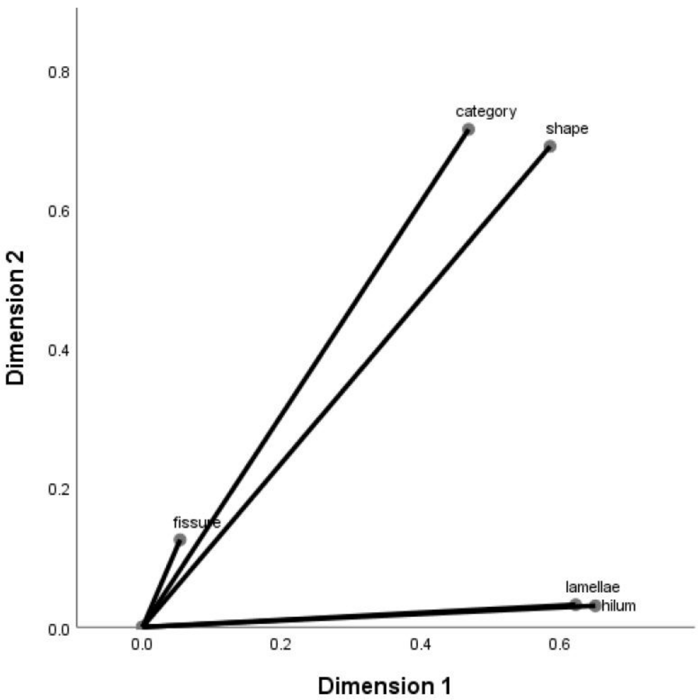

Figure 6. 29 Plot of discrimination measures of all the samples at category level

The model summary of the second analysis (Table 6.17) shows that the variance in the data is accounted for 58.8% by the first dimension and 38.5% by the second.

Table 6. 17 Model summary of multiple correspondence analysis of all samples at category level

		Variance Accounted For		
Dimension	**Cronbach's Alpha**	**Total (Eigen value)**	**Inertia**	**Percentage of variance**
1	0.776	2.351	0.588	58.794
2	0.468	1.542	0.385	38.543
Total		3.893	0.973	
Mean	.648[a]	1.947	0.481	48.668

a Mean Cronbach's Alpha is based on the mean Eigen value

The second plot of discrimination measures (Figure 6.30) indicates that the variables (lamellae visibility and hilum position) have close relationships with the first dimension. Therefore, the categories of these two variables are distinguished along the first dimension only. The granule shapes and plant species have relatively large values on both dimensions, indicating discrimination in both the first and second dimensions.

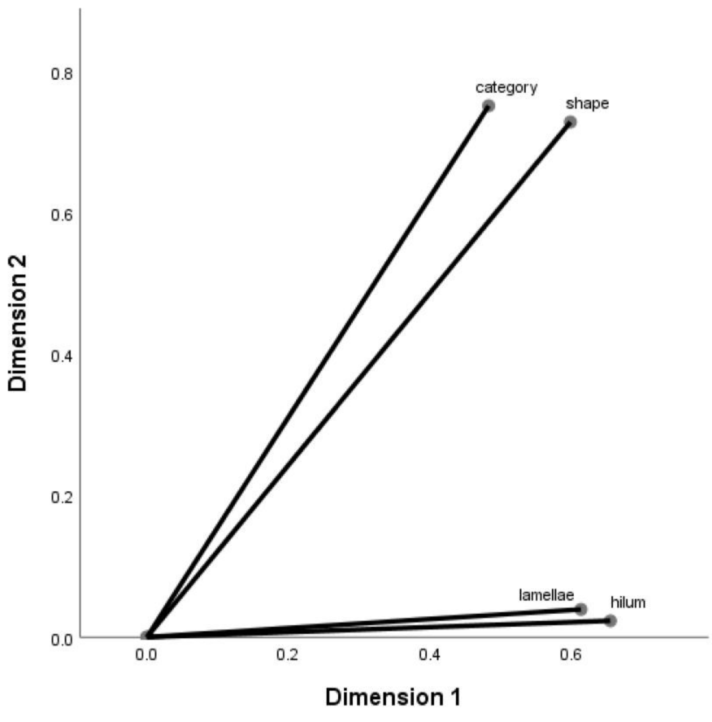

Figure 6. 30 Plot of discrimination measures of palm pith starch data, except the fissure type.

The result of multiple correspondence analysis shows that these four categories could almost be identified since the points representing these categories are located in the different quadrants. As the lamellae visibility and hilum position have large contributions to the first dimension, Figure 6.31 shows that the acorn and cycad pith have granules with centric hilum and invisible lamellae, while geophytes and palm pith are different.

In terms of granule shapes, the drop shape, irregular polyhedron, bell shape, sphere, and polyhedron locate in the first quadrant, alongside the point of the acorn. Combining to the observation, the drop-shaped granules, irregular polyhedron granules, bell-shaped granules could be identified further as *Quercus*, *Castanopsis*, and *Cyclobalanopsis* separately. The point of palm pith is in the second quadrant, around which the pestle-shaped granules, polygon granules, oval granules, and triangle granules are located. But the cycad pith is more likely to produce the spherical cap granules and combination shape of spherical cap and polyhedron granules.

The irregular shape granules, rounded triangular granules, and elongate granules have a higher proportion to appeared in the starch population of geophytes in the third quadrant. However, the situation of this plant category is complicated. Based on the analysis above, it cannot be ignored that there should be a group of small-size granules that also produce spherical cap granules and combination shape of spherical cap and polyhedron granules, like what cycad pith does. That is probably why this point is close to the fourth quadrant rather than to the lower-left corner.

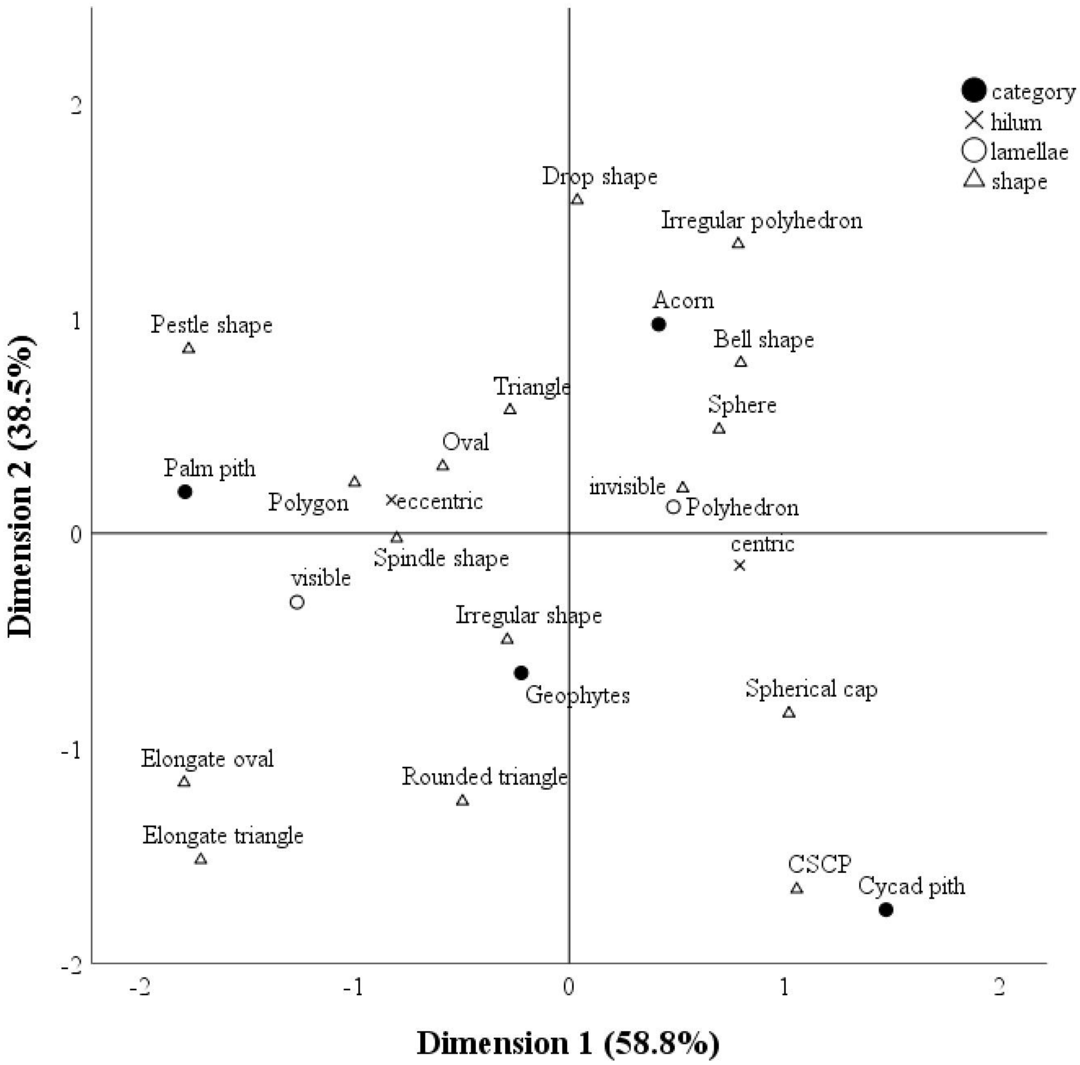

Figure 6. 31 Multiple correspondence analysis results of all the modern samples at category level

6.4 Starch identification of the whole database in this thesis

Based on all the above analyses, including observation, size data analyses, and multiple correspondence analyses of morphological features, some identifiable features of these examined starch grains were picked up. In this section, these features were summarized as follows.

1. The combination shape of spherical cap and polyhedron or spherical cap type granules are identified as geophytes or cycad, including *Alisma plantago-aquatica*, *Amorphophallus paeoniifolius*, *Amorphophallus* sp., *Smilax glabra*, *Schizocapsa plantaginea, Amorphophallus konjac, Cycas pectinate* and *Cycas panzhihuaensis.*

Most of them have smooth surface and centric hilum without hilum and visible lamellae. The size data help to distinguish them further:

1) If the granule size is between 20µm and 30µm, it is more inclined to be identified as konjac (*Amorphophallus konjac*), *Cycas panzhihuaensis* or possibly *Cycas pectinate*.

2) If the granule size is larger than 30µm, it should come from *Cycas panzhihuaensis*.

2. The drop shape granules are probably from *Quercus.* And the pit at the narrow end of a granule increases the credibility of the identification further.

3. Rounded triangle granules could be identified as *Fritillaria cirrhosa, Lilium brownii, Potentilla anserine* or *Sagittaria trifolia*

   1) Within these four species, *Potentilla anserine* has the smallest size;

   2) *Lilium brownii* has relatively larger size, and its granules often have clear visible lamellae which could be identifiable;

   3) Fissure-bearing helps to identify *Fritillaria cirrhosa.* These granules sometimes have diverse fissure types, like π-shape, Y-shape or V-shape fissures.

4. Irregular polyhedron granules smaller than 20µm could be identified as *Castanopsis*, especially *Castanopsis hystrix* and *Castanopsis fargesii.*

5. Bell-shaped granules with rough surfaces could be identified as *Cyclobalanopsis*.

6. Pestle shape granules tend to be identified as palm pith, including *Arenga westerhoutii* and *Caryota obtusa.* Within the three samples collected, the granule size of *Caryota obtusa* is smaller than *Arenga westerhoutii*.

7. The elongate oval or triangular granules, with clear visible lamellae and eccentric hilum, could be identified as yams or lotus roots.

8. The starch granules of *Angiopteris yunnanensis* has large size. Its maximum length could be up to 143.34µm, which is the largest granule observed in all the samples.

Chapter 7: Starch grain analysis of archaeological samples

Chapter 7 presents the results of the archaeological samples. The materials for analyses consist of a range of formal and informal stone tools (N=61) identified as implements primarily used for food processing (Table 1.2). The majority of the samples is grinding stones (N=40), consisting of top and bottom stones (handstones and netherstones) and pestles used in grinding and pounding activities. The remainders are pounders (N=21): the most difficult group to assign a type as these are informal cobble and pebble tools that have not been shaped in any way. Some of these tools were originally classified as tools used in stone tool manufacture and not as tools using to process plant foods. Justification for sample selection and the methods used to extract starch residues were presented in Chapter 5.

The discussion of the results is organised into two sections. The first section reviews the results of the starch analysis for each sample site, from 5,900 BP up to 3,000 BP, spanning 2,900 years of the Holocene. In each section, I present the key starch morphotypes recovered and then present a summary review of the entire site assemblage. In the final section, I compile these results to provide an analysis of diet and subsistence practices across the study region as a whole. These analyses form the basis for discussing the ancient plant exploitation strategies and their changes in the Pearl River Delta in the next two chapters.

7.1 Starch analysis by study site

Detailed descriptions of each site including site location and stratigraphy were given in Chapter 4, including discussions of the stone tools from each location. The methods of granule identification and the processes followed were presented in Chapter 6. In brief, each starch granule was assigned a group based on morphological similarities. Each group is initially assigned a letter from A to Z. Following this level of classification, further analysis of starch morphology is undertaken with the study reference material in order to determine the most likely match.

7.1.1 Guye site (c. 5,900-5,000 BP)

A total of 190 starch granules were recovered from grinding tools and unmodified pebbles (Table 7.1). These starch granules were organised into seven groups, except unidentifiable 59 granules.

Group A (Figure 7.1 Group A): Granules classified to this group have smooth surfaces and irregular polyhedron shapes. Their mean length is 17.15 ± 3.86 μm, and the size range is from 12.49 to 24.57 μm. Some granules have linear, Y-shaped, or transverse fissures. This group of starch grains may come from *Castanopsis* (D. Don) Spach. The closest match among this genera is *Castanopsis hystrix* J. D. Hooker & Thomson ex A. de Candolle.

Group B (Figure 7.1 Group B): This group contains drop-shaped grains which have a crater at their narrow end, with a mean length of 14.66 ± 3.19 μm, and their size range is from 9.69 μm to 19.86 μm. Most of them have smooth granule surfaces that are without fissures or lamellae. These are characteristic features of the genus *Quercus* Linnaeus.

Group C (Figure 7.2 Group C): The key features of this group are spherical shape, a centric hilum, and smooth surface. The mean length of this group is 13.21 ± 2.53 μm, which range is from 5.96 μm to 17.66 μm. Some of them have linear or Y-shaped fissures. The closest match with the reference collection is with *Lithocarpus* Blume.

Group D (Figure 7.2 Group D): The granules of this group are primarily bell-shaped or oval shaped. These granules have a mean length of 15.40 ± 2.75 μm and range in size from 8.54 μm to 19.19 μm. Characteristics of this group are rough granule surface and lacking fissures. The closest match with the reference material is with the genus *Cyclobalanopsis* (Oersted) C. K. Schneider.

Group E (Figure 7.3 a to d): Granule sizes range from 8.54 to 26.51 μm. Those 25 granules have morphological features similar to those from genera of Fagaceae, with some differences or damages. For example, the irregular polyhedron granules (Figure 7.3 a) with fissures seem to be identified as *Castanopsis* (D. Don) Spach, but the pits on its surfaces make this identification uncertain, as the *Castanopsis* granules are mostly smooth (Figure 7.3 d). There are also pitted bell-shaped granules without complete extinction cross, like Figure 7.3 b and c, which are probably from *Cyclobalanopsis* (Oersted) C. K. Schneider. Therefore, I group these granules as Fagaceae.

Group F (Figure 7.3 g and h): This group consists of large-sized granules, with a mean length of 40.47 ± 11.84 μm , ranging in size from 20.41 μm to 67.56 μm. These granules are primarily oval-shaped or kidney-shaped. Every granule has an eccentric hilum, and some of them bear linear, transverse, or longitudinal fissures. It is difficult to find good matches at the genus or species level, but overall, their size and shape is consistent with starches from geophytes (see Section 6.2.2).

Group G (Figure 7.3 e): This group is characterized by a granule with a rounded polyhedron shape with a linear fissure. This granule is 18.04 μm. It has a very distinctive form that matches with granules from the family of millets (e.g. Liu et al. 2014; Yang et al. 2012). Based on comparisons with my own reference material and online sources, it is closest to granules from foxtail millet (*Setaria italica*) or job's tear (*Coix lacryma-jobi*).

Group H (Figure 7.3 f). There is also a group of small granules that cannot be identified beyond the family level, but which are likely to derive from the grasses (Poaceae) (Yang et al. 2012).

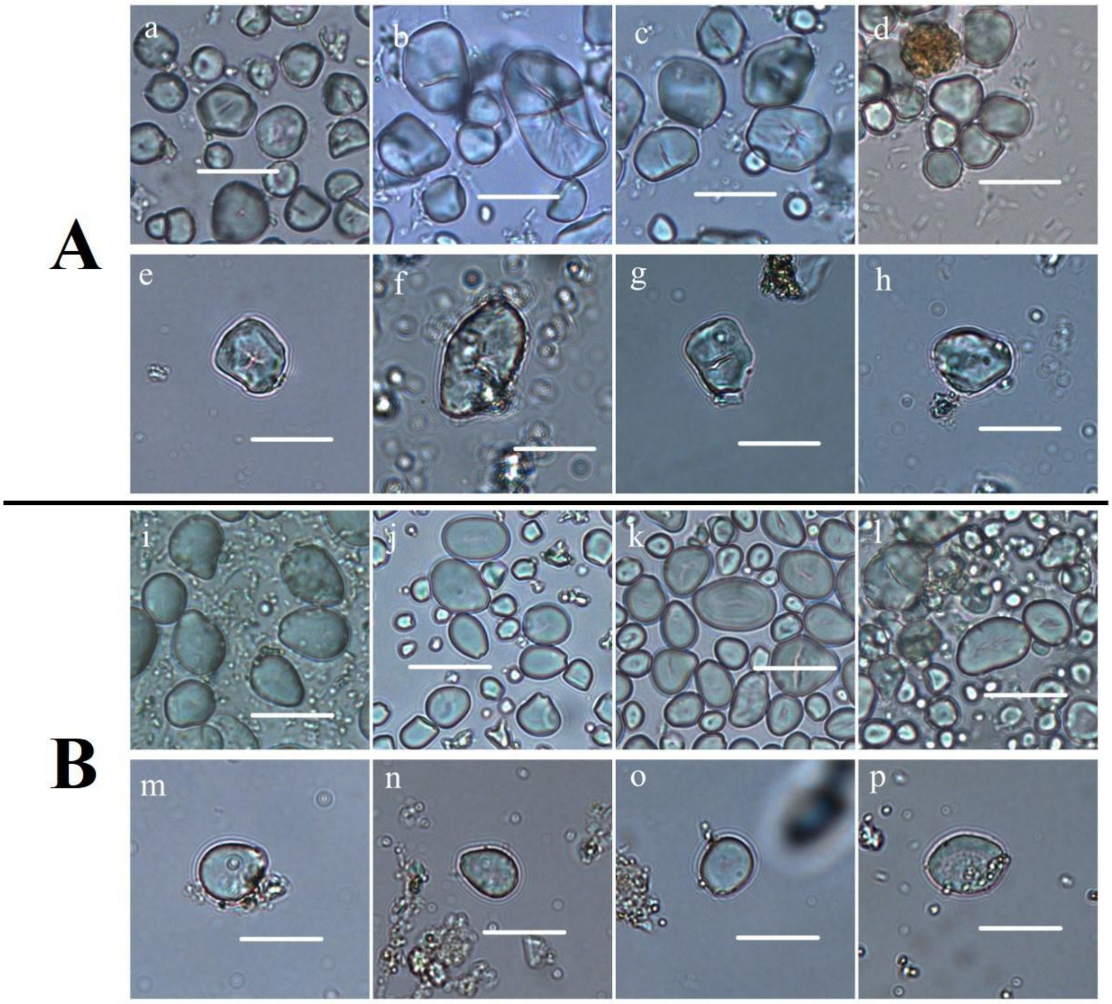

Figure 7. 1 Acorn starch grains from Guye site and modern references-part 1. Group A, starch grains from *Castanopsis*. a – d, modern references: a, *Castanopsis platyacantha*; b and c, *Castanopsis hystrix*, d, *Castanopsis fargesii*; e -h, ancient starch granules from *Castanopsis*. Group B, starch grains from *Quercus*. i – l, modern references: i, *Quercus cocciferoides*, j, *Quercus franchetii*, k, *Quercus variabilis*, l, *Quercus oxyphylla*; m – p, ancient starch granules from *Quercus*. Scale, 20 μm.

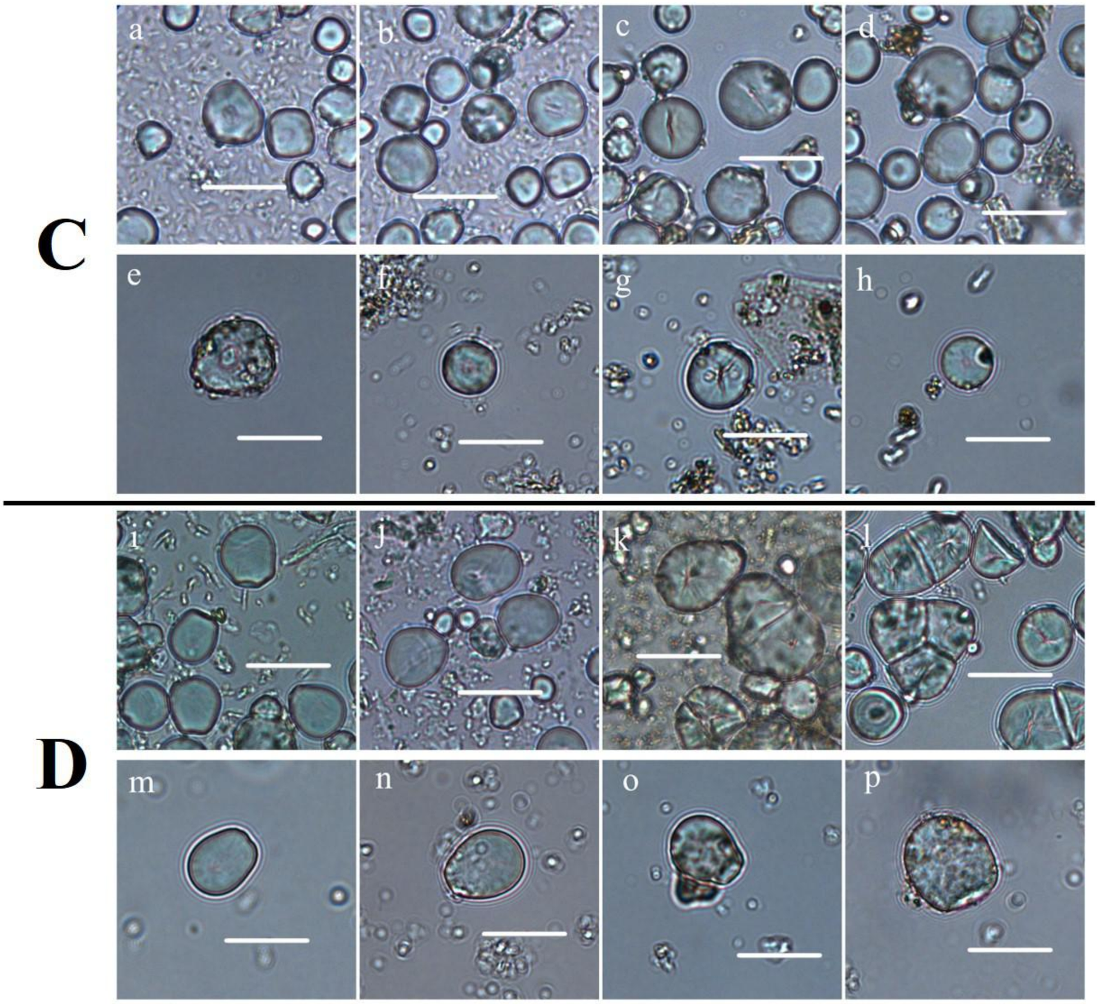

Figure 7. 2 Acorn starch grains from Guye site and modern references-part 2. Group C, starch grains from *Lithocarpus.* a – d, modern references: a and b, *Lithocarpus litseifolius*; c and d, *Lithocarpus cleistocarpus*; e -h, ancient starch granules from *Lithocarpus*. Group D, starch grains from *Cyclobalanopsis*. i – l, modern references: i, *Cyclobalanopsis chapensis*, j, *Cyclobalanopsis phanera*; k, *Cyclobalanopsis gambleana*, l, *Cyclobalanopsis glauca*; m – p, ancient starch granules from *Cyclobalanopsis*. Scale, 20 μm

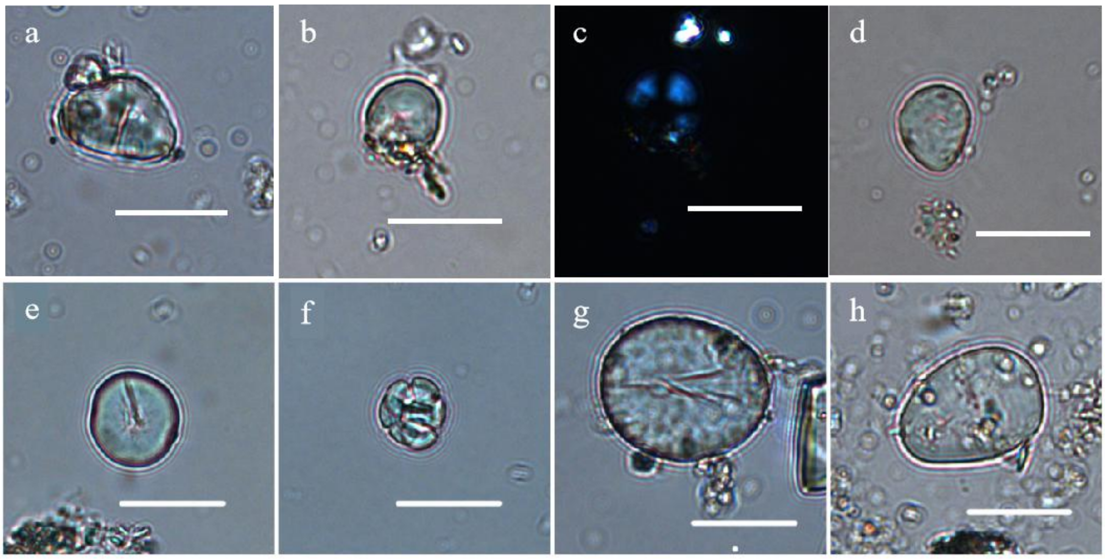

Figure 7. 3 Other ancient starch grains from Guye site. a-d, possible acorn granules; e, millet; f, Poaceae; g and h, roots or tubers. Scale, 20 μm

Table 7. 1 Identification of starch granules recovered from Guye tools.

Tool type	**Tool number**	**Fagaceae**	***Castanopsis***	***Cyclobalanopsis***	***Quercus***	***Lithocarpus***	**Poaceae**	**Millet**	**root and tuber**	**Unidentified**	**Total**
Netherstone fragment	TS10W09④: 38	0	3	0	0	0	0	0	1	4	8
Netherstone fragment	TN01W04⑤: 9	2	0	0	1	3	0	0	1	1	8
Netherstone fragment	TS02W04⑥: 1	5	2	5	0	6	0	0	2	4	24
Netherstone fragment	TS09W08⑥: 8	0	0	1	0	1	0	0	0	34	36
Netherstone fragment	TN01W04⑥: 14	12	10	1	4	5	0	1	6	8	47
Netherstone fragment	TS09W07⑥: 43	3	5	11	0	8	1	0	3	5	36
Handstone (complete)	TS09W06⑦: 69	1	0	4	2	1	0	0	0	1	9
Hammerstone	TS10W07④: 15	1	0	0	0	1	0	0	1	2	5
Hammerstone	TS09W07④东: 50	1	6	0	3	6	0	0	0	0	16
Hammerstone	TN01W04⑧: 32	0	0	0	0	0	0	0	1	0	1
	Totals	25	26	22	10	31	1	1	15	59	190

Guye starch results: diet and technology

The starch grains of acorns (including genera of *Castanopsis, Lithocarpus, Cyclobalanopsis,* and *Quercus*) are the largest group of all recovered starch morphotypes, accounting for nearly 60% of the total recovered starch. *Lithocarpus* and

Castanopsis are the leading genera recovered from samples of grinding tools and unmodified pebbles (pounding tools). However, the *Cyclobalanosis* starch grains were only recovered from ground stone tools, as were those of Poaceae. Geophyte starches accounted for 8% (N=15) of the total starch granules recovered from Guye site.

The dominance of acorn starch at this site shows that they were important food resources. The grinding and pounding tools where these starch granules were recovered in large number is also consistent with what has been recorded ethnographically (see Section 3.1.2). Assuming year-round processing and the seasonal availability of this resource, the storage methods of those nuts were necessary. No storage pit, like those discovered at Tianluoshan (Fuller and Qin 2010; Fuller et al. 2011), was discovered in the study region. However, there is another above-ground storage granaries, being practiced in communities dependent on acorns, which were first placing a circle of poles snugly in to the ground (Ortiz 1996). Some post holes unearthed at these sites may have this function.

The ecological restoration of Guye site (Figure 4.3) and the macro plant remains recovered (Table 7.2), support the identification of Fagaceae starch at this site. About 3,000 seeds and additional innumerable crushed nutshell fragments, primarily of acorn, were identified from 86 samples picked directly by hand from a total of 15 excavation trenches (Figure 7.2). These remains belong to at least 25 species from 21 families (Table 7.2). A large number of intact seeds of Chinese olive (*Canarium album*) (>1500), acorns (Fagaceae) (>1500), a member from genus *Premna* (>1000), and *Cordia dichotoma* (>700) were identified. The starch research recovered wider distribution of acorn species than the nutshells, including three new genera, *Quercus, Cyclobalanopsis* and *Castanopsis*. This is further supported by the pollen sequence obtained near this site (GY1) which reveals that during Guye occupation, forests were dominated by *Castanopsis*/*Lithocarpus* (Figure 2.4) (Peng et al. 2015).

Table 7. 2 Guye site results of identification for hand-picked macroplant samples

Family	Genus	Species	Count
Vitaceae		*Cayratia japonica*	1
Cucurbitaceae		*Lagenaria siceraria*	1
		Lagenaria siceraria var. *microcarpa*	5
		Trichosanthes kirilowii	6
		Actinostemma tenerum	1
Burseraceae		*Canarium album*	>1500
Fagaceae			innumerable†
	Lithocarpus sp.		innumerable
		Lithocarpus amygdalifolius	2
		Lithocarpus corneus	2
Boraginaceae		*Cordia dichotoma*	700
Verbenaceae	*Premna* sp.		1070
Elaeocarpaceae	*Elaeocarpus* sp.		294
		Eleaocarpus sylvestris	77
		Eleaocarpus apiculatus	4
		Elaeocarpus japonica	5
Theaceae		*Schima superba*	136
Poaceae		*Oryza sativa**	36
Menispermaceae		*Cocculus orbiculatus*	26
		Cocculus laurifolius	3
Santales		*Dendrotrophe frutescens*	46
Meliaceae		*Melia azedarach*	179
Annonaceae		*Artabotrys hexapetalus*	31
Symplocaceae	*Symplocos* sp.		21
Anacardiaceae		*Choerospondias axillaris*	106
Alangiaceae		*Alangium chinense*	27
Lauraceae	*Lindera* sp.		34
	Litsea sp.		7
		Cinnamomum camphora	1
Rutaceae	*Zanthoxyllum* sp.		36
		Zanthoxylum nitidum	1
Asteraceae		*Xanthium sibiricum*	1
Euphorbiaceae			1
		Claoxylon indicum	2
Myricaceae		*Myrica rubra*	1

*were measured by AMS ^{14}C and demonstrated them are modern contamination. † The nutshells of Fagaceae have huge number, therefore, they are not counted by the excavators.

Changes in the diet over time

In this analysis, I re-organised the starch data by excavation layers to discuss changes in plant resource use over time. The results are shown in Table 7.3 and Figure 7.4. The most important trend is the overwhelming majority of starch remains recovered from grinding stone fragments in Layer 6 of the site. This layer accounts for 75% of the site sample. Such an uneven result in starch counts is not unusual in starch studies due to the large number of variables that can influence starch preservation (see Barton 2007; Barton and Matthews 2006). However, the data should still be useful for making broad comparisons in terms of site function.

Table 7. 3 Starch grains analysis of each layer of Guye site

	Acorn	**Millets**	**Poaceae**	**Geophytes**	**Unidentified**	**Total**
Layer 4 (n=3)	21	0	0	2	6	29
Layer 5 (n=1)	6	0	0	1	1	8
Layer 6 (n=4)	79	1	1	11	51	143
Layer 7 (n=1)	8	0	0	0	1	9
Layer 8 (n=1)	0	0	0	1	0	1
Total	114	1	1	15	59	190

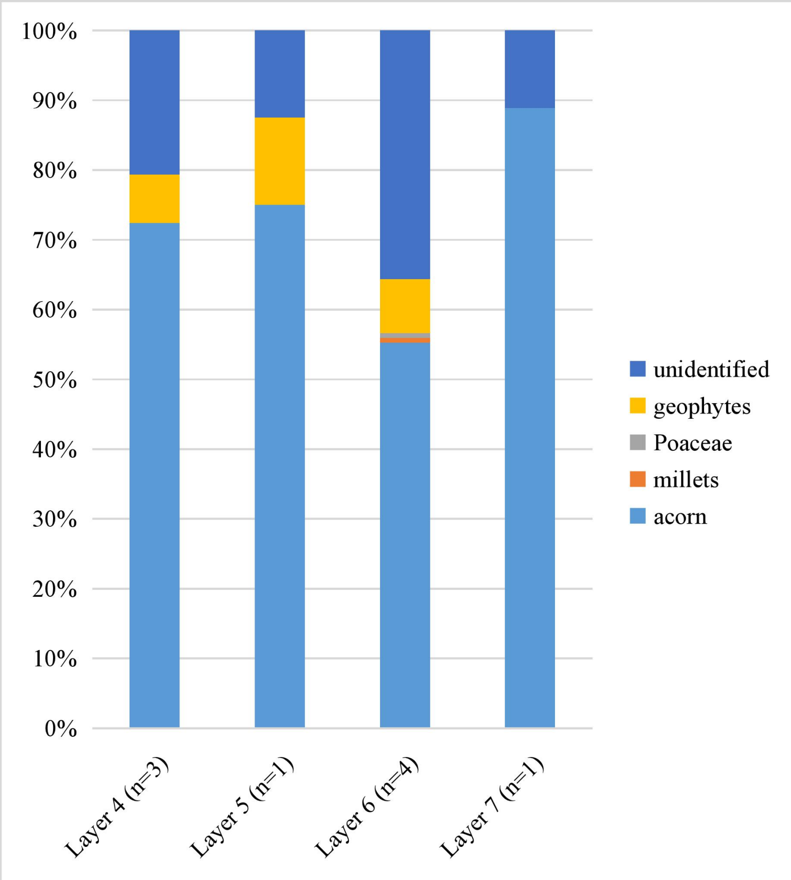

Figure 7. 4 Starch grains from each layer of Guye site. N count equals tool numbers sampled, total numbers of starch granules are shown in Table 7.2.

The proportions of geophyte starch grains are around 10% from layer 4 to layer 6. These low proportions indiccate that as a food resource, they may not have been as important as acorns. In thinking about tool function and starch recovery, it is important to understand that the ways in which foods were processed have a significant bearing on what ends up on pounding and grinding tools. Acorns need processing to remove tannins, as noted in Chapter 3, and a variety of stone tools have been used for this purpose. Many root crops do not require processing to render them edible but may be processed to help remove minor toxins, and for culinary reasons, such as to remove the fibrous portion (e.g. Bradbury et al. 1988; Ding 2007; Wang and Long1995).

Figure 7.5 reflects the changes in these four identifiable genera of Fagaceae. In the combination of acorns, it is noteworthy firstly that *Lithocarpus* and *Quercus* are always included in the acorn assemblage, which were probably stable acorn sources, and except in layer 7 (only one tool was sampled, and 8 granules were recovered), the proportion of *Lithocarpus* granules is higher than that of *Quercus*, indicating its distinct importance in Guye community. Another evident change occurred in *Cyclobalanopsis*, which declined rapidly from 44% in layer 7 to 13% in layer 6, and then disappeared in layers 5 and layer 4.

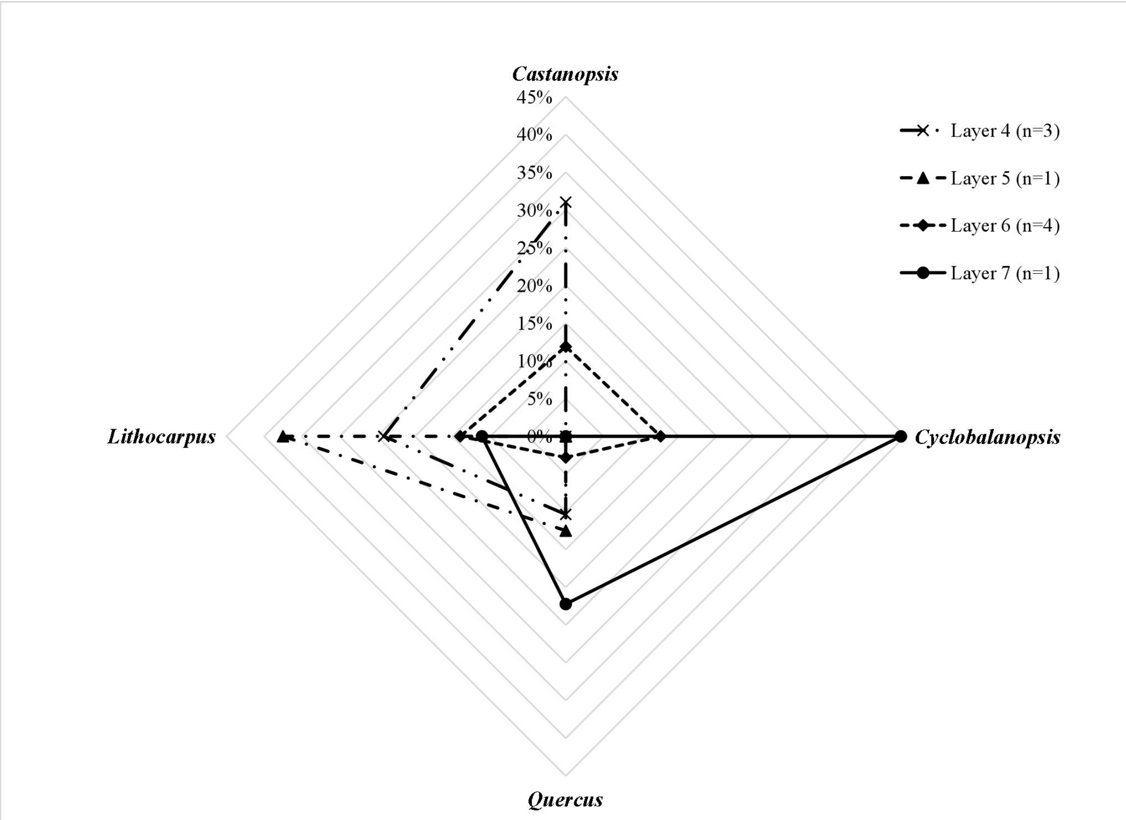

Figure 7. 5 Proportional changes of acorn starch granules of layers at Guye site. Data shows in Table 7.4

Table 7. 4 Number of acorn starch grains in layers at Guye site

	Castanopsis	*Cyclobalanopsis*	*Quercus*	*Lithocarpus*	**Total**
Layer 4 (n=3)	9	0	3	7	21
Layer 5 (n=1)	0	0	1	3	6
Layer 6 (n=4)	17	18	4	20	79
Layer 7 (n=1)	0	4	2	1	8
Layer 8 (n=1)	0	0	0	0	0
Totals	26	22	10	31	114

7.1.2 Yinzhou site (c. 4,500 BP)

The number of starch granules found from Yinzhou site is 25, including six unidentified granules (Table 7.5). The other 19 granules were classified into seven groups as follows.

Group A (Figure 7.6 a). This group includes three starch granules, which have irregular polyhedron shapes, which is the most identifiable features of *Castanopsis*. Their sizes are 15.76 μm, 15.83 μm, and 17.94 μm, separately, matching the length range of *Castanopsis* as well. Therefore, these three starch granules were identified as *Castanopsis* (D. Don) Spach (see Section 6.2.1).

Group B (Figure 7.6 b). Only one drop-shape granules was found at this site, which has smooth surface. In addition, the maximum length of this granule is 14.74 μm. All these features consistent with those of *Quercus* Linnaeus (see Section 6.2.1).

Group D (Figure 7.6 c). The two oval starch grains with rough surfaces were identified in this group. They are 18.75 μm and 20.38 μm respectively. They both have eccentric hilum without lamellae and fissures. This group was identified as *Cyclobalanopsis* (Oersted) C. K. Schneider based on the previous analysis of modern reference collection (see Section 6.2.1).

Group F (Figure 7.6 d and e). There are five granules which sizes are between 40 μm and 99.11 μm. They have rounded triangle shape, spindle shape, oval shapes (Figure 7.7 f) or irregular shape (Figure 7.7 g), with smooth surfaces and lamellae. It was difficult to identified them at genus, but, at least, they were identified as geophytes at present, based on the modern reference samples (see section 6.2.2).

Group G (Figure 7.6 f). Only one sub-round polyhedron granule was recovered as this group, which has linear fissure and centric hilum. These features are close to the millet granules (Liu et al. 2014; Yang et al. 2012). The length of this grain is 24.96 μm, may be inclined to be identified as job's tear (Liu et al. 2014).

Group I (Figure 7.6 g). Five granules fall into this group, which sizes range from 23.03 μm to 85.08 μm. They have different shapes, including elongate triangle shape, irregular shape, and oval shape, corresponding to the shape features of *Dioscorea* Linnaeus (see

Section 6.2.2). And their commonalities, including eccentric hilum, visible lamellae, and no fissures, are also useful for them to be identified as *Dioscorea*.

Group J (Figure 7.6 h). The only combination shape of spherical cap and polyhedron shape granule was picked out for one category, which length is 20.77 µm. This granule bears no fissure and visible lamellae. Its features and size allow a conservative identification as cycad or geophytes (Figure 6.28).

Table 7. 5 Identification of starch grains recovered from Yinzhou tools

Type	Tool number	*Cyclobalanopsis*	*Castanopsis*	*Quercus*	Millets	*Dioscorea*	Geophytes	Cycad or geophytes	Unidentified	Total
Netherstone	93SDTW5S1④	0	2	0	0	1	0	1	0	4
Netherstone	93SD Pond II	1	0	0	0	1	1	0	3	6
Netherstone	93SDT03②	0	0	0	0	1	3	0	0	4
Netherstone	92SDTE3N1 M53	1	1	1	1	1	1	0	4	10
Netherstone	92SDE8N1 d7	0	0	0	0	1	0	0	0	1
	Total	2	3	1	1	5	5	1	7	25

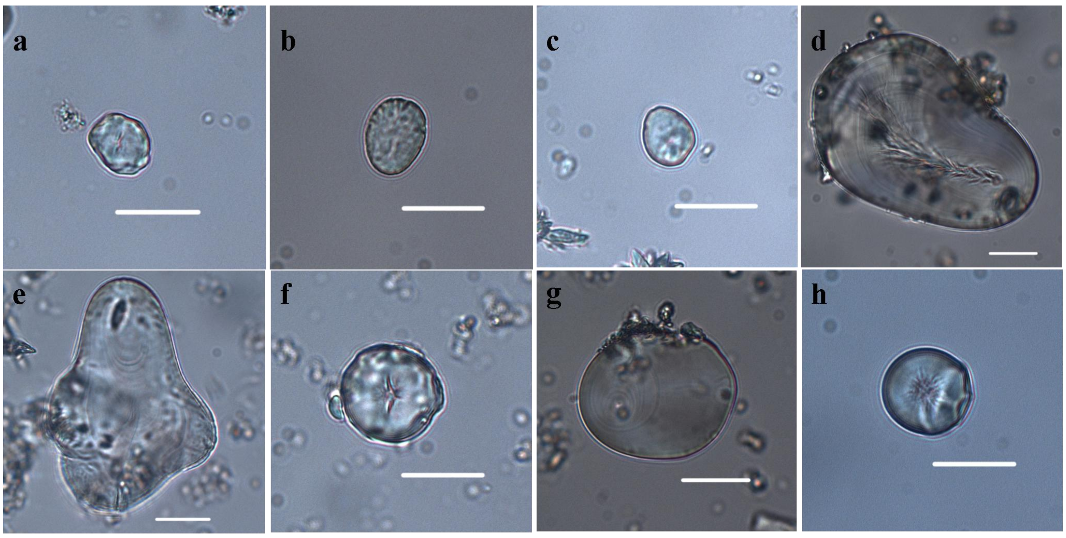

Figure 7. 6 Starch grains recovered from Yinzhou site. a, group A identified as *Castanopsis*; b,group B identified as *Quercus*; c, group C identified as *Cyclobalanopsis*; d and e, group F identified as geophytes; f, group G identified as millets; g, group I: identified as *Dioscorea*; h, group J, identified as geophytes or cycad. Scale, 20µm.

Neolithic diet at Yinzhou site

The layer 2 of T03 is a Ming Dynasty layer, so the results of nether stone unearthed from this layer was excluded in the following analysis, including four geophyte granules. The other 21 granules were recovered from four Neolithic netherstones, and the respective proportions of each group of plant are shown in the figure below (Figure 7.7). Overall, the starch plant diet at Yuanzhou community included acorns (29%) and geophytes (33%) mainly. Unlike the results of Guye site, however, the proportion of geophytes (inc. *Dioscorea* spp.) exceeded that of acorns.

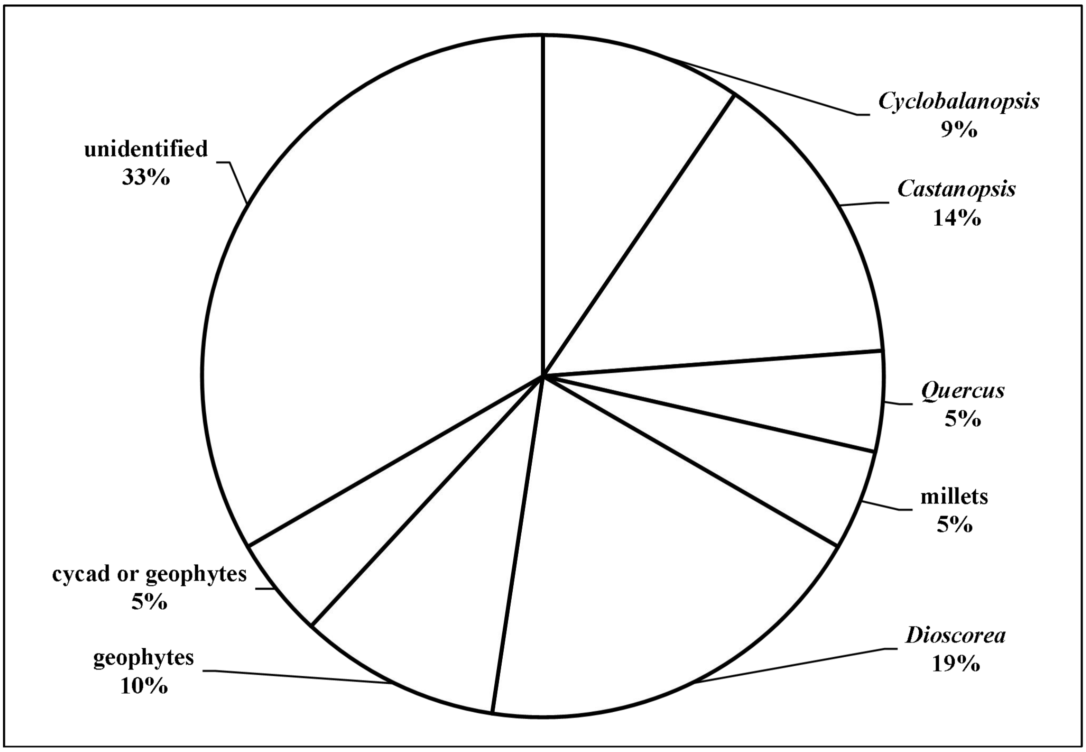

Figure 7. 7 Proportion of each kind of starch granules recovered from Yinzhou site. Data are in Table 7.5.

Within the acorn group, *Castanopsis* is the dominant genus, followed by *Cyclobalanopsis*, while *Quercus* is the one in the least quantity. Compared with Guye results, the geophyte group included more plants. Besides *Dioscorea* (yam) granules, there is also a granule with a combination shape of spherical cap and polyhedron, which is close to a different group of geophytes (see Section 6.2.2), suggesting the progressive understanding of geophyte plants in the late Neolithic period. However, it cannot be ruled out the cycad pith was included in the diet of Yinzhou communities, as the starch grain with a combination shape of spherical cap and polyhedron recovered at this site may also be identified as *Cycas* spp.

7.1.3 Hengling site (c. 4,000BP)

A total of 80 starch granules, including 26 unidentifiable ones, were found from samples of Hengling sites (Table 7.6). 52 of them were from formal stone tools, such as pestles, hammers, handstones, and netherstones, while others were from informal groups (others). These granules are classified into six groups as follows.

Group A (Figure 7.8 a to c). The irregular polyhedron granules were classified into this group, including 24 individuals. The size range of those granules is from 9.29 μm to 28.23 μm, and only few of them are larger than 20 μm. All these granules have smooth surfaces without any lamellae, but several of them bear fissures. Both the morphological features and size data indicated that these 24 granules were identified as *Castanopsis* (D. Don) Spach (see Section 6.2.1).

Group C (Figure 7.8 d). Three starch granules which have spherical shape with linear fissures were classified in this group. Their sizes are 10.87 μm, 10.99 μm, and 11.04 μm respectively. All these starch granules have smooth surfaces without any visible lamellae, which make these granules identified as *Lithocarpus* Blume (see Section 6.2.1).

Group F (Figure 7.8 e). Three oval granules, without visible lamellae, were classified into this group, which sizes are 21.22 μm, 26.36 μm, and 42.67 μm, separately. These granules seem to be produced by some geophytes plants, but it is difficult to confirm their genera (Wang et al. 2018).

Group G (Figure 7.8 f). Four smooth polyhedron granules with centric hilum were categorized into the same group. Their sizes are from 16.77 μm to 20.42 μm. Based on the published materials, these granules were identified as millets (Yang et al. 2012).

Group H (Figure 7.8 g). Two compound group granules were recovered. Each of them contains five small size granules. It is difficult to identify their species, but this kind of starch granules have a higher possibility to be produced by some grass seeds (Yang et al. 2012).

Group J (Figure 7.8 h). 18 granules, which have spherical cap shape or a combination shape shape of shperical cap and polyhedron, were recovered. Based on their unique shape features, those granules were identifiable as some geophytes or cycad (Figure 6.28). The sizes of all these granules are around 10 µm. According to their size data, these granules are more likely from geophytes, although the possibility of *Cycas pectinata* cannot be excluded.

Table 7. 6 Identification of starch grains recovered from Hengling site.

Type	**Tool number**	***Lithocarpus***	***Castanopsis***	**Millets**	**Geophytes**	**Cycad or geophytes**	**Grass**	**Unidentified**	**Total**
Handstone	2013CHT1726③	0	0	0	0	5	0	3	8
Netherstone	2013CHT1624③b	1	0	0	0	1	1	2	5
Pestle	2013CHT1937③	0	0	1	0	2	0	7	10
Stone hammer	2013CHT2436 北隔梁③	0	2	2	0	4	0	3	11
Handstone	2013CHT1826④	0	6	0	0	0	0	1	7
Handstone	2013CHT2245 东隔梁④	0	1	0	2	0	0	0	3
Netherstone	2013CHT2038④	0	2	0	0	0	0	0	2
Stone ball	2013CHT1826⑤	0	2	0	0	2	0	2	6
	Total	1	13	3	2	14	1	18	52
Others	2013CHT1725③	1	0	1	0	1	0	1	4
Others	2013CHT2244③：2	1	5	0	0	0	0	3	9
Others	2013CHT1725④	0	0	0	0	0	1	1	2
Others	2013CHT1926⑤-1	0	3	0	1	1	0	2	7
Others	2013CHT1926⑤-2	0	3	0	0	2	0	1	6
	Total	2	11	1	1	4	1	8	28
Total		3	24	4	3	18	2	26	80

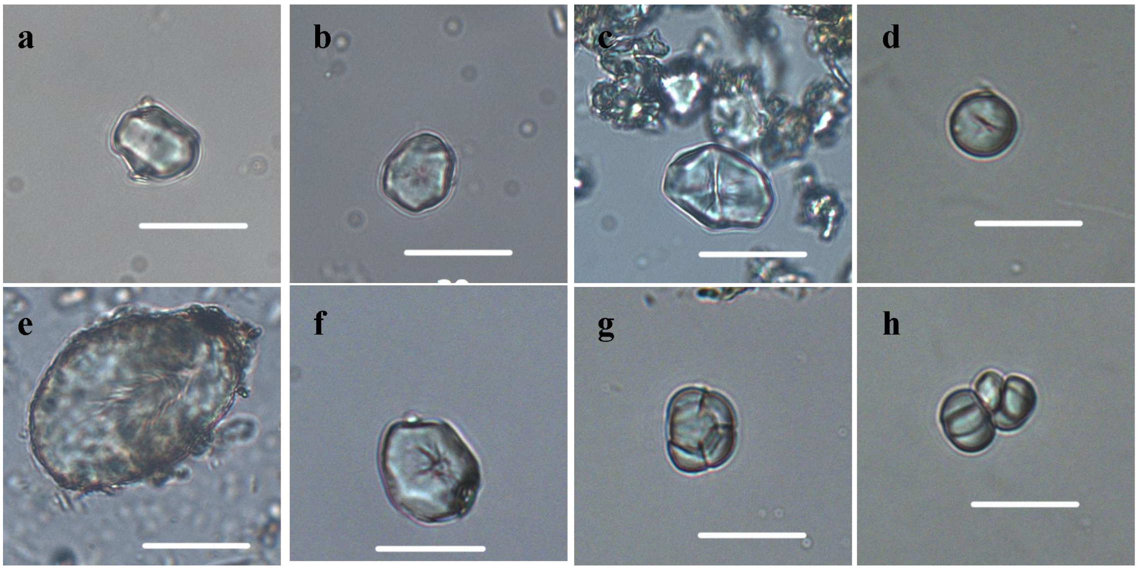

Figure 7. 8 Starch grains recovered from Hengling site. a-c, Group A identified as *Castanopsis*; d, group C identified as *Lithocarpus*; e, group F identified as geophytes; f, group G identified as millets; g, group H identified as grass; h, group J identified as geophytes or cycad. Scale, 20μm.

Diet changes at Hengling site over time

In this analysis, I re-organised the starch data by periods to discuss changes in plant resource use over time (Table 7.7). As reviewed in Section 4.1.3, layer 3 of this site belongs to the Early Shang Dynasty (c. 3,600-3,300 BP) and layer 4 and 5 belong to the Late Neolithic period (around 4,000 BP). Based on this sequence, the starch grains were sorted (Figure 7.9). The result shows that besides the similar percentage of grass starch grains, the proportion of acorns declined, together with the increase of geophytes and the emergence of millet (Figure 7.9).

The acorn composition of Hengling site was relatively simpler, containing only two identifiable genera. During the late Neolithic period, the acorn starch grains accounted for 52% of the total, revealing the importance of acorn in the indigenous carbohydrate assemblage during that time. In addition, during this period, only *Castanopsis* starch grains were identified. Then, in the Early Shang period (c. 3,600-3,300 BP), the overall proportion of acorn decreased from 52% to 21%, and *Lithocarpus* were added in the acorn combination at the same time, accounting for 6% of the total.

Table 7. 7 Starch grain categories in each period of Hengling site

	Lithocarpus	Castanopsis	Millets	Geophytes	Cycad or geophytes	Grass	Unidentified	Total
Early Shang Period (3,600 – 3,300 BP)	3	7	4	0	13	1	19	47
Late Neolithic Period (around 4,000 BP)	0	17	0	2	5	1	8	33

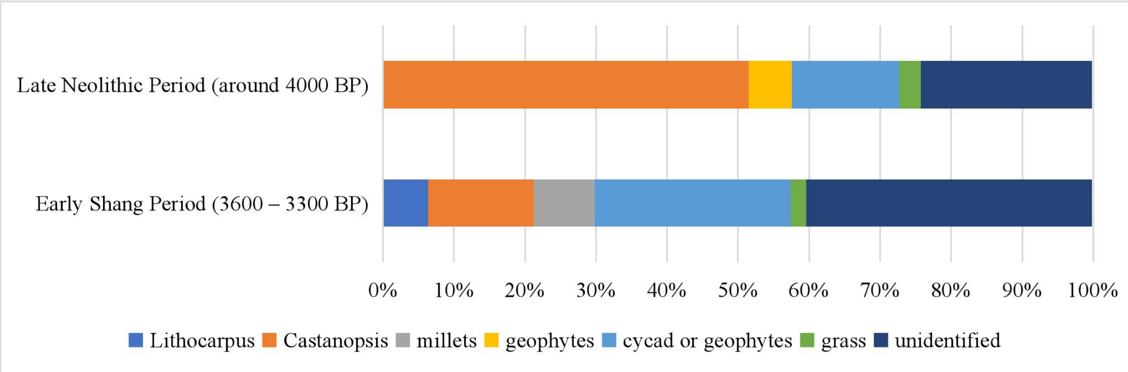

Figure 7. 9 Proportion of starch grain categories during each period of Hengling site

The starch grains of geophytes, another significant source of carbohydrates, presented an increasing trend. In the late Neolithic period, this group possibly included two types, making up 21% of the total. But, in the early Shang Dynasty (c. 3,600-3,300 BP), one category which was identified geophytes disappeared, with the increase of the other group identified as geophytes/cycads, accounting for 28% of the total. And these geophytes became the first carbohydrate source, higher than that of acorns (21%).

In the early Shang Dynasty (c. 3,600-3,300 BP), the millets emerged in the carbohydrate set at this site, taking up 9% of the total. At the same time, the proportion of unidentified starch grains exceed 40% of the total, which may suggest that the consumed starch plant assemblage became more diverse.

Comparison between formal and informal tools

The starch residues recovered from all formal and informal stone tools reveal their similar types of identifiable starch grains (Table 7.6), including acorns, millets, geophytes, geophyte/cycad, and grass seeds. This reflects the universal use of those stone tools for plant food processing, that is, both formal stone tools and natural pebbles were used for similar plant processing tasks. Therefore, some natural pebbles unearthed at archaeological sites were used as plant processing tools and this should not be ignored in future research.

However, the count and proportion of each category reveal some differences (Figure 7.10). The first difference is the proportion of acorn starch residues. Although the numbers of acorn starch grains recovered from informal pounding tools (N=13) and formal stone tools (N=14) are similar, the proportion of those recovered from informal tools (46%) is 1.7 times higher than that of formal ones (27%). Besides, in terms of the same number of grass seed residues, its proportion recovered from formal stone tools is half of that from others. However, both the count and proportion of the starch granules, identified as millet, geophyte, and geophyte/cycad, recovered from formal stone tools are higher than those from informal pounding tools. These differences suggest that the informal pounding tools were more likely to be selected for acorn processing rather than for millets and some geophytes or cycad processing, which tend to be processed by formal shaped tools.

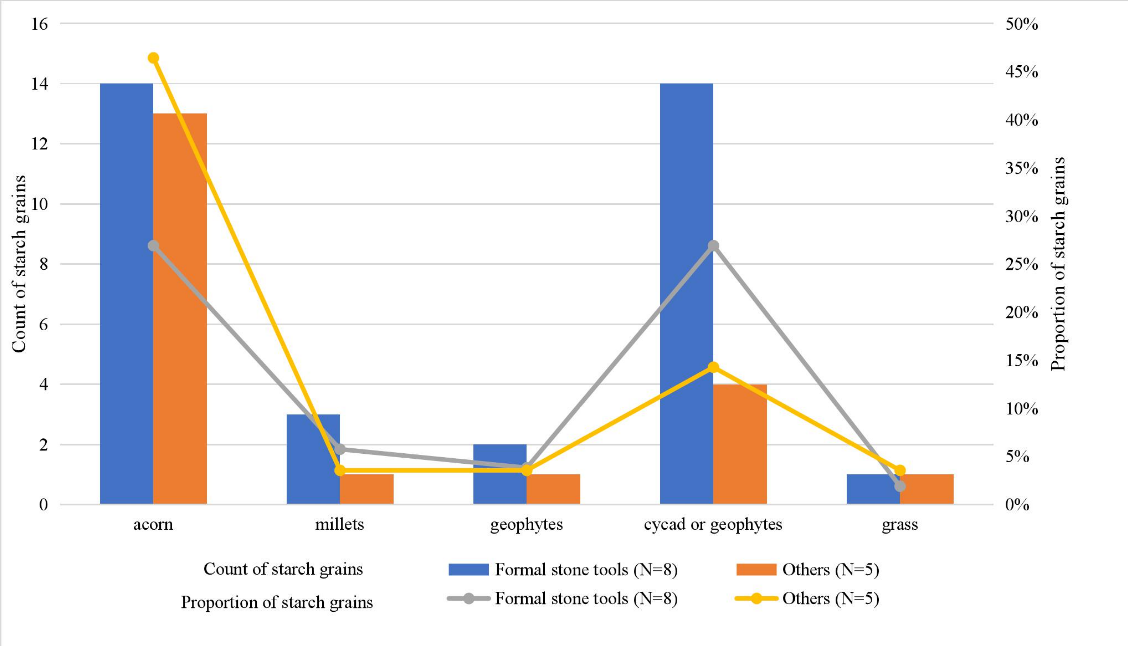

Figure 7. 10 Count and proportion comparison of starch grains recovered from stone tools and natural pebbles at Hengling site

7.1.4 Haogang site (6,000-4,000 BP)

From 14 tools unearthed at Haogang site, 252 starch granules were recovered in total (Table 7.8). Within them, 113 starch granules were found from one netherstone (03DHT0306⑤: 34 北扩). All the starch granules were classified into 11 groups, except 82 unidentified individuals.

Group A (Figure 7.11 a). This group is most numerous, including 51 granules, which length range is from 10.74 μm to 23.24 μm. The irregular polyhedron shapes with invisible lamellae make them identifiable. According to section 6.2.1, such granules were identified as *Castanopsis* (D. Don) Spach.

Group B (Figure 7.11 b). Nine granules which formed drop shapes were classified into this group. Those granules have smooth surfaces without visible lamellae. And their size is from 8.84 μm to 20.94 μm, according to the modern references in this thesis (see Section 6.2.1), those granules were identified as *Quercus* Linnaeus.

Group C (Figure 7.11 c). Six spherical granules were categorized into this group. They mainly have smooth surface and centric hilum, but none of them bears visible lamellae and fissure. Their lengths are from 9.1 μm to 17.88 μm. Compared with the description in Section 6.2.1, both size and morphological features of these granules suggest that these six granules come from *Lithocarpus* Blume.

Group D (Figure 7.11 d). This group contains 28 single granules. 26 of them are smaller than 20 μm, and the sizes of other two granules are 20.15 μm and 25.83 μm separately. The most identifiable features include bell shape, rough surface, and invisible lamellae. These granules were identified as *Cyclobalanopsis* (Oersted) C. K. Schneider.

Group F (Figure 7.11 e). This group contains 28 granules, including oval shape, rounded triangular granules and irregular shape granules. The lengths of these granules widely distribute from 27.27 μm to 96.76 μm. It is difficult to identify those granules as a specific genus. But the large sizes and shape features suggest that they are more like to come from some geophytes.

Group G (Figure 7.11 f). A total of 13 granules were categorized into this group, which size range is from 10.53 μm to 19.73 μm. All of them are polyhedron granules with centric hilum, fissures, and invisible lamellae. Based on the previous studies, these granules were identified as millet (Yang et al. 2012).

Group I (Figure 7.11 g). Ten granules belong to this group, with wide size range which is from 19.55 μm to 50.42 μm. They have oval shapes or rounded triangular shapes, with smooth surface and eccentric hilum. Most of them have visible lamellae. This group is identified as *Dioscorea* Linnaeus (see Section 6.2.2 and Hang et al. 2006).

Group J (Figure 7.11 h). The spherical cap granules and combination shape of spherical cap and polyhedron granules were divided into this group, which capacity is 24. Most of them do not bear lamellae and fissures. Except for one 24.52 μm granules, the size range of this group is from 11.49 μm to 19.71 μm. According to the description of modern reference (see Section 6.2.2 and 6.2.3), this group should come from some underground storage organs of geophytes or cycad. Further, that 24.52 μm granules are more likely to be identified as *Cycas*.

Group K. There is one oval starch granule, 18.3 μm, different from others. This granule bears clear longitudinal fissure without visible lamellae. And the shape of its extinction cross is special as well, which looks like >--<. All these features are similar to granules from edible legumes as described by Wang et al. (2013).

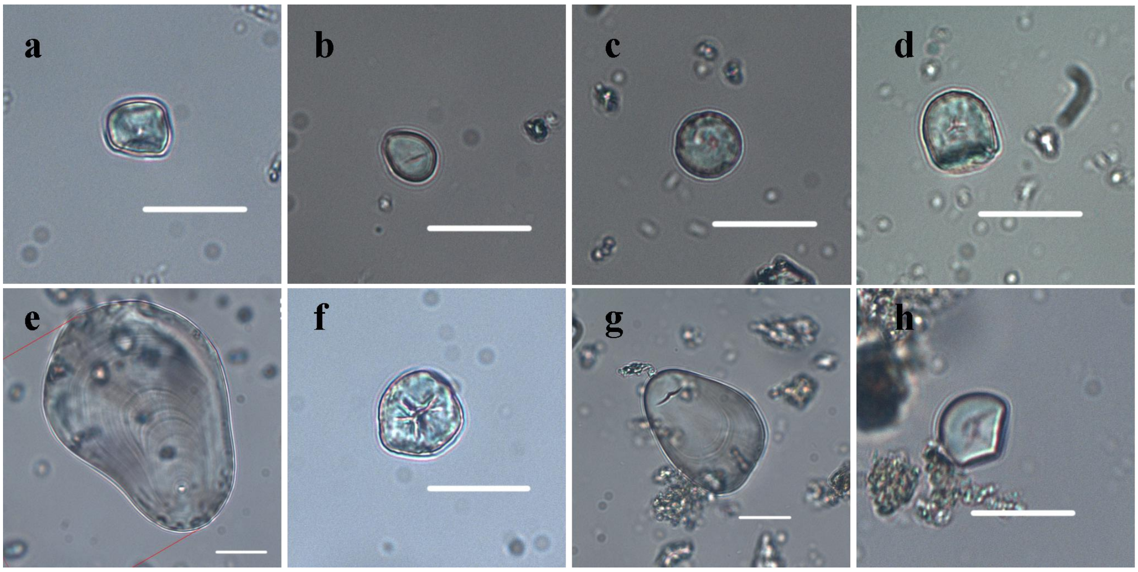

Figure 7. 11 Starch grains recovered from Haogang site. a, group A, identified as *Castanopsis*; b, group B, identified as *Quercus*; c, group C identified as *Lithocarpus*; d, group D identified as *Cyclobalanopsis*; e, group F identified as geophytes; f, group G identified as millets; g, group I identified as *Dioscorea*; h, group J identified as geophytes or cycad. Scale, 20μm

Table 7. 8 Identification of starch granules recovered from Haogang site

Type	Tool number	*Lithocarpus*	*Cyclobalanopsis*	*Castanopsis*	*Quercus*	Millets	*Dioscorea*	Geophytes	Geophytes or cycad	Food legumes	Unidentified	Total
Handstone	T0305 ⑤:35 北扩	0	0	4	1	0	1	1	1	0	4	13
Handstone	03DHT0407⑤：28	1	4	2	0	0	0	4	7	0	7	25
Handstone	T0306⑤：36	0	0	0	0	0	2	3	1	1	5	12
Handstone	03DHT0405②：2	0	0	1	1	0	2	5	2	0	7	18
Pestle/handstone	03DH H6	0	4	1	1	0	0	0	1	0	3	10
Netherstone	03DHT0306⑤：34 北扩	3	13	36	2	12	0	10	9	0	28	113
Netherstone	03DHT0306⑤：193	0	3	1	1	0	0	0	0	0	3	8
Netherstone	03DHT030⑥：168	0	0	0	0	0	0	0	0	0	2	2
Stone hammer	layer 2	0	1	0	0	0	0	1	0	0	1	3
Stone hammer	layer 2	0	0	0	1	0	0	1	0	0	1	3
Stone hammer	03DHT0406②：13	0	2	3	0	0	2	2	0	0	10	19
Stone hammer	03DHT0304②：2	2	0	1	2	0	3	0	3	0	3	14
Stone hammer	03DH H9：1	0	0	2	0	0	0	2	0	0	3	6
Stone hammer	layer 4	0	1	0	0	1	0	0	0	0	5	7
	Total	6	28	51	9	13	10	28	24	1	82	252

Temporal changes in starch foodstuffs at Haogang site

In this part, I summarised the starch database on the phase of Haogang site (Table 7.9), to explore the changes in starch foodstuffs at this site. According to previous introduction in Section 4.1.3, the layer 2 to layer 4 of Haogang site belongs to its third phase (4,500-4,000 BP), and the layer 5 and layer 6 are the second (5,500-5,000 BP). Besides, two sampled tools which are unearthed from pits are summarised separately (Figure 7.12).

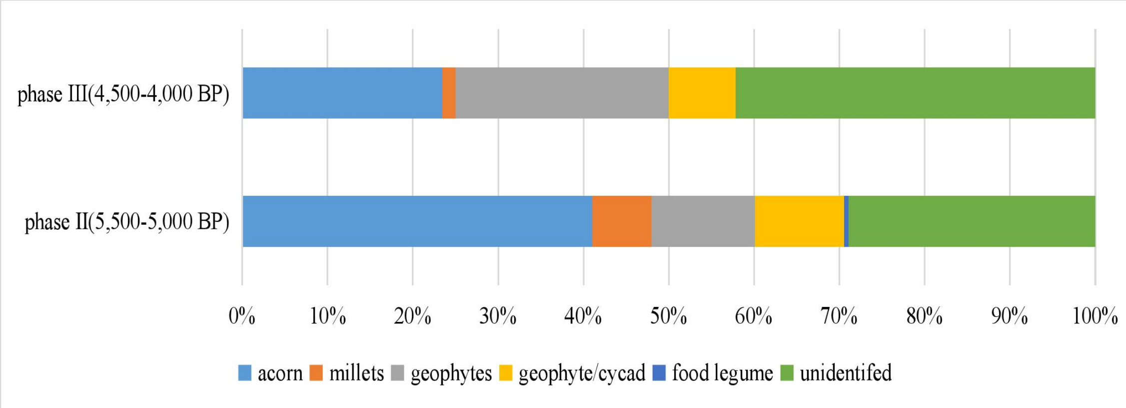

Figure 7. 12 Proportion of starch grain categories in different phase of Haogang site. Data are shown in Table 7.9

Table 7. 9 Starch grains in different phases of Haogang site

	Lithocarpus	***Cyclobalanopsis***	***Castanopsis***	***Quercus***	**Millets**	***Dioscorea***	**Geophytes**	**Geophytes or cycad**	**Food legumes**	**Unidentified**	**Total**
Phase II (5,500-5,000 BP)	4	20	43	4	12	3	18	18	1	50	173
Phase III (4,500-4,000 BP)	2	4	5	4	1	7	9	5	0	27	64
Pits	0	4	3	1	0	0	1	1	0	6	16

The number of starch grains in the second phase (5,500 to 5,000 BP) is 1.5 times larger than that in the third phase (4,500 to 4,000 BP) (Table 7.9). And between 5,500 BP and 5,000 BP, the identifiable types of carbohydrates seem to be a little more complex, including acorns, geophytes, geophyte/cycad pith, millets, and food legumes. Overall, in the late period (4,500 to 4,000 BP), the millet and acorn granules decreased evidently, together with the proportional increase of geophytes.

In the case of the decline of acorns over time, from 41% to 23%, Figure 7.13 reflect specific changes in different acorn genera. In the second phase (5,500 to 5,000 BP), *Castanopsis* is the dominant genus, accounting for 25% of the total, followed by *Cyclobalanopsis*, 12%. And *Lithocarpus* and *Quercus* are minority groups, which are only 2% of the total. In the later period, between 4,500 and 4,000 BP, the most apparent decrease occurred in the genus *Castanopsis*, decreasing from 25% to 8%, while the proportion of *Cyclobalanopsis* reduced by half. Conversely, *Lithocarpus* and *Quercus* increased slightly.

Changes shown in Figure 7.13 indicate that the decline of acorn consumption at Haogang site (Figure 7.12) may be heavily related to the decrease of *Castanopsis*. The reason for this obvious change in *Castanopsis* is probably related to the forest evolution. The pollen records revealed that the oak forest experienced a fluctuated declining period after around 4,500 BP (e.g. Figure 2.4) (e.g. Ma et al. 2018; Peng et al. 2015; Wang et al. 2009). This decline may have greatly affected the availability of acorns, and further influenced the acorn consumption. Meanwhile, in the case of insufficient acorn/oak-chestnut supply, the increasing of geophyte starch granules, from 23% in the second phase to 33% in the third phase (Figure 7.12) suggested that they were possible substitutes to fill the shortage of oak-chestnuts.

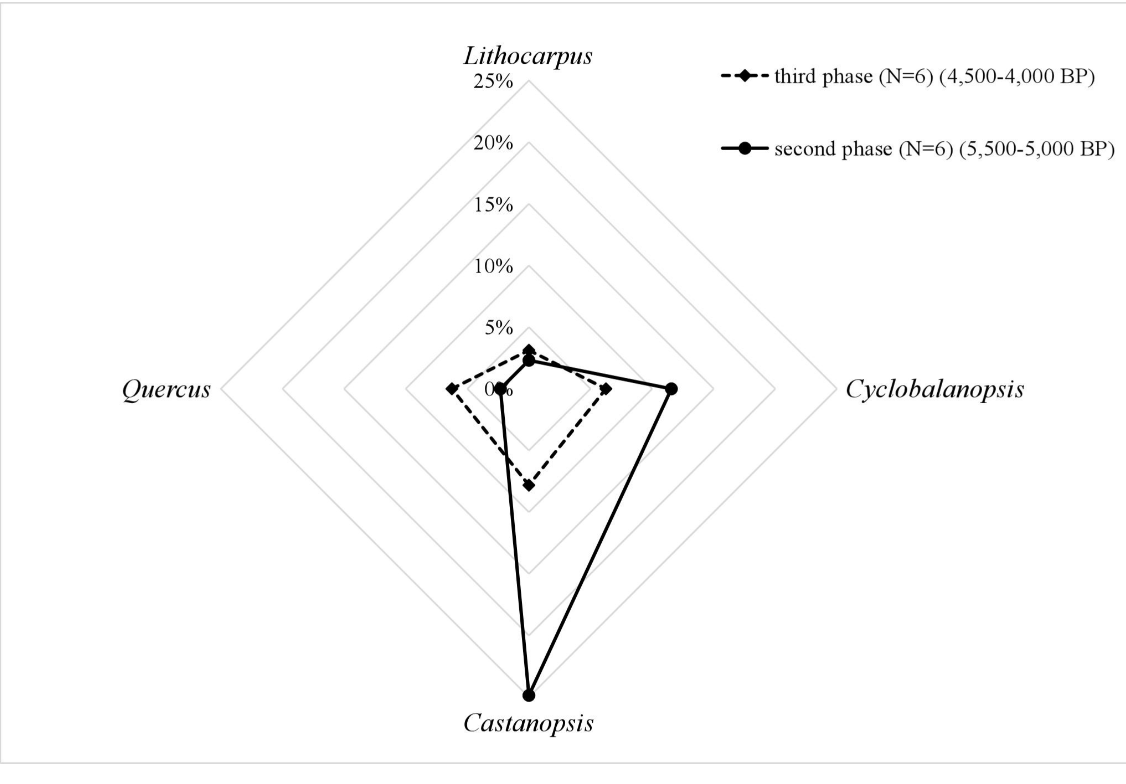

Figure 7. 13 Percentage of identifiable genera of Fagaceae during two phases of Haogang site. N is the number of stone tools, and starch granule counts are shown in Table 7.9

7.1.5 Yuanzhou site (c. 4,500 BP)

A total of 25 starch granules were recovered from four selected netherstones at Yuanzhou site (Table 7.10). Except six unidentifiable granules, other 19 granules were classified to six groups as follows:

Group B (Figure 7.14 a): One 12.66 μm drop-shape granule with an eccentric hilum, smooth surface and a crater at its narrow end was classified into a separated group alone. And these features observed above made it identifiable as *Quercus* Linnaeus (see Section 6.2.1).

Group C (Figure 7.14 b): This group contains three smooth spherical starch granules which are smaller than 15 μm in size. Every granule has a centric hilum without any visible lamellae and fissure. These above features indicate that these granules could be identified as *Lithocarpus* Blume (see Section 6.2.1).

Group D (Figure 7.14 c): Five granules were included in this group. Besides two compound granules, one of them is oval-shaped, which size is 17.33 μm, and others are bell-shaped, which are 12.77 μm, and 12.93 μm, separately. Another evident features is their rough surfaces. According to this characteristic, these individuals were identified as *Cyclobalanopsis* (Oersted) C. K. Schneider (see Section 6.2.1).

Group F (Figure 7.14 d): There are eight oval-shaped granules which length range is from 25.78 μm to 54.83 μm. Everyone has an eccentric hilum and visible lamellae. These features are similar to some geophyte granules (see Section 6.2.2).

Group J (Figure 7.14 e): The combination shape of spherical cap and polyhedron shape is special in the modern starch grains database, which are from *Cycas* or some geophytes, like some ferns, *Alisma, Amorphophallus* and *Smilax* (Figure 6.28). Only one combination shape of spherical cap and polyhedron starch granules, which size is 13.92 μm, was recovered from the tools of Yuanzhou site. It has smooth surface without any fissures and visible lamellae. Therefore, this granule were identified as geophyte/cycad.

Group L (Figure 7.14 f): One spindle-shaped granule is unique among all the recovered starch granules, which size is 51.87μm. This granule has eccentric hilum without any fissure and visible lamellae. Compared with the description of modern starch references, this granule is possibly from palm pith.

Table 7. 10 Identification of starch granules recovered from Yuanzhou tools.

Type	Tool number	*Lithocarpus*	*Cyclobalanopsis*	*Quercus*	Geophytes	Cycad or geophytes	Palm pith	Unidentified	Total
Netherstone	98DSYT0304③: 14	0	2	1	0	0	1	4	8
Netherstone	98DSYT0105 ③	0	0	0	2	0	0	0	2
Netherstone	98DSY T0304④: 13	0	0	0	1	0	0	0	1
Netherstone	98DSYT0304④: 15	3	3	0	5	1	0	2	14
	Total	3	5	1	8	1	1	6	25

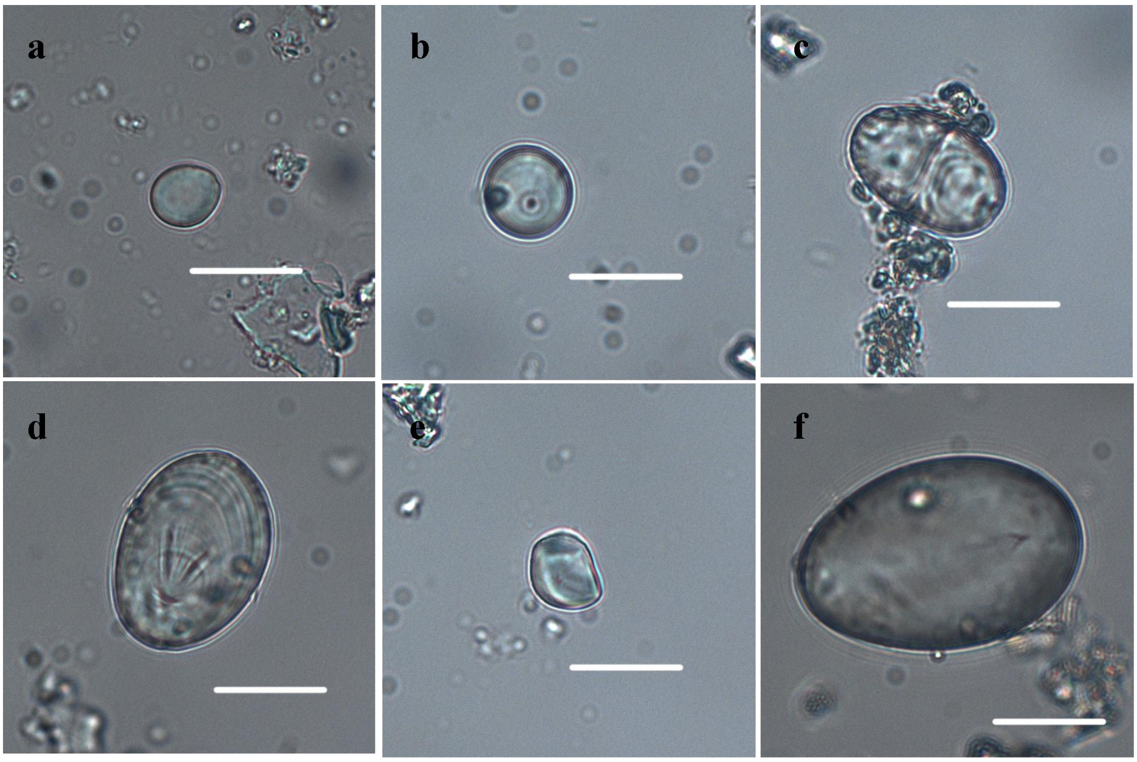

Figure 7. 14 Starch grains recovered at Yuanzhou site. a, group B identified as *Quercus*; b, group D starch grains identified as *Cyclobalanopsis*; c, group C identified as *Lithocarpus*; d, group F granules identified as geophytes; e, group J identified as geophytes or cycads; f, group L, identified as *Arenga*. Scale, 20μm.

Temporal changes in starch plants at Yuanzhou site

Compared with the Haogang site, the count of starch grains recovered at Yuanzhou site is relatively sparse. And no Poaceae and *Castanopsis* granule was recovered (Table 7.10). According to the cultural sequences reviewed in Section 4.1.5, three netherstones, which sample numbers are 98DSYT0304④: 15, 98DSYT0304④: 13 and 98DSYT0304③: 14, belong to the first phase of this site (c. 4,500-4,000 BP), while the remaining one (98DSYT0105 ③) is from the second phase (c. 4,000-3,500 BP) (Li, Z. and Li, Y. 1997). The starch residues recovered from this site were sorted by this sequence in Table 7.11.

Table 7. 11 Starch grains from different phases of Yuanzhou site

	Lithocarpus	***Cyclobalanopsis***	***Quercus***	**Geophytes**	**Cycad or geophytes**	**Palm pith**	**Unidentified**	**Total**
Phase 2 (c. 4,000-3,500 BP)	0	0	0	2	0	0	0	2
Phase 1 (c. 4,500-4,000 BP)	3	5	1	6	1	1	6	23
Total	3	5	1	8	1	1	6	25

In the first phase of this site (c. 4,500-4,000 BP), the carbohydrate combination contained acorns, geophytes, and palm pith (Table 7.11). And the proportion of acorns is slightly higher than that of geophytes. In the acorn assemblage, the dominant genus is *Cyclobalanopsis*, with a small amount of *Lithocarpus* and *Quercus*. This acorn assemblage is different from that at Haogang site (see Section 7.1.4) in the same area. In the second phase of this site, only two starch granules, identified as geophytes, were recovered. At this period, other starch sources, like acorns and starch pith, disappeared.

7.1.6 Cuntou site (c. 4,100-3,000 BP)

A total of 122 single granules and ten compound groups were recovered from 12 Cuntou tools (Table 7.12). 41 of them were unidentified based on an existing database. Others were classified to eight groups and some were identified at the genus level further. The identification of those grains is as follows.

Group A (Figure 7.15 a). The smooth irregular polyhedron shape makes these 14 granules unique. Their sizes are smaller than 20μm mainly, while three of them are between 20 μm and 25 μm. This size range does not exceed those of *Castanopsis*, while the morphological features are also consistent, so the starch granules of this group were identified as *Castanopsis* (D. Don) Spach (see Section 6.2.1).

Group B (Figure 7.15 b). This group contains three starch granules which size range is from 10.55 μm to 15.96 μm. Everyone is smooth drop-shape granule with smooth surface and eccentric hilum. All the evidence of size and morphological features indicate that this group of granules should be identified as *Quercus* Linnaeus (see Section 6.2.1).

Group C (Figure 7.15 c). Six smooth spherical granules were classified into the same group. Their size range is from 8.40 μm to 12.25 μm, with a mean size of 9.97±1.06 μm. Every granule has a centric hilum without any visible lamellae and fissures. Referring to the database in this thesis, they were probably from *Lithocarpus* Blume (see Section 6.2.1).

Group D (Figure 7.15 d). Eight rough bell-shape or oval shape granules were classified into this group. Their size range is from 13.64 μm to 18.71 μm, and the mean size is 15.72±1.88 μm. Based on the size range, shape features, and especially the rough surface, these granules may be produced by plants of *Cyclobalanopsis* (Oersted) C. K. Schneider (see Section 6.2.1).

Group F (Figure 7.15 e and f). Nine granules belongs to this group, which have a wide size range, from 13.98 μm to 60.90 μm. They have oval-shape or rounded triangular shape, smooth surface and eccentric hilum. These features are more likely from the starch granules of geophytes (see Section 6.2.2; Hang et al. 2006; Wang et al. 2017).

Group G (Figure 7.15 g). The four polyhedron granules were classified into this group.

The size range of these four granules is from 11.75 μm to 21.02 μm. They all have smooth surfaces without visible lamellae. Three of them bear fissure, including stellate-shape, linear, and Y-shape groups. Those features are similar to what Yang et al. (2012) have described, which make them identified as millet.

Group H (Figure 7.15 h). This group contains ten compound starch groups consisting of three or more small-sized granules. They all have smooth surfaces without lamellae and fissures. It is difficult to judge which species or genus they are from, but they seem to come from some grass seeds (Yang et al. 2012).

Group J (Figure 7.15 i to l). A total of 26 granules were distinguished because of their spherical cap or combination shape of spherical cap and polyhedron. The all have smooth surfaces but none of these granules bears lamellae and fissure. The majority of them are smaller than 20 μm. In summary, they were identified as geophytes or cycad (Figure 6.28), but difficult to be identified further.

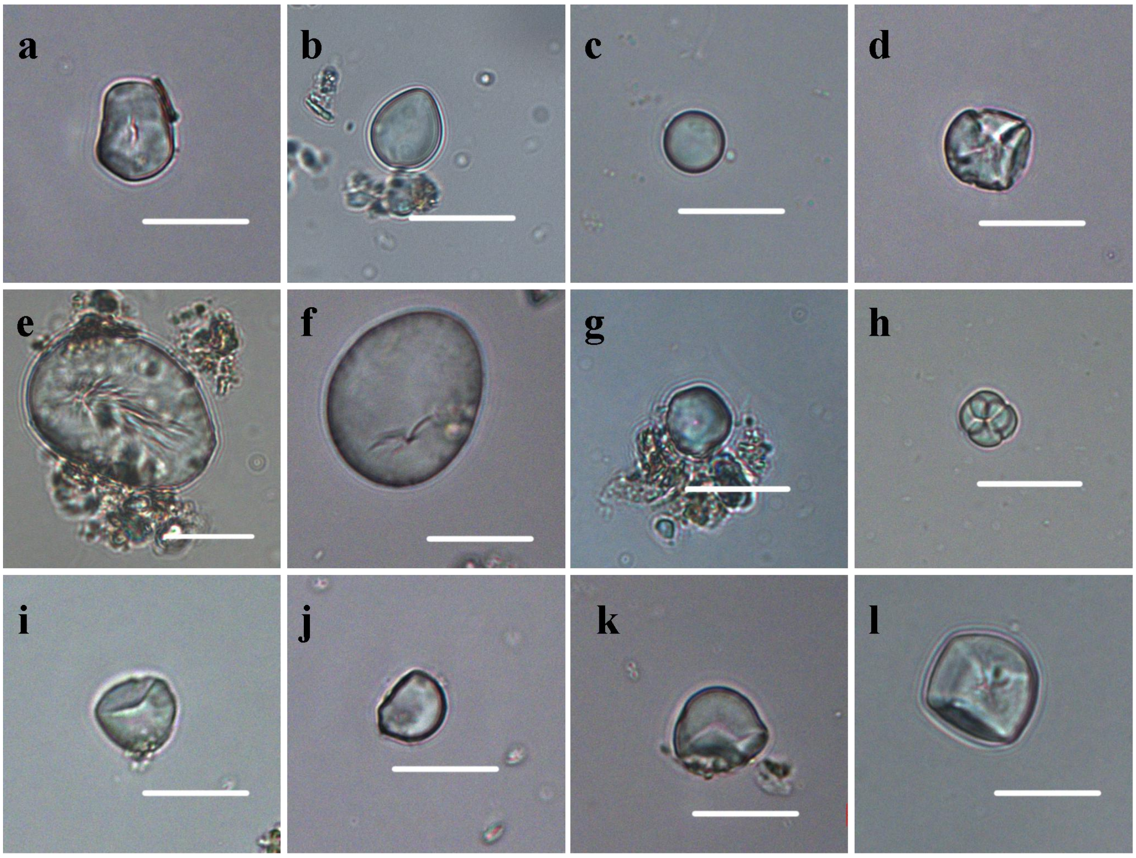

Figure 7. 15 Starch grains recovered from Cuntou site. a, group A identified as *Castanopsis*; b, group B identified as *Quercus*; c, group C identified as *Lithocarpus*; d, group D identified as *Cyclobalanopsis*; e and f, group F identified as geophytes; g, group G identified as millets; h, group H identified as grass; i to l, Type J identified as geophytes or cycad pith. Scale, 20μm.

Table 7. 12 Identification of starch grains recovered from Cuntou tools

Type	Tool number	*Lithocarpus*	*Cyclobalanopsis*	*Castanopsis*	*Quercus*	Milltes	Geophytes	Geophytes or cycad	Grass	Unidentified	Total
Handstone	93DCT1614③B：6	0	1	0	0	1	0	1	0	2	5
Handstone	93DCT1416④：10	0	2	1	0	0	0	1	0	4	8
Netherstone	93DCT2211F17:2	0	2	2	0	0	0	1	1	2	8
Netherstone	89DCT0613③：6	0	0	0	1	0	0	7	1	7	16
Netherstone	89DCT1504G6:2	0	0	0	0	0	0	0	0	2	2
Pestle	89DCT1010③E：6	0	0	0	0	0	1	0	0	0	1
Pestle	89DCT0712H93：1	0	0	2	1	0	3	3	1	7	17
Stone tool	93DCT1615③：14	0	0	6	0	2	1	1	0	1	11
Hammerstone	93DCT0707③C:28	2	3	2	1	1	3	9	1	9	31
Tapered hammer	89DCT1406④C：7	4	0	0	0	0	1	1	5	3	14
Waisted hammer	93DCT1615④：19	0	0	1	0	0	0	3	1	3	8
	Total	6	8	14	3	4	8	27	10	40	121

Changes in starch plant at Cuntou site over time

In this part, all the starch granules ere summarised according to the place where they were unearthed, in order to figure out whether their plant use strategy changed over time (Table 7.13). Within all the sampled tools, four are unearthed from Layer 3 (c. 3,700 BP), three from Layer 4 (c. 4,500 BP), and four from other remains, such as house foundations, pits, and trench. Figure 7.16 demonstrates this change.

Table 7. 13 Starch granules from each Neolithic layer of Cuntou site.

	Lithocarpus	***Cyclobalanopsis***	***Castanopsis***	***Quercus***	**Millets**	**Geophyte**	**Geophytes or cycad**	**Grass**	**Unidentified**	**Total**
Layer 3 (c. 3,700 BP)*	2	4	8	2	4	5	18	2	19	64
Layer 4 (c. 4,500 BP)	4	2	2	0	0	1	5	6	10	30
Others	0	2	4	1	0	3	4	2	12	28

* The data here refer to Table 4.6 and Table 4.7

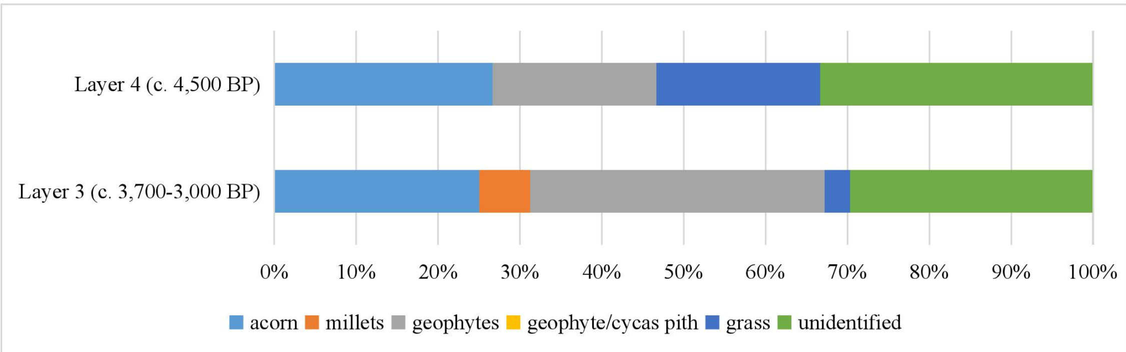

Figure 7. 16 Percentage of starch granules from each layer of Cuntou site

At Cuntou site, the acorn use seems to be stable over time which proportion was 27% in layer 4 and 25% in layer 3 (Figure 7.16). The apparent changes occurred in the other three starch granule groups (Figure 7.16). The proportions of both two groups of geophyte starch grains increased, including the one which has large-size granules, and the other has small-sized spherical cap granules or the combination shape of spherical cap and polyhedron granules (which is also possibly identified as cycad pith). And the latter type of geophyte has a relatively larger proportion at Cuntou site, which is different from other study sites. In terms of herb use, the millet starch grains emerged in the later layer, together with the decrease of grass.

The temporal changes in acorn/oak-chestnut are presented in Figure 7.17. The acorn assemblages contain different genus in each layer (Figure 7.17). Within four identifiable genera, the proportions of *Cyclobalanospsis* are relatively stable, which are 6% and 7%, respectively. But the other three genera have changed. In layer 4 of Cuntou site, *Lithocarpus* is the dominant acorn genus, accounting for 13% of the total. This proportion is near twice as much as *Cyclobalanopsis* (7%) and *Castanopsis* (7%). In layer 3 of this settlement, *Castanopsis* replaced *Lithocarpus*, becoming the first class of the acorn assemblage (13%). This is possibly related to the vegetation changes as well. The pollen sequence (GY1) revealed the oak forest in the Pearl River Delta had a short-term recovery between 4,000 BP and 3,500 BP, after the declining tendency in the previous several hundred years (c, 4,500 BP-4,000 BP) (Figure 2.4) (e.g. Ma et al. 2018; Peng et al. 2015). Meanwhile, *Lithocarpus* and *Quercus* have the same lowest percentage of 3% of the total.

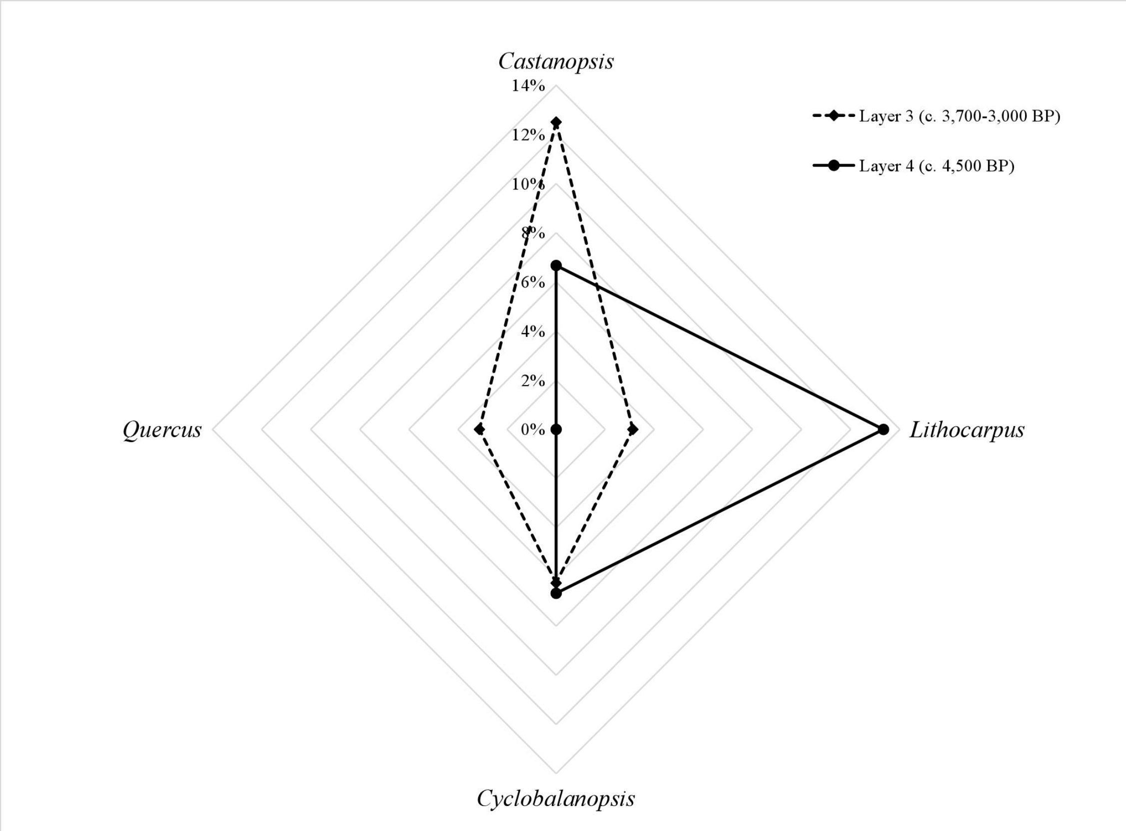

Figure 7. 17 Proportional changes in acorn starch granules at Cuntou site

7.2 Analyses of starch granules across the study region.

I compiled these results to provide an analysis of diet across the study region as a whole in this section. These analyses form the bases for discussing the ancient plant exploitation strategies and their changes in the Pearl River Delta in the next two chapters. Firstly, I examined the temporal changes in the starch plant use. Although not all sites have radiocarbon dates, most have been assigned a culture grouping and relative date based on pottery typologies. Based on these sequences, the temporal changes in each location and the whole region could be analyzed. Then, I analysed the spatial differences. Because these six studied sites are not only different in time, their spatial distributions are also significantly different. Therefore, in this part, the results of starch grains were compared between sites distributed in different regions during a similar period.

7.7.1 Temporal differences of starch plant assemblages

These six sites are located in three sub-region of the delta.Therefore, the starch grain data are firstly compiled by regions, and then, analyzed across the whole delta. In this section, I first discussed the temporal changes in starch plant use in the same sub-regions, from the estuarine area to the northern edge of the delta. According to the site locations, Haogang site, Yuanzhou site, and Cuntou site are close to the esturaine area; Guye site and Yinzhou site are in the hinterland of the delta; and Hengling site in the northern delta (Figure 4.1). Then, I examined the oval changes across the whole delta.

East of the estuarine area

The chronological sequence of three studied sites in this region during the Neolithic period is divided roughly (Table 7.14). The starch grains recovered in Dongguan city were summarized by these three phase in the Table 7.15 and Figure 7.18, indicating the changes of starch plant assemblage in this area.

Table 7. 14[56] Schematic diagram of chronological sequence at Dongguang site from 6,000 to 3,000 BP

6,000-5,000 BP	5,000-4,000 BP	4,000-3,500 BP	3,500-3,000 BP
Haogang site			
		Yuanzhou site	
			Cuntou site

First phase (5,500 to 5,000 BP): the second phase of Haogang site, dating around 5,500 to 5,000 BP;

Second phase (4,500 to 4,000 BP): the third phase of Haogang site, dating around 4,500 to 4,000 BP; the first phase of Yuanzhou site, corresponding to late Shixia culture, dating 4,290 to 4095 cal. BP.

56 This table is modified after that displayed in Dongguan Museum.

Third phase (4,000 to 3,000 BP): the second phase of Yuanzhou site, corresponding to the second phase of Youyugang site, which has two calibrated dating data: 3,345 ± 150 BP and 3,840 ± 125 BP.

Table 7. 15 Starch grains recovered in Dongguan city

	Acorn	Geophytes	Geophyte/ cycad pith	Millets	Palm pith	Food legume	Grass	Unidentified	Total
5,500 - 5,000 BP	71	21	18	12	0	1	0	50	173
4,500 - 4,000 BP	15	18	5	1	0	0	0	27	66
4,000 - 3,000 BP	40	15	28	4	1	0	10	47	145
Total	126	54	51	17	1	1	10	124	384

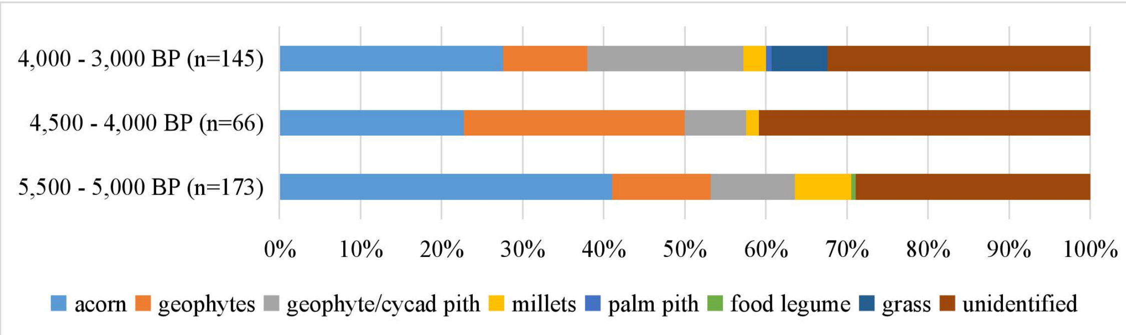

Figure 7. 18 Starch grain categories in Dongguan city in three phases (n is the total count of recovered starch grains).

Overall, acorns and geophytes constituted the majority of carbohydrate assemblages in Dongguan city from 5,500 to 3,000 BP (Figure 7.18). In the first phase, this combination of acorns and geophytes accounted for 64% of the total and then decreased slightly to 58% (second phase), and 57% (third phase). And millets were always included in this combination, which proportions are persistently low than 10%. Besides, the occasionally recovered starch granules of food legume, starch pith, and some grass seeds suggest the diverse diet in Dongguan during this period.

In terms of acorn and oak-chestnut consumption, including *Lithocarpus,* *Cyclobalanopsis, Castanopsis*, and *Quercus*, it shows a declined trend, from 41% in the first phase (c. 5,500-5,000 BP) to 23% in the second phase (c. 4,500-4,000 BP), and slightly then bounced back to 28% during the third period (c. 4,000-3,000 BP) (Figure 7.18). The trends of *Castanopsis* and *Cyclobalanopsis* were similar to the overall trend (Figure 7.19). The percentage of *Castanopsis* dropped from 25% to 8% and then increased to 10% after 4,000 BP (Figure 7.19). And *Cyclobalanopsis* decreased from 12% to 6% and then rose to 9% (Figure 7.19). The other two genera, which proportions are relatively low, present different trends. The one is the opposite trend of *Quercus*, which increased first from 2% to 6%, then fell to 3% again, and the other is the continuous increase of *Lithocarpus* from 2% to 6% (Figure 7.19). In the case that the fluctuations of other genera were not marked, the overall decline of acorn consumption seemed to be closely related to the *Castanopsis* decrease. These changes corresponded to the oak forest fluctuation in the middle Holocene (Figure 2.4 and Figure 2.5) (e.g. Ma et al. 2018; Peng et al. 2015; Wang et al. 2009). Therefore, the availability of acorns and oak-chestnuts was possibly one major factor that influences their consumption.

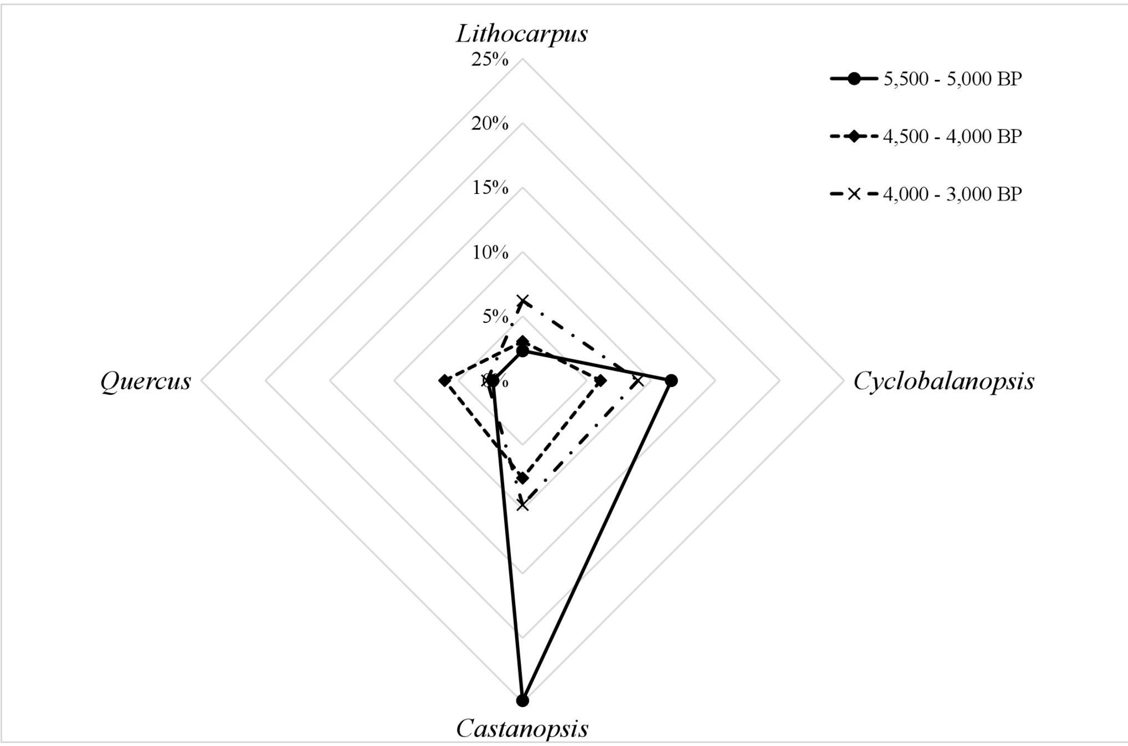

Figure 7. 19 Changes in each acorn genus in Dongguan city.

The proportion of geophyte plants is overall a rising trend (Figure 7.18). But, the integral tendency of geophytes is the completely opposite of acorns, which increased first from 23% (c. 5,500-5,000 BP) to 35%(c. 4,500-4,000 BP) and then dropped a little to 29% (c. 4,000-3,000 BP) (Figure 7.18). Therefore, this may suggest that the acorn/oak-chestnuts and geophytes, as two main carbohydrate sources, complement each other.

Although the possibility of the spherical cap granules and combination shape of spherical cap and polyhedron granules identified as *Cycas* cannot be rule out, I temporarily classified them as a group of geophytes, because the recovered granule sizes are relatively small. But I excluded 24.52 microns one at Haogang site here, which is more likely from *Cycas*, according to size data (Figure 6.26). Figure 7.20 reveals the changes of these two types of geophytes. However, because of the geophyte granules are difficult to be identified further, in this part, I did not discuss their internal changes further.

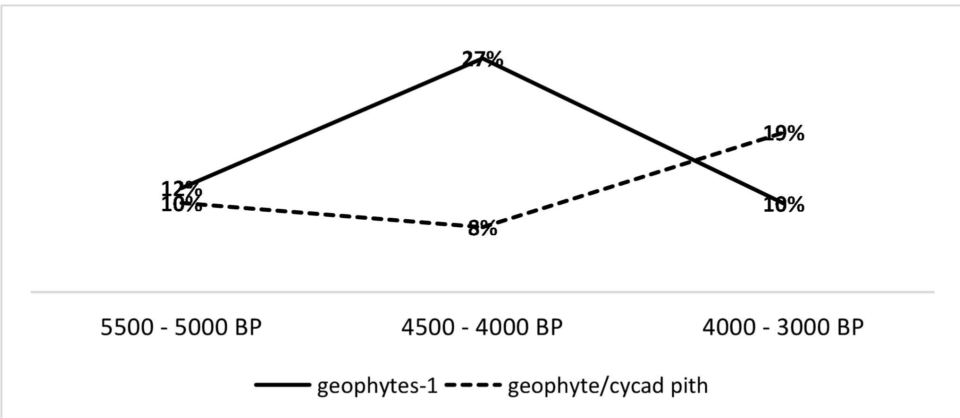

Figure 7. 20 Changes in different types of geophyte starch grains in Dongguan city.

Hinterland of the delta

The archaeological samples from Foshan city, in the hinterland of the Pearl River

Delta, were collected at Guye site (c.5,900-5,000 BP) and Yinzhou site (c. 4,500 BP). The changes of each starch grain category in Foshan city (Figure 7.22) are similar to that of Dongguan city (Figure 7.18). The acorns declined obviously, from 60% of the total at Guye site to 29% at Yinzhou site, along with the increases of geophytes (from 8% to 29%).

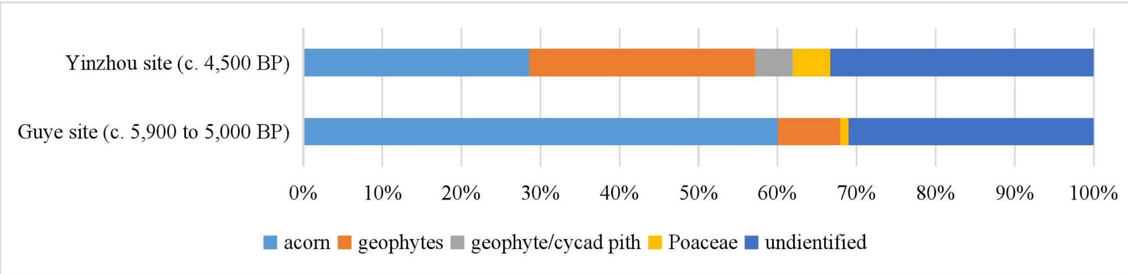

Figure 7. 22 Starch grain categories at Guye site and Yinzhou site in Foshan city

At Guye site, within the four identified Fagaceae genera, the highest component is *Lithocarpus* (16%), and the lowest (5%) is *Quercus* (Figure 7.23). However, *Lithocarpus* disappeared at Yinzhou site, while *Castanopsis* became crucial, accounting for 14% of the total (Figure 7.23). Besides, *Quercus* is the smallest composition at acorn assemblages of both Guye site and Yinzhou site. The changes in acorns are not consistent with those in the other two cities. In Guangzhou and Dongguan, the percentage of *Castanopsis* was relatively high in the earlier period and declined later, while the proportion of *Lithocarpus* was always at a relatively low level. But in Foshan city, the *Lithocarpus* was of importance at Guye site but disappeared at the Yinzhou site. And *Castanopsis* played an important role at Yinzhou site, but was not valued at Guye site.

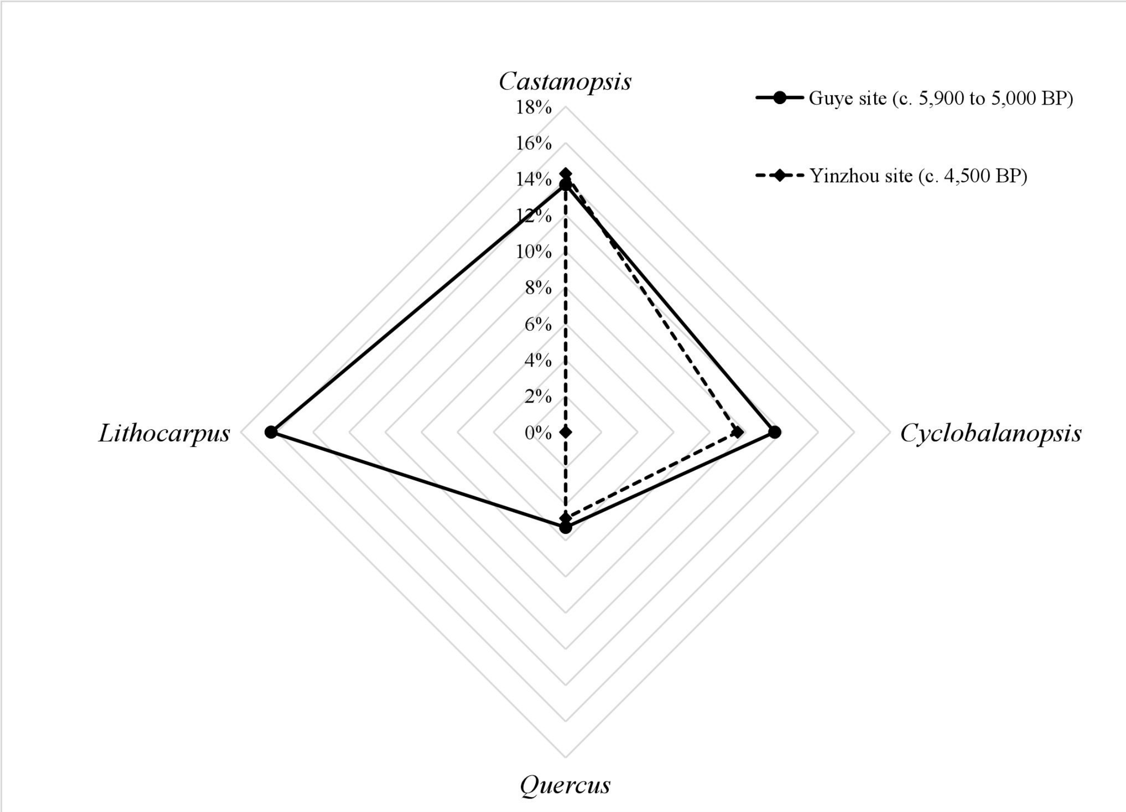

Figure 7. 23 Composition of acorn assemblages at Guye site and Yinzhou site in Foshan city. The data are shown in Table 7.1 and Table 7.5.

When the total proportion of geophytes increased from 8% at Guye site to 33% at Yinzhou site, the type of geophytes began to change a little as well (Figure 7.22). The starch grains with spherical cap shape or combination shape of spherical cap and polyhedron shape were found in Yinzhou site, indicating that some other types of geophytes, such as arrowroot, and konjac, or possibly cycads, were included in the starch plant assemblage at Yinzhou site.

Transitional zone between delta and hilly area

Although the samples of Guangzhou city, northern edge of the Pearl River Delta where is the confluence of the North River, the East River and the West River, three main tributaries of the Pearl River, in this thesis come from Hengling site (north Guangzhou) only, starch analysis was done at Lujingcun site, located in the south

Guangzhou city (Wan 2012; Wang 2017). And both these two communities settled in Guangzhou city during a similar period, roughly from 4,000 to 3,000 BP. Here, the starch plants assemblages could be discussed during the millennium from 4,000 BP to 3,000 BP.

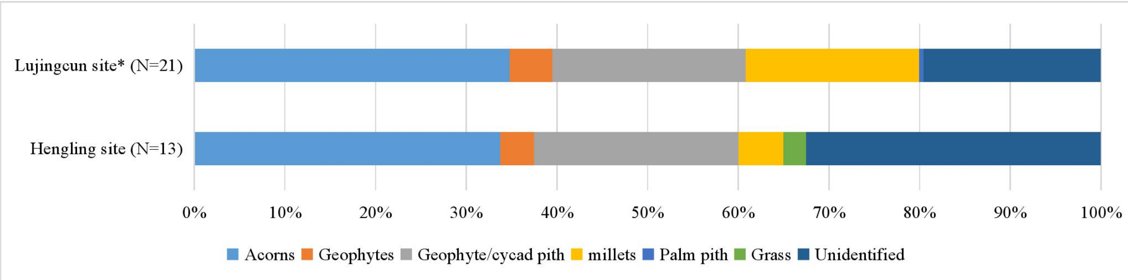

Figure 7. 21 Starch grain categories at Hengling site (n=80) and Lujingcun site (n=802) in Guangzhou city. N is the count of sampled tools.
* The tools sampled at Lujingcun site include one perforated axe and two adzes. As Wang (2017) did not report the detailed identification (except geophytes), all the starch granules recovered at this site are shown in this figure.

As there is no detailed report of Lujingcun starch granules (Wang 2017), the results cannot be analysed further. However, Figure 7.21 reflects that the integral starch assemblages in Guangzhou city from 4,000 to 3,000 BP were basically stable, including similar proportions of acorns and two types of geophytes mostly. What is different is that the millet proportion at Lujingcun site is higher than that at Hengling site.

Temporal changes of starch plant use in the Pearl River Delta

Overall, the sampled sites are divided into two groups chronologically. The first group contains Guye site and the second phase of Haogang site, around 6,000 to 5,000 BP, while the second group includes the third phase of the Haogang site, Yuanzhou site, Cuntou site, Hengling site, and Yinzhou site, about 4,500 to 3,000 BP. The recovered starch grains were reorganised in Table 7.16, and their trends become clear (Figure 7.24). From 6,000 to 3,000 BP, the consumption of acorns declined from 51% to 32%, with the increase of geophytes from 15% to 24%. Meanwhile, the proportion of millets also had a slight increase, so did grass starch granules. Besides, the palm piths may be included in the native diet in the Pearl River Delta.

Table 7. 16 Starch grain categories during two periods in the Pearl River Delta.

	Acorn	Millets	Geophytes	Geophytes or cycad	Starchy piths	Grass	Unidentified	Total
4,500 - 3,000 BP	81	4	30	29	2	10	95	251
6,000 - 5,000 BP	185	13	36	18	0	1	109	362

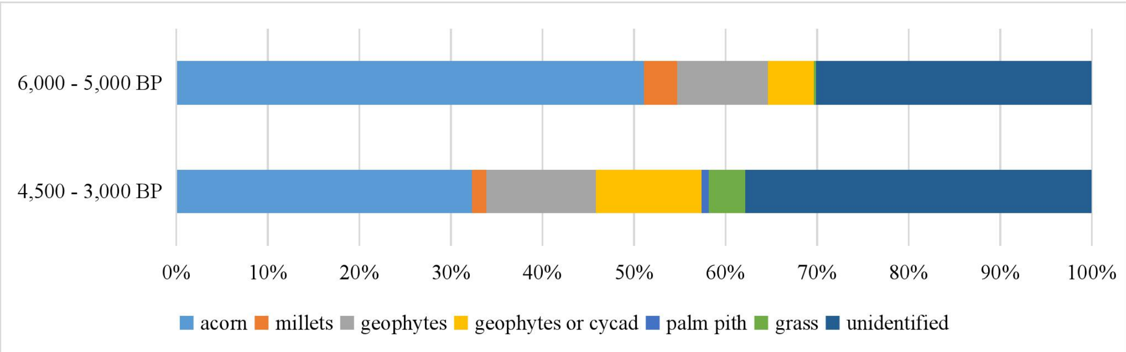

Figure 7. 24 Proportion of starch grain categories during two periods in the Pearl River Delta.

The changes of acorns and geophytes, which formed the main component of the starch plant assemblage, were compared among each site (Figure 7.25). These two components account for 56% (the second phase of Haogang site) to 72% (Yuanzhou site) of the total. But their fluctuations in the trend is the opposite (Figure 7.25). The decline of acorns occurred evidently between 6,000 BP and 5,000 BP, alongside with the increase of geophytes, while after 4,500 BP, their amplitudes of changes weakened, remaining a relatively stable ratio.

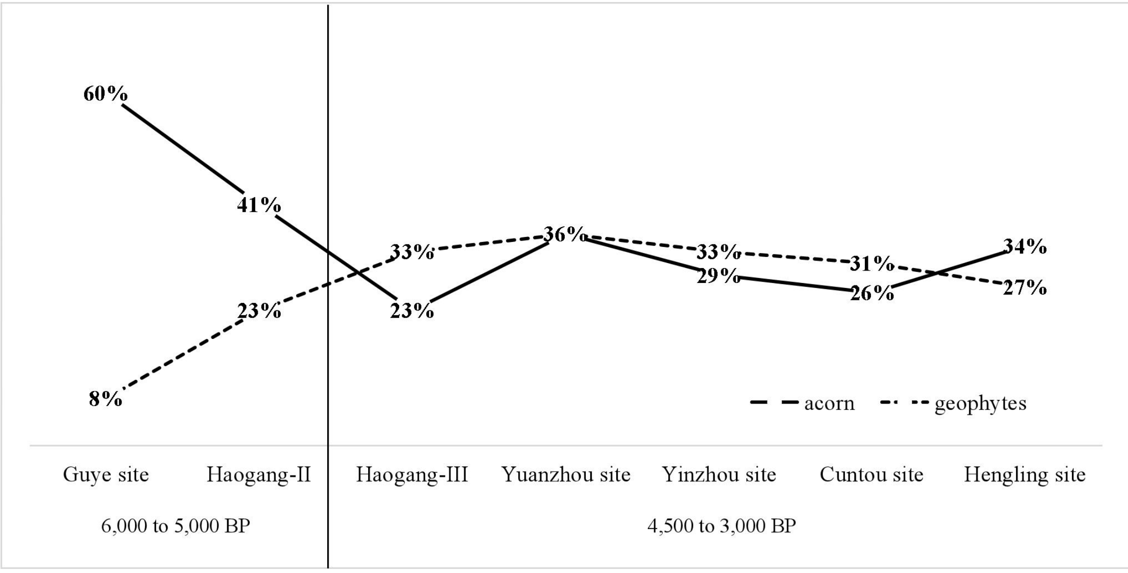

Figure 7. 25 Proportions of acorns and geophyte starch grains at each study site.

Besides starch grain categories, another difference occurred in the numbers of recovered starch grains (Figure 7.26). The most obvious change is the decrease of both the total number of starch granules and the average count from each sampled tool. During the period from 6,000 to 5,000 BP, the quantities of starch grains were relatively large, so were their average numbers. However, the apparent decline emerged in the later period after 4,500 BP, especially in the aspect of the average count. This quantity change is synchronized with the compositional changes of the starch plant assemblage (Figure 7.24). Even though the quantity of acorn and oak-chestnut declined, their assemblage seemed not to be changed across the region (Figure 7.27), although there were some individual differences in different sites. Within all identifiable acorn genera, overall, *Castanopsis* remained the dominant genus.

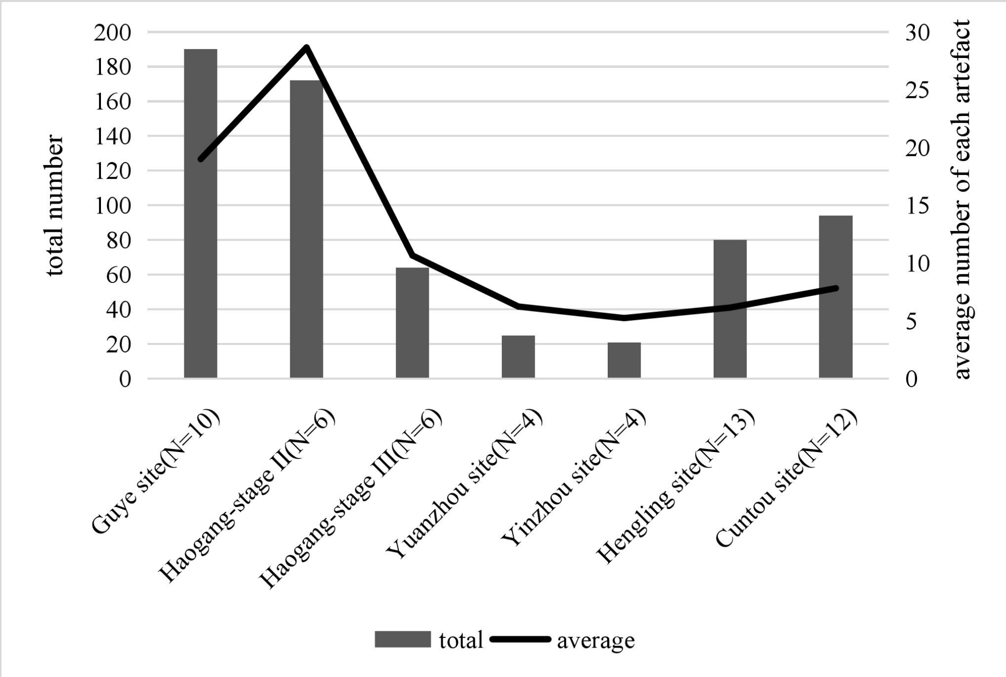

Figure 7. 26 Total number of recovered starch granules and the average starch count from each sampled tool.

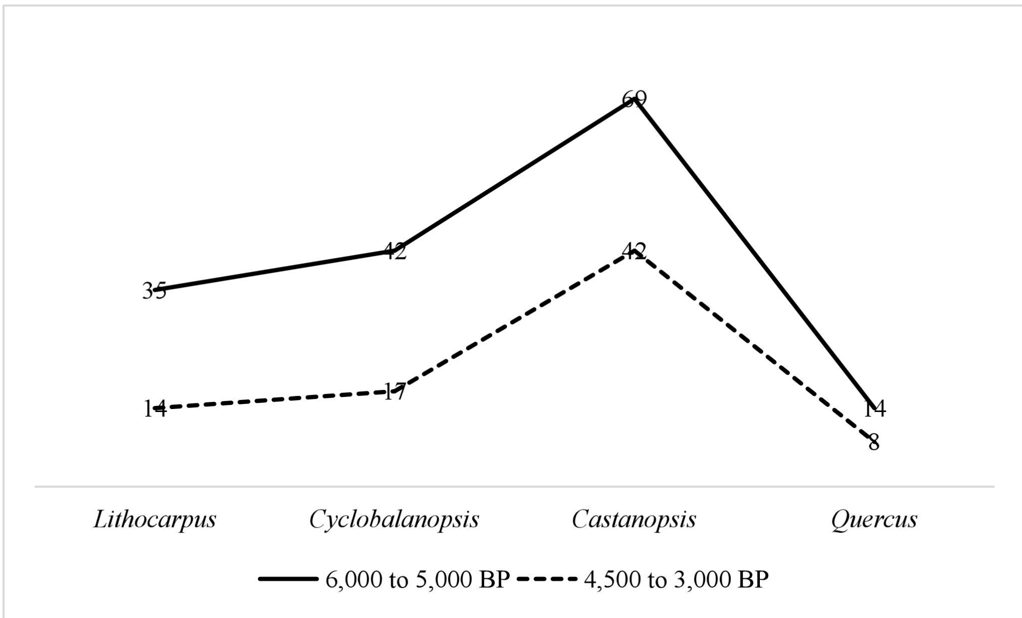

Figure 7. 27 Acorn assemblages during two periods in the Pearl River Delta

7.2.2 Spatial difference of starch plant assemblages in the Pearl River Delta

In this section, I analysed the spatial differences of starch plant use in the delta. First, I compared the differences between the two main sub-delta of the Pearl River Delta according to the data from Guye site and Haogang site, Yinzhou site and Yuanzhou site separately. Then, I examined the difference between estuary and transitional area from delta to hilly region, based on the data from Cuntou site and Hengling site.

The differences between the West-North River Basin and the East River Basin

Within the six studied sites, Guye site and Yinzhou site are along the West and North River, while Cuntou site, Yuanzhou site, and Haogang site are in another sub-delta formed by the East River (Figure 4.1). In this part, the results of Guye site and the second phase of Haogang site were compared to reveal the differences during the period from 6,000 to 5,000 BP, while Yinzhou site and Yuanzhou site were analyzed for the later period, around 4,500 to 3,000 BP.

6,000 to 5,000 BP

Results of Guye site (c. 5,900-5,000 BP), along the West River and the West River, and those of the second phase of Haogang site (5,500 to 5,000 BP), in the delta formed by the East River, were sorted in Table 7.17.

Table 7. 17 Summarized results of starch grains at Haogang site and Guye site.

	Acorn	Poaceae	Millets	Geophytes	Geophytes or Cycads	Unidentified	Total
Guye site (N=10*)	114	1	1	15	0	59	190
Haogang-PhaseII (N=6*)	71	0	12	21	18	50	172
Total	185	1	13	36	18	109	362

*N is the number of studied stone tools, and the same below

Figure 7.28 presents the differences between these two sites. The total proportions of acorn/oak-chestnut and geophytes at these two sites are similar (Figure 7.28 a). Within them, acorn/oak-chestnuts have greater proportion at Guye site (Figure 7.8 a), and the ratio between acorn and geophytes is 7.6 at the Guye site, much higher than 1.8 at Haogang site. However, the Haogang people probably had a more complex diet, which included another type of geophytes and a relatively higher percentage of millets (Figure 7.28 a).

In the acorn assemblage, the identifiable genera also display the differences (Figure 7.28 b). Which kind of nuts were processed at each site are clearly discriminated. The proportion of acorn collected by the Guye people is relatively close to each other. Except for the low percentage of *Quercus* (5%), the proportions of other three genera are all above 12%, with the slight advantage of *Lithocarpus* (16%) (Figure 7.28 b). However, Haogang people seem to incline to *Castanopsis* (Figure 7.28 b), and other three genera accounted for a low proportion, which are lower than 5%.

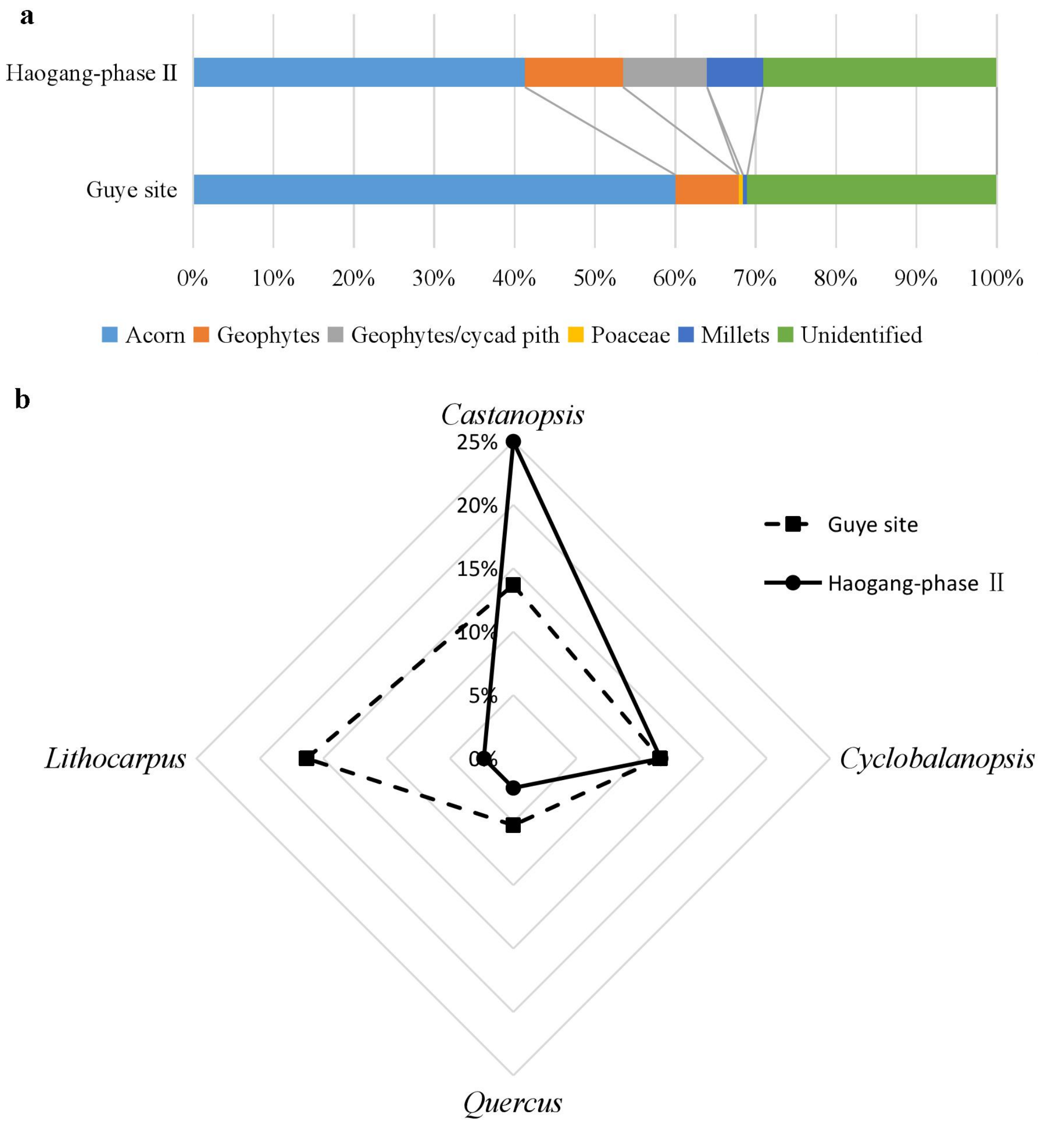

Figure 7. 28 Result comparison between Guye site and the second phase of Haogang site.a, proportion of each starch granule category at Guye site and Haogang site (Data are shown in Table 7.16); b, comparison of identifiable acorn starch granule at these two sites(Data are shown in Table 7.1 and Table 7.8).

c. 4,500 BP

The results of Yinzhou site and Yuanzhou site were discussed below, not only because they were located in different sub-delta separately, but also because they had some similar cultural characteristics (see Section 4.1). A total of four Neolithic netherstones were sampled each at both sites. The starch results were summarized in Table 7.18.

Table 7. 18 Comparison of starch grains from Yinzhou site and Yuanzhou site

	Acorns	Geophytes	Geophyte/ cycad pith	Millets	Palm pith	Unidentified	Total
Yuanzhou site (N=4)	9	8	1	0	1	6	25
Yinzhou site (N=4)	6	6	1	1	0	7	21

Compared with Guye site and Haogang site, few granules were recovered at Yuanzhou site and Yinzhou site, but the total granule counts at these two sites is similar (Table 7.18). The categories of recovered starch granules are also characterised by acorn and geophytes, which total proportions are 72% (Yuanzhou site) and 62% (Yinzhou site) separately (Figure 7.29). The compositional difference is that one millet starch grain was found at Yinzhou site, while one palm pith granule was recovered at Yuanzhou site (Table 7.18).

Within the acorn categories, the integral proportion at Yuanzhou site is higher than that at Yinzhou site, which is 36% and 29%, respectively. However, the identified genera is evidently different (Figure 7.29 b). Along the East River, the dominant genus of acorns is *Castanopsis* at Yuanzhou site, which was not found at Yinzhou site, in the delta formed by the North and West River, where *Cyclobalanopsis* became the dominant genus. Another different genus is *Lithocarpus*, which took the second place at Yuanzhou site, but such granule was not recovered at Yinzhou site. Besides, the only similarity between these two assemblages is the *Quercus* content in low proportion.

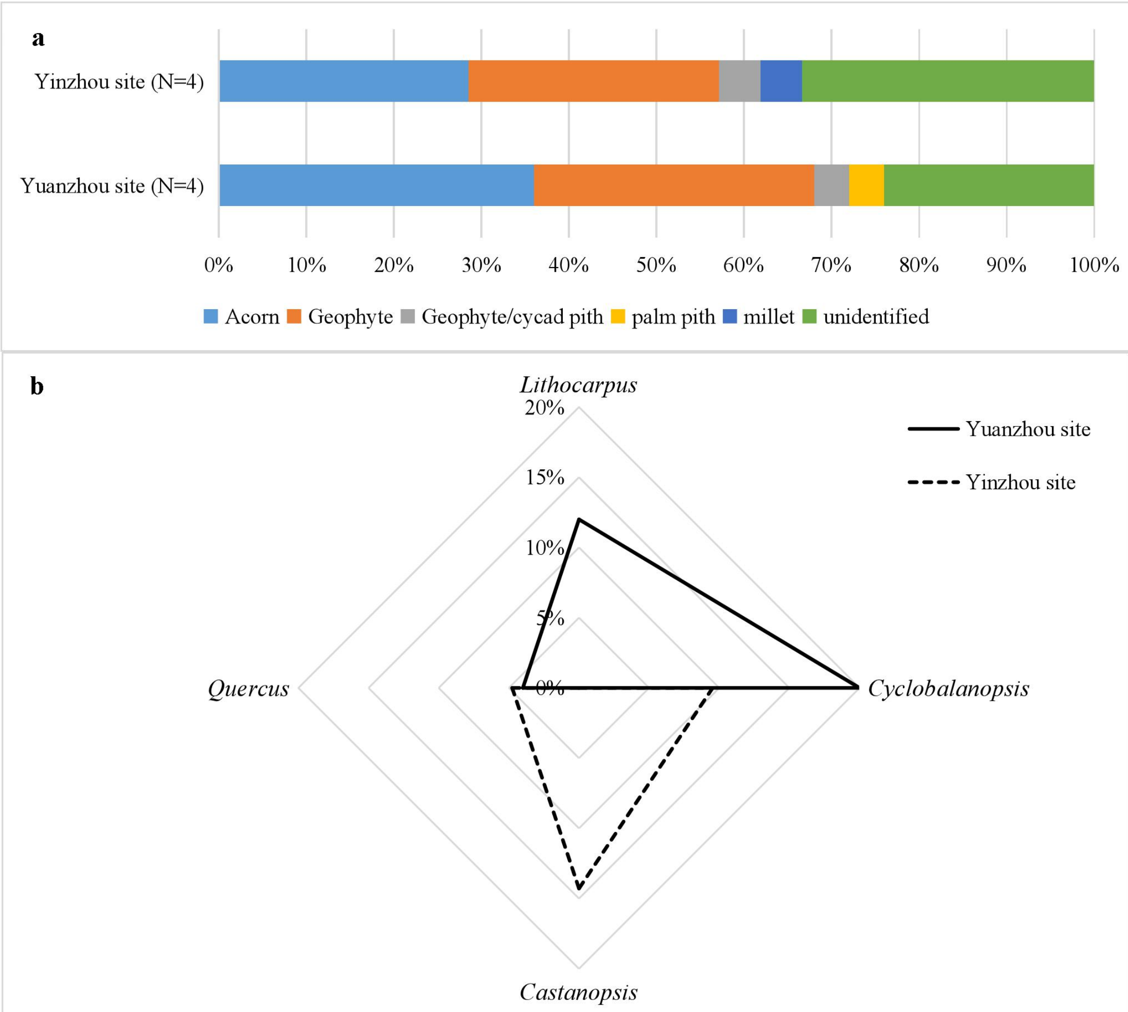

Figure 7. 29 Result comparisons between Yinzhou site and Yuanzhou site. a, starch grain categories (N is the number of studied netherstones); b, identifiable genera of acorn starch grains.

The differences between estuary and the north transitional zone

In terms of the modern geographic environment, Cuntou site located in the estuarial region of the Pearl River (the part of the East River Basin), while Hengling site is located in the north transitional zone between the delta and hilly area of North Guangdong (Figure 1.2). The comparisons between these two sites revealed different starch plant combinations in the two geographical regions (Table 7.19). The major component of starch plants assemblages in these two regions were still acorn/oak-chestnuts and two types of geophytes, while a small amount of Poaceae, including millet, was included in these assemblages, which only had slight differences in proportion.

Table 7. 19 Comparison of starch grains from Cuntou site and Hengling site

	Acorns	Geophyte	Geophyte/cycad pith	Millets	Grass	Unidentified	Total
Cuntou site (N=12)	24	6	24	3	8	29	94
Hengling site (N=12)	27	3	18	4	2	26	80

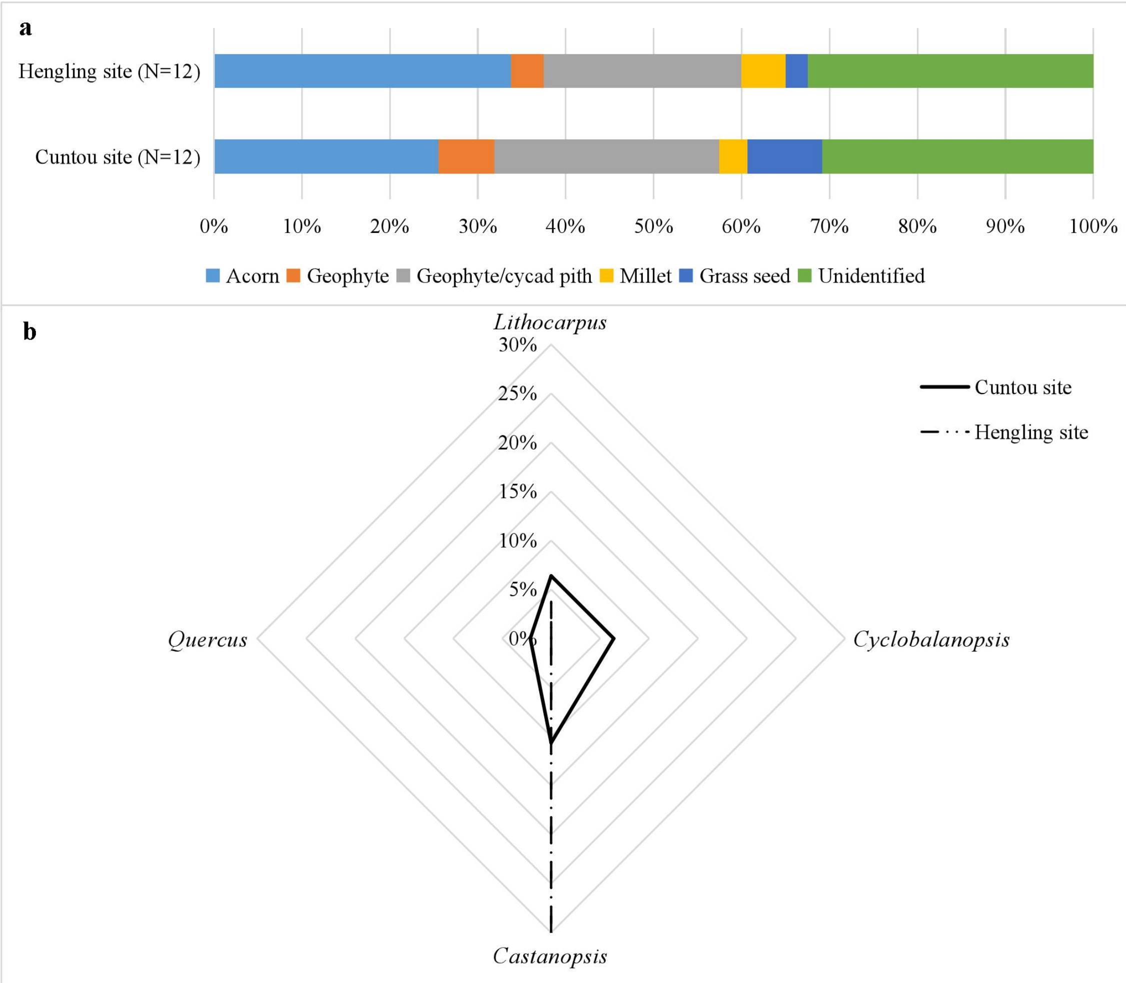

Figure 7. 30 Result comparisons between Cuntou site and Hengling site. N=number of stone tools sampled. a, starch grain categories; b, identifiable genera of acorn starch grains.

The identifiable genera of acorns presented the obvious distinction between these two sites, although *Castanopsis* were the dominant genus at both two sites (Figure 7.30 b). Hengling site had a more simple acorn combination than any other study sites in this thesis, which only contained *Castanopsis* (30%) and *Lithocarpus* (4%). But, at Cuntou site, the starch grains of each acorn genus had relatively balanced proportions, besides *Castanopsis* (11%), which are 6% for *Lithocarpus*, 6% for *Cyclobalanopsis*, and 2% for *Quercus*.

7.2.3 Summary

Based on all the above analyses, the starch plant use in the Pearl River Delta and its changes are summarized as follows:

1. In general, the starch plants the communities in the Pearl River Delta during the period from 6,000 BP to 3,000 BP used mainly included acorns and geophytes, with a small amount of Poaceae, palm or cycad.
2. The combination of acorns and geophytes changed between 6,000 and 5,000 BP, with an increase of geophytes and a decline of acorns. At the same time, the average count of starch grains recovered from every stone tool were relatively large.
3. From 4,500 to 3,000 BP, the proportions of acorns and geophytes became stable but the average counts of the recovered granules became much lower than that in the previous period.
4. On the site scale, the contents of each acorn genera have evident changes, however, throughout the delta, their proportions did not changed over time, although their overall use declined.
5. On the aspect on geophytes, besides the overall increased use, the types of geophyte plants used in the Pearl River Delta had some changes. However, due to the identification limitations, it is difficult to analyze the reason for these changes.

Chapter 8: Principal starch foodstuffs in the Pearl River Delta during middle and late Holocene

In this chapter, I interpreted the ancient starch results shown in Chapter 7, combined with the ethnography and palaeoecology materials. I will, firstly, discuss the acorn and oak-chestnut consumption in the Pearl River Delta between 6,000 and 3,000 BP. The results show that acorn and oak-chestnut were consumed widely throughout this region in these three millennia, although its proportion had a decreased tendency in the earlier phase (6,000-5,000 BP). Then, I suggested that geophytes was not as significant as the previous ethnological hypothesis speculated, although the possibility that some geophytes were consumed without processed by grinding or pounding tool cannot be ruled out. Although between 6,000 and 5,000 BP, the geophytes seems to be supplementary foodstuffs, their importance was recognized gradually and began to be long-term used in a similar proportion of acorns/oak-chestnuts after c. 4,500 BP. The results present a new view of staple foods, which is composed of acorn/oak-chestnuts and geophytes at the same time, in the Pearl River Delta between 6,000 to 3,000 BP, prior to the adoption of rice farming.

8.1 Acorns and oak-chestnuts

This section reviewed the results of the starch analysis for acorns and acorn processing. In this section, I attempted to put the starch data into a wider context and consider the implications of populations dependent upon this resource during the mid- to late-Holocene ahead of the arrival of domesticated rice and of other systems of plant cultivation that followed. The starch analysis shows that acorns may have been exploited as a food staple up to at least 3,000 BP.

The tree nuts, such as chestnuts (*Castanea*), acorns (*Quercus*), horse chestnut (*Aesculus*) and oak-chestnuts (*Castanopsis*), were an important staple carbohydrate resource for many hunter-gatherer communities during Holocene (e.g. Kawashima

2016; Morales 2018; Noshiro 2016; Sasaki and Noshiro 2018; Stevens and McElreath 2015; Tushingham and Bettinger 2013). Although those tree nuts were believed to be labour-intensive food sources: the collection is relatively easy (though the temporal window for collection may be limited, so careful planning is necessary), but they are labour intensive to be processed before consumption (Basgall 1987; Liu et al. 2010; Messner 2011). For example, in East Asia, the archaeobotanical materials from Japan indicate that chestnut and horse chestnut were considered as key staple food sources during the Jomon period (c.16,000-3,000 BP) (Kawashima 2016; Sasaki and Noshiro 2018; Noshiro 2016). Large quantities of nutshells, including *Castanopsis* and *Juglans*, were found at several Hoabhinian sites (c. 20,000-9,000 BP) in Southeast Asia, suggesting a similar period of intensively acorn consumption in this region (Higham 2014; Lentfer et al. 2013; Yen 1977). The intensive use of acorn also occurred between 7,500 BP and 5,000 BP in California (Basgall 1987; Tushingham and Bettinger 2013).

Acorns, including *Quercus* spp., and *Lithocarpus/Cyclobalanopsis* spp., also have been widely used in China (Figure 8.1). At Donghuling site in Beijing (11,000-9,500 BP) (temperate North China), starch granules recovered from grinding slab and hand stone could be roughly identified as *Quercus* sp. and *Lithocarpus/Cyclobalanopsis* sp. (Liu et al. 2011a). During a similar period, starch granules of *Quercus* were identified at Shangshan site (11,400-8,600 BP) in Zhejiang Province (Lower Yangtze River Basin) (Liu et al. 2011b). Most dates of archaeobotanical evidence of tree nuts, including evidence of macro remains and starch granules show a concentration of acorn use during the Early and Middle Holocene (Table 8.1 and Table 8.2). Dates that roughly overlapped with the emergence of rice farming in the Yangtze River Basin and millet agriculture in North China (e.g. Fuller and Qin 2010; Ma et al. 2016; Yang et al. 2012). Along the Yangtze river, the decline in the pollen of acorn bearing trees although not be entirely regional synchronous, took place sometime between 6,000 BC and 4,000 BC (e.g. Atahan et al. 2008; Tao et al. 2006; Yi et al. 2003; Zong et al. 2007), which pushed the increasing dependence on rice. Although human activities would have also contributed to deforestation, based on micro-charcoal records (Atahan et al. 2008; Zong et al. 2007), Fuller and Qin (2010) suggested it seems to be climate-driven result, as such trends correlated with the temperature and precipitation reduction in the Mid-Holocene.

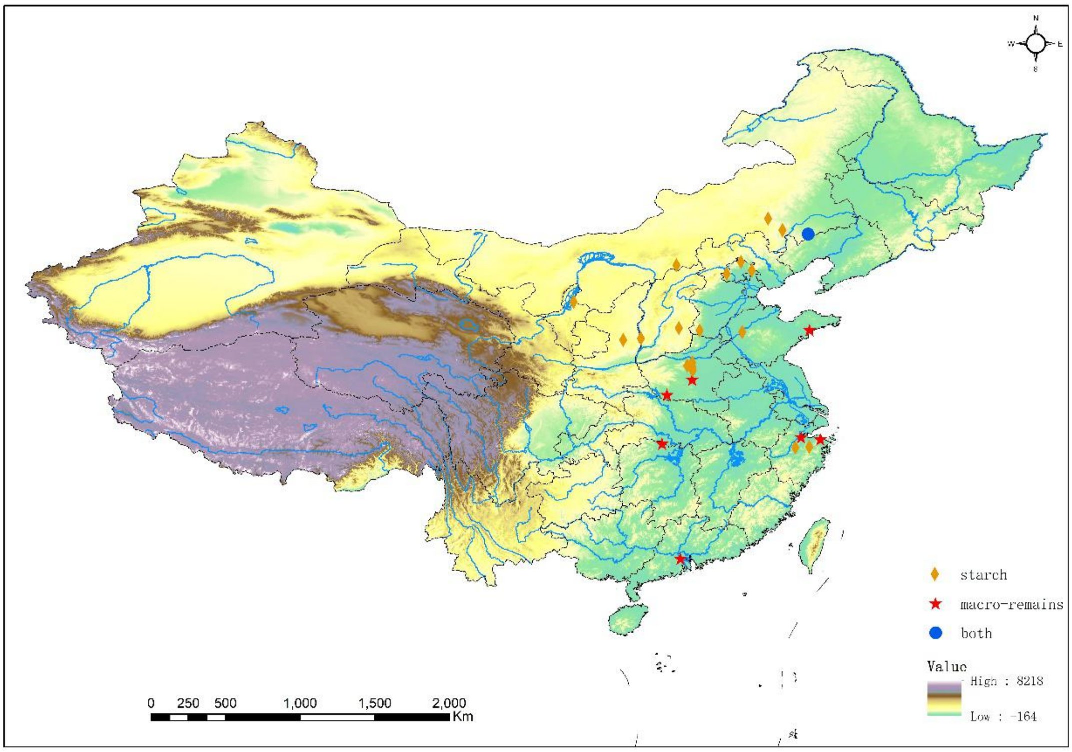

Figure 8. 1 Sites where acorn remains were recovered in China. (data are shown in Table 8.1 and Table 8.2).

Although the pollen records showed that oak woodlands were widely distributed in the Pearl River Delta, the number of the nutshells was small at few sites, like Longxue site (c. 6,000 BP) (Table 2.4) and Maogang site (c. 3,500 BP) (Table 2.5) (Yang et al. 2015: 266; Yang 1985). In 2006, a large sample of preserved nut exocarps, mainly *Lithocarpus* were unearthed during the excavation of Guye site (c. 5,900-5,000 BP) (Cui 2007), suggesting acorn consumption in large quantities after 6,000 BP in the Pearl River Delta region (Yang et al. 2018).

The acorn starch results in this thesis detected that, in the Pearl River Delta, acorn

(*Lithocarpus/ Cyclobalanopsis/ Quercus*) and oak-chestnut (*Castanopsis*) were stable starch foodstuffs in three millennia from 6,000 to 3,000 BP. Based on the starch results, the choice of tree nuts and temporal changes of acorn consumption were revealed. Further, combined with the ethnographic studies and pollen analysis, the processing method of acorn/oak-chestnut and the management of oak woodlands could be further speculated.

8.1.1 Choice of tree nuts

Analyses of starch and macro plant remains from northern China and the Yangtze River Basin indicates that acorn consumption was dominated by the species of *Quercus* (Table 8.1 and Table 8.2). In the study region, there appears to be a preference for *Castanopsis*. The starch results present that *Castanopsis* became the primary food choice of acorns in the later phase of Guye site (c. 5,000 BP) (Figure 7.6), and the other study sites, except Yuanzhou site (c. 4,500 BP), also show a tendency of *Castanopsis* preference(Figure 7.27). The preferential selection of those tree nuts did not change even during the acorn decline (Figure 7.27). This preference seems to be similar to that in mainland Southeast Asia. Those Hoabhinnian sites in Thailand and Vietnam have preserved a large number of nutshells of *Castanopsis* and *Juglans* (Higham 2014; Lentfer et al. 2013).

A reason for the preference of *Castanopsis* may be the accessibility of this genus. Pollen sequences reflected the arboreal flora around delta, indicating that during the late Holocene: this area was thickly covered by *Castanopsis, Lithocarpus, Quercus*, and *Pinus*, within them, *Castanopsis* is dominant (e.g. Ma et al. 2018; Peng et al. 2015; Wang et al. 2009; Yang et al. 2012; Zhao et al. 2014; Zheng et al. 2004; Zong et al. 2009). Another possible reason for the tree nut choices could derive from their taste. Acorns contain tannin, which makes them taste a little bitter and astringent (Bai et al. 2000; Xie and Xie 2002). However, some oak-chestnuts may produce sweet kernels, such as *Castanopsis eyrei*, owing to their higher reducing sugar content (Liu et al. 2009; Yang et al. 2005). Yang et al. (2005) tested the reducing sugar content of eight wild acorns collected from Jiangxi Province and north of Guangdong. Their results showed that the nuts of *Castanopsis*, especially *Castanopsis eyrei*, have better taste and sweetness than *Cyclobalanopsis*, and *Lithocarpus*. The similar work from Liu et al. (2009), examining ten samples, supported the the previous study.

Further analysis of the acorn choices shows the regional differences in the Pearl River Delta. During the period when acorns were used in large quantities (6,000 to 5,000 BP), the comparison between Guye site and Haogang site indicates the difference of acorn use between the North River and East River to some extent. The apparent differences derived from *Castanopsis* and *Lithocarpus* (Figure 7.29 b). The results of Guye site, located in the North River Basin, show the possibility of *Lithocarpus* use was slightly higher than *Castanopsis* (Table 7.3), but in Haogang community, the residents showed a clear preference for *Castanopsis* (Table 7.7).

When the use of acorn reduced (4,500 to 3,000 BP), the regional difference became clear. During this period, *Castanopsis* was not the first tree nut sources in the East River Delta. It has the same proportion as *Cyclobalanopsis* at Cuntou site (Table 7.12). The most extreme case is Yuanzhou site, at which no starch granules of *Castanopsis* were recovered (Table 7.10). In contrast, the results of Yinzhou site, along the North-West River, *Castanopsis* became the leading genus of tree nuts (Table 7.4), replacing the dominance of *Lithocarpus* recovered at Guye site. Meanwhile, the residents in the northernmost region of the Pearl River Delta tended to keep consuming *Castanopsis*, because the simple combination of acorn starch granules at Hengling site only contains *Castanopsis* (n=24) and *Lithocarpus* (n=3) (Table 7.5). However, the reason for these changes is still not clear.

Table 8. 1 Macro-remains of acorns recovered in China during Holocene

Site name	Xinglonggou Loc.1	Beiqian09&11	Jiahu	Baligang	Bashidang	Kuahuqiao	Tianluoshan	Guye
Province, District city	Inner Mongolia	Shandong	Henan	Hena/	Hunan	Zhejiang	Zhejiang	Guangdong
County	Chifeng	Jimo	Wuyang	Dengzhou	Lixian	Xiaoshan	Yuyao	Foshan
Age range (cal yr BP)	8,000~7,500	6,200~5,500	9,000~7,800	8,700~8,300	9,000~7,600	8,200~7,000	7,000~6,000	5,900~5,000
Data references	Sun 2014	Wang 2012	Zhao and Zhang 2009	Deng et al. 2015	Institute of Cultural Relics and Archaeology of Hunan 2006	Pan 2011; Institute of Cultural Relics and Archaeology of Zhejiang and Museum of Xiaoshan District 2004	Fuller et al. 2011	Yang et al. 2018
***Cyclobalanopsis* sp.**	0	0	0	116	0	0	13	0
Fagaceae	0	0	0	0	0	267	0	innumerable
Lithocarpus	0	0	0	0	0	0	0	innumerable
Lithocarpus pachyphyllus	0	0	0	0	0	0	26	0
Lithocarpus amygdalifolius	0	0	0	0	0	0	0	2
Lithocarpus corneus	0	0	0	0	0	0	0	2
***Quercus* sp.**	33	7	365	0	5	0	31268	0
Quercus fabri	0	0	0	0	0	22	0	0
Quercus acutissima	0	0	0	0	0	26	0	0
Quercus variabilis	0	0	0	0	0	10	0	0

Table 8. 2 Starch grains of acorns recovered in China during Holocene

Site name	Province, District city/County	Age range (cal yr BP)	*Cyclobalanopsis* sp.	Fagaceae	*Lithocarpus*	*Quercus* sp.	*Quercus mongolica*	*Quercus acutissima*	*Quercus dentata*	Data references
Zhuannian	Beijing/Huairou	11,000~9,700	0	0	0	1	0	6	0	Ma 2014
Donghulin	Beijing/Mentougou	11,000~9,500	0	0	>30	~92	0	0	0	Liu et al 2010a
Shangzhai	Beijing/Pinggu	7,400~6,700	0	0	0	2	3	9	8	Yang et al 2009
Cishan	Hebei/Wuan	8,000~7,000	0	0	0	5	0	0	0	Ma 2014
Shigu	Henan/Changge	8,000~7,000	0	0	22	10	0	0	0	Liu et al 2010b; Zhang 2011
Egou	Henan/Xinmi	8,500~7,000	154	0	153	53	0	0	0	Liu et al 2010b; Zhang 2011
Tanghu	Henan/Xinzheng	7,800~7,000	0	0	0	21	0	0	0	Yang et al 2015
Shawoli	Henan/Xinzheng	8,500~7,000	0	0	0	65	0	0	0	Zhang 2011
Peiligang	Henan/Xinzheng	8,500~7,000	0	0	0	495	0	0	0	Zhang et al 2011
Gouwan	Henan/Xichuan	8,500~4,000	0	0	0	5	0	0	0	Zhao 2018
Xinglonggou Loc.1	Inner Mongolia/Chifeng	8,000~7,500	0	0	0	2	0	0	0	Liu et al 2015
Beishandong	Inner Mongolia/Chifeng	~8,200	0	0	0	6	0	0	0	Ma et al. 2016
Beishanxi	Inner Mongolia/Chifeng	~8,200	0	0	0	9	0	0	0	Ma et al. 2016
Aohanyingzidong	Inner Mongolia/Chifeng	8,200~7,400	0	0	0	8	0	0	0	Ma et al. 2016
Aohanyingzixi	Inner Mongolia/Chifeng	8,200~7,400	0	0	0	3	0	0	0	Ma et al. 2016
Baiyinchanghan	Inner Mongolia/Chifeng	8,500~7,400	0	3	0	19	0	1	0	Tao et al 2011
ShihushanII	Inner Mongolia/Liangcheng	7,000~6,700	0	0	0	3	0	0	0	Liu et al 2014a; Liu et al 2014b
Yuezhuang	Shandong/Changqing	8,000~7,800	0	0	0	21	0	0	0	Wang et al 2012
Liujizhuangzi	Shandong/zhucheng	~7,500	0	0	0	1	0	0	0	Wu et al. 2017
Zhangmatun	Shandong/Jinan	~9,000	0	0	0	9	0	0	0	Zhao et al. 2017

Niubiziwan	Shanxi/Wuxiang	8,000~7,000	0	0	0	32	0	0	0	Liu et al 2014c
Shangshan	Zhejiang/Pujiang	11,400~8,600	0	0	0	100	0	0	0	Liu et al 2010c
Xiaohuangshan	Zhejiang/Shengzhou	9,000~7,700	0	0	18	10	0	0	0	Liu et al 2010c; Yao et al. 2016

8.1.2 Temporal changes of acorn consumption

The starch granules results (Figure 7.25) reflected an obvious declined trend of acorn use from 6,000 to 5,000 BP, which proportion decreased from 60% at Guye site to around 30% at the other five settlements, together with the reduction in the total and the average count of starch granules recovered from those studied tools (Figure 7.26). The first speculation of this decline is environmental factors, like the discussion in the lower Yangtze River (Fuller and Qin 2010). But the Pearl River Delta, according to pollen analyses, was covered by subtropical evergreen forest, dominant by *Castanopsis/Lithocarpus* and *Quercus* before around 4,000 BP, only with slight fluctuations (e.g. Huang et al. 2014; Ma et al. 2018; Peng et al. 2015; Zhao et al. 2012). Therefore, the availability change of tree nut may be influenced the acorn consumption at site scale, but was hard to have regional impacts.

Another possibility is the emergence of other alternative resources. Unlike in the Lower Yangtze region, where the decline of oak forests encouraged the development of rice cultivation (Fuller and Qin 2010), in the Pearl River Delta, the alternative resources are possibly the abundant geophyte resources (Figure 7.25). The most likely reason derives from the relatively lower return rate of the acorn than geophytes, which reveals the relationship between energy obtained from foods and their gathering, processing, cooking, and storage cost. The two major starch plants used in the Pearl River Delta, geophytes and acorns, ripen and be gathered in the autumn/early winter, and late winter/early spring separately (Chinese Flora Editorial Board, Chinese Academy of Sciences 2004). It seems that their consumption should not conflict with each other. But acorn/oak-chestnut are often considered as labor-intensive foods, which may delay their use of (Basgall 1987; Tushingham and Bettinger 2013). The return rate of geophytes, which evaluated in North America, is the highest, followed by nuts, small seeds, and aquatic roots (Table 8.3). The return rate of yams (*Dioscorea* sp.) in Guangxi (around 1,300 kcal/h) is also much higher than that of the wild rice (*Oryza rufipogon*) (116 kcal/h) (Zhao et al. 2005). In the case of the much higher return rates of geophytes, the reduction in acorn use can be understood. Therefore, the proportion adjustment between geophytes and acorns during the period from 6,000 to 5,000 BP in the Pearl River Delta probably was related to this return rate ranking.

Table 8. 3 Return rates (kcal/h) for North America (Wohlgemuth 2010)

Resources	Terrestrial roots	Non-toxic nuts	Toxic nuts	Small seeds	Aquatic roots
Range	1,000-4,000	609-1,700	448-1,150	91-1,307	154-208
Mean	2,266.7	935.6	832.3	363.7	181.5

The declined tendency seems to have stopped at around 4,500 years ago (Figure 7.25), and the starchy foodstuff assemblage started the period of long-term balance during the period between 4,500 BP and 3,000 BP. Based on the starch results, this assemblage at least included around 30% tree nut, 30% geophytes, and a small amount of starch piths and small seeds.

8.1.3 Processing tools

The starch results in this thesis provide some direct evidence of acorn processing on a variety of ground and pebble tools, including handstones, netherstones, hammerstones, and pestles. My results show that netherstones in the Pearl River Delta were mainly used for acorn and geophyte processing, but rarely for small seed processing. For example, at Haogang site, the acorn starch grains recovered from netherstones account for 48% of the total, with 10% millet (Figure 7.16). And at Yuanzhou site and Cuntou site, there is no record of millet starch granules from the sampled netherstones (Table 7.10 and Table 7.12). This tendency is also found in other regions of China as well, such as at Shizitan site (c. 13,800-8,500 BP) in North China and Xiaohuangshan site (c. 11,800-8,000 BP) in the Lower Yangtze River (Liu et al. 2010; 2011).

The starch results show that acorns were processed using pestles. This extends our functional understanding of these tools, which were also considered to be used for dehusking cereals, or pounding seasoning or palm pith (see Section 3.3). The recovery of starch from hammerstones and some unmodified pebbles also demonstrates their role in acorn processing (Figure 7.4 and Figure 7.10). The results correspond to the ethnographic observation in Japan, which shows that some hammerstones used for several years to process acorns may appear to be unmodified (Liu 2010). Therefore, the presence of unmodified stones (cobbles and pebbles) recovered from these sites should also be considered likely food processing technology and not ignored or discarded.

8.1.4 Management of arboreal resources

One of the implications raised by this study is whether wild oaks were under some form of management by the people who exploited them. Indigenous systems of *in situ* tree management are widespread throughout island Southeast Asia (Colfer 1997: 79; Peluso and Padoch 2003: 155) and across the Pacific (Kennedy and Clarke 2004). The potential management of oaks in southern China is not an area of current research, and it has not been proposed in previous studies, however, knowledge of historic management strategies in Japan and California could provide useful comparisons.

For Jomon people in Japan, the chestnut trees around settlements were not only used for food sources but also as timber resources for lowland construction (Kawashima 2016; Noshiro 2016; Noshiro and Sasaki 2014). The timber ages of *Castanea crenata* were mostly younger than ten years old, while other timber species from the secondary forest may be up to 30 years old, at Shimo-yakebe site with Jomon culture in Japan, suggesting that the management system of native chestnut trees has been established (Noshiro and Sasaki 2014). The simulated experiment of timber felling revealed that the chestnut trees could be felled by stone axes, and it is an easy task to fell a chestnut tree less than ten cm in diameter, which will take less than ten minutes (Noshiro and Sasaki 2014). But for native Californians, the management of oak forests was burning their undergrowth for improvement of acorn productivity, according to historical and ethnographic records (e.g. Anderson 2013; Lightfoot et al. 2013, Wohlgemuth 2010). However, this fire management system is difficult to be identified due to the challenge of distinguishing the natural and humanity fire records (Wohlgemuth 2010).

In the Pearl River Delta during the late Holocene, low-frequency fire activities, revealed by sparse charcoal records, could be recognised (Peng et al. 2015; Ma et al. 2018). Meanwhile, the proportion of woodworking tools, for example, stone adze, increased. It could be speculated that the subtropical forest around Neolithic settlements in the Pearl River Delta possibly to be managed, through conscious choice for timber or fire activities, like other communities did in southern California and Japan (e.g. Kawashima 2016; Lightfoot and Parrish 2009; Lightfoot et al. 2013; Noshiro 2016; Wohlgemuth 2010). But more diagnostic evidence is still needed to determine the existence of forest management and recognize the accurate management way of the forest.

8.2 Geophytes

Some geophytes, like potato (*Solanum tuberosum*), yams (*Dioscorea* spp.) and taro (*Colocasia esculenta*), are globally important crops (Denham et al. 2020). In China, the long history of geophyte use, reviewed in chapter 3, was not only recorded by ethnic minorities' oral history and legends in southern China but also indicated by the starch residues recovered from grinding stone tools. (Figure 8.2) (e.g. Dong et al. 2014; Li et al. 2010; Liu et al. 2014; Tao et al. 2015; Wan et al. 2011; Wu et al. 2015; Yang et al. 2013; Zhang et al. 2011). These plants mainly include *Dioscorea* spp., *Nelumbo nucifera*, *Lilium* spp., *Alisma* spp., *Sagittaria* sp., Zingiberaceae (Table 3.8), as well as *Colocasia,* which starch residues were recovered from the stones tools only at Zengpiyan site (c. 12,000 BP-7,000 BP) in Guangxi, South China (Lu 2003).This section will discuss the geophyte use and its temporal change in the Pearl River Delta from 6,000 to 3,000 BP. And combined with the ethnological records in southern China, the cultivation practices could be inferred.

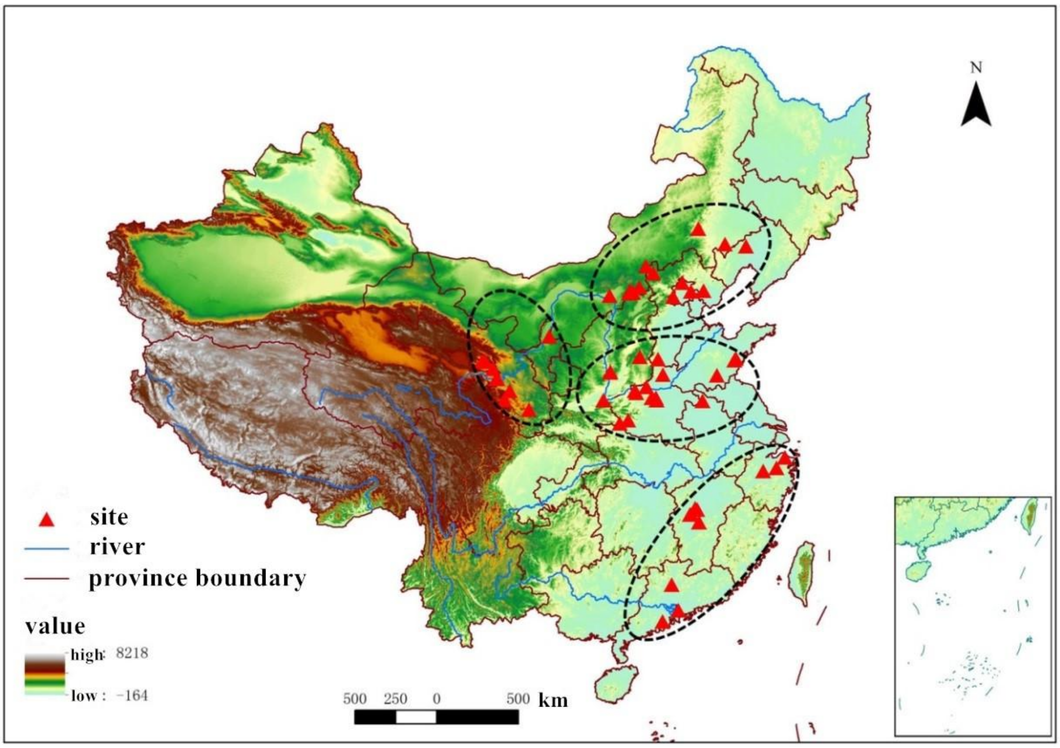

Figure 8. 2 Distribution of the sites where geophyte starch grains recovered in Paleolithic and Neolithic China (from Wang 2017)

8.2.1 Geophytes use in the Pearl River Delta

Previous starch residue analyses in the Pearl River Delta included two case studies: the one is Xincun site (5,300-4,400 BP), and the other is Lujingcun site (c. 4,000 BP) (Wan 2012; Wang 2017; Yang et al. 2013). At Xincun site, the geophyte starch granules include lotus (cf. *Nelumbo nucifera*) (N=2), Chinese arrowhead (*Sagittaria* sp.) (N=17), water chestnut (cf. *Eleocharis dulcis*) (N=29), and fern-root (*Angiopteris* sp.) (N=38), which total count is similar to that of sago palms (N=86) (Yang et al. 2013). Although this result proposed the importance of sago, the geophyte also an unignored kind of plant food at this site (Yang et al. 2013). At Lujingcun site, the total number of geophyte starch granules is 209, smaller than that of acorns (279), within them, the identified geophyte plants are different from those at Xincun site, including *Dioscorea*, *Fallopia*, and *Trichosanthes* (Wang 2017).

Regardless of the identifiable genus, in terms of the proportions, the geophyte starch granules are within the top two types in both these two case studies, which is 19% at Xincun site (N=454), the same as that of sago palms (19%), and 25% at Lujingcun site

(N=841), lower than that of acorns (33%). This tendency is similar to the results of my thesis. After 4,500 BP, the geophyte starch granules have similar proportions to acorns at five study sites, which are around 30% (Figure 7.25).

However, the situation from the previous millennium (6,000-5,000 BP) seems to be different. At that time, the geophytes were not likely staple foods, but supplementary carbohydrate sources in the Pearl River Delta, as the proportions of geophytes are much lower than those of acorns (Figure 7.25). This may suggest that in the oak woodlands of the Pearl River Delta, people did not depend heavily geophytes in the early period. Although the reasons for the early disregard of geophytes are unclear, these results at least show that these plants have been continuously used in the Pearl River Delta during these three millennia, and have become significant foods over time.

8.2.2 Cultivation of geophytes

Although the starch results cannot reflect the cultivation practices, according to the long-term use of these plants, together with the ethnological studies in southern China and historic documents, it could be speculated that geophyte cultivation possibly existed in the Pearl River Delta. The earliest geophyte cultivation may not require much space, which can be carried on in the forest space, cleared by axes (see section 3.1). Therefore, the geophyte cultivation in woodlands would have been emerged before slash and burn cultivation. Combined with charcoal record (in section 2.1), the initial geophyte cultivation in the delta possibly began before 3,500 BP.

One reason for pushing the cultivation is the reduced availability of resources. Li and Lu (1987) provided an example of wild tuber cultivation in Bijiang county, northwest of Yunnan.The local name of the plant is Bai'er (败儿, *Hemsleya* sp.), which have perennial good-taste tubers that can weigh up to 25 kg (Li and Lu 1987). In order to prevent it from disappearing due to excessive collection, Nu people began to cultivate it about 150 years ago (Li and Lu 1987). The method is cut the germinant part of the tuber and planted in its original position or in the garden. Li and Lu (1987) also mentioned that Nu people still collected "wild" taro (maybe feral ones) and transplant them in the field.

The long-period cultivation may cause the phenotypic variability. The earliest crop, taro (*Colocasia esculenta*), in a Nu village, shows such changes (Li and Lu 1987: 130): 1) The leaves of wild taro is long and small, and have red edge and vein, but those of cultivated taro are round, big and green. 2) The tuber of wild have small size and red colour, with few cormels, but the cultivated one are white and large-size with several cormels. 3) The cultivated tubers are ease of cook and have better taste. However, the archaeobotanical remains are still ambiguous to distinguish wild and domesticated taros (Denham et al. 2020).

8.3 Starch plant assemblages in the Pearl River Delta

The starch evidence in this thesis provided information about the plant exploitation assemblages in the Pearl River Delta during the period from 6,000 to 3,000 BP. Totally, during these three millennia, acorns/oak-chestnuts and geophytes were the essential carbohydrate sources, with a low proportion of starch pith and some small seeds. During the middle Neolithic period, acorns and oak-chestnuts undoubtful were the most essential starch sources for the indigenous communities in the Pearl River Delta, and other plants, such as geophytes and small seeds, should be supplementary resources at that time. After around 4,500 BP, the starchy food assemblage in the Pearl River Delta became stable. From then on, the proportion of two key plants, acorns/oak-chestnuts, and geophytes, has stabilized at around 30% of the total separately. While the oak forest management and geophyte cultivation probably emerged these three millennia.

However, the average counts of recovered starch granules declined with the stability of these two plants, suggesting that at that time, the original plant-related subsistence system possible influenced by some factors and have some transitions. Some other starch foodstuffs, for example, rice, probably were introduced in the diet of these communities. These will be discussed in the next chapter.

Chapter 9: Changes in subsistence practices in the Pearl River Delta

The discussion in this chapter focused on the subsistence changes in the Pearl River Delta during the three millennia from 6,000 to 3,000 BP. Assessed materials will include ancient starch recovered in this study and plant and animal remains published elsewhere. Evidence of changes in the toolkits, especially of grinding and pounding tools, provided additional evidence about changes in subsistence practices, was also reviewed. The purpose of this review is to situate the results of this study into a wider archaeological context and to better understand local and regional changes in subsistence practices during the mid- to late-Holocene. A secondary aim is also to better understand prehistoric lifeways into which rice and perhaps other grains were introduced and adopted after 4,500 BP.

In this chapter, I first discussed what we know of foraging from 6,000 BP. Then, I will examine the subsistence changes that occurred at around 4,500 BP, including the changes in native food processing technologies and external impacts from other regions. The results strongly suggest that agriculture probably emerged in the late, rather than the early or middle Neolithic. The analyses of tools and starch granules in this thesis, suggests that the earliest forms of food production in the region possibly involved small-scale horticulture (roots and tubers) or forest management (e.g. of oaks), with very limited impact from cereal cultivation (e.g. rice and millets).

9.1 Broad-spectrum foraging and woodland exploitation in the middle Neolithic

In the early to middle Neolithic period, 7,000-5,000 BP, there is as yet, no evidence of agricultural activities in coastal Guangdong, while there is evidence for sedentary village occupation, use of pottery, polished stone tools and burial of the dead (see Chapter 2). These communities are normally classified as hunter-fisher-gatherers and as complex hunter-gatherers (e.g. Zhang and Hung 2009; 2016). Because organic preservation in the region is generally poor, there is little direct evidence of foraging activity apart from shellfish middens and the well-preserved macro plant remains from the Guye site (5,900-5,000 BP). In the Pearl River Delta, fishing should be a significant part, as this region was once a broad estuary (Figure 4.1). Here the midden remains have been useful, with large numbers of marine oysters recovered at Haogang site (c. 6,000-4,000 BP), freshwater mollusk shells collected at Guye site (5,900-5,000 BP), together with fish bones and tortoise bones at a number of sites (e.g. Cui 2007; Feng 2007; Yang et al. 2015). It is also suspected that the pointed tools (e.g. Figure 4.8) are designed to open shellfish (e.g. Li 2019). Forest hunting must have been important, with some remains of terrestrial animals recovered, including deer, pig (wild), dog (wild), water buffalo (wild), and elephant *Elephas* (see Section 2.2) (Cui 2007; Yang et al. 2015).

Plant use and plant-based subsistence in the study region is poorly understood. Prior research has proposed two possibilities. The first is that geophytes (roots, tubers, corms) were a primary food resource, a view largely based on ethnographic observations from the region, up to and prior to the 1950s (e.g. Cao et al. 2007; Dao et al. 2003; Li and Lu 1987; Liu et al. 2012; Lu 2007; Wang and Long 1995; Yan 2005; Ye 1992a; 1992b; Yin 2000), and the other is that inicipient or early forms of horticulture, perhaps involving the use of sago palms and geophytes, were either in place or emerging from the mid-Holocene onwards (Table 9.1) (Yang et al. 2013). Studies in areas with similar humid subtropical or tropical climates, indicate that pre-agricultural plant use strategies of foragers were often more diverse than thought (e.g. Barker et al. 2007; Barton 2005). For example, floral data at Niah cave site from Early Holocene suggest the consumption of palm starch (sago), yam, aroid tubers (related to or including taro), and nuts (requiring detoxification), representative of a wider Island Southeast Asian forest vegecultural adaptation (Barton and Denham 2011). In mainland Southeast Asia, work at Spirit Cave in northwest Thailand produced a diverse seed assemblage associated with Hoabhinian material culture (9,000-5,500 BC), including a predominance of endocarp fragment of *Canarium*, as well as shell of *Prunus, Castanopsis* (oak-chestnut) and *Terminalia*, indicating a exploitation of nuts and fruit from surrounding forests (Higham 2014).

Starch analyses in this thesis adds significantly to this data set and to the information available for southern China (Table 9.1). So far, what can be confirmed is that, in the Pearl River Delta during the middle Neolithic, sedentary communities were heavily reliant on acorns, especially species well represented in lowland broadleaf evergreen forest, as well as roots and tubers from forest and swamp environments and from species that do well in disturbed habitat.

The presences of these forest resources in the Neolithic diet further imply that the indigenous communities had high-level knowledge of woody starch plant process. Both acorns and sago recovered in the delta are considered as labour-intensive food resources gathered from the woodlands. For example, although the acorn collection is relatively easy (though the temporal window for collection may be limited, so careful planning is necessary), but they are labour intensive to be dried, stored, and processed before consumption (e.g. Basgall 1987; Messner 2011), and some toxic types require more complicated processing for detoxification, such as boiling or repeated soaking (Dong 1994; Tuechler 2014). The traditional palm processes also include shredding the pith and repeated washing to release the starch flour (Ge 2015).

Table 9. 1 Plant remains in the Pearl River Delta before 5,000 BP

Site	Date (BP)	Plant remains			Source
		Macro remains	Starch grains	Phytoliths	
Guye	5,900-5,000	*Lithocarpus* spp.; *Canarium album*; Urticaceae mainly	acorn 60%; geophytes 8%		Cui 2007; Yang et al. 2018; this thesis
Xincun	5,300-4,420		palms; *Musa* sp.; cf. *Nelumbo nucifera*; *Sagittari*a sp.; cf. *Eleocharis dulcis*; *Angiopteris* sp.; *Coix* spp; *Quercus* sp.	palms; sedge; fern; *Oryza*; bamboo; others	Yang et al. 2013
Haogang-2	5,500-5,000		acorn 41%; geophytes 23%		This thesis

However, the forest can not only provide valuable foods, but also support other activities, such as the space obtaining through forest clearance and some woodworking activities. For example, some delicate wooden tools preserved at Guye site and Fanfoan site (c. 6,500 BP) (Cui 2007; Shenzhen Cultural Relics and Archeology Institute 2013). Besides, another evidence, suggestive of the existence of skilled workers, is the stone bark cloth beater widely unearthed across the delta, and being ever pandemic in south China and Southeast Asia (Deng 2007). These beaters are the stones have a grooved surface, with several parallel grooves (Figure 3). It is argued that this kind of tools was creatively used for transforming bark fibers to cloth, alternative to textiles (Deng 2007). In addition, Li people in Hainan believes that the best trees for bark cloth making is *Antiaris toxicaria* with strong toxicity (Wang 2006), which, on the other hand, suggest that the inhabitants of the middle Neolithic were presumably already aware of trees.

9.2 Indigenous evolution of plant-related subsistence in the Pearl River Delta

The evidence recovered in the late Neolithic period suggest that hunting and gathering remained an important subsistence strategy until the late Holocene (e.g. Huang et al. 2016; Ma et al. 2018; Peng et al. 2015; Xia et al. 2019; Yang 1985; Zheng et al. 2004; Zhang and Hung 2010). For example, charred remains of Leguminosae, Solanaceae, Amaranthaceae, and *Canarium* sp. floated at Chaling site (c. 4,500 BP) in the coastal region (Xia et al. 2019) (Table 9.2). And 135 olive seeds (*Canarium*), with a small number of ginkgo (*Ginkgo*), jujube (*Ziziphus*) and persimmon (*Diospyros*) found at Maogang site (c. 3,500 BP) in the north part of the delta (Table 9.2) (Yang 1985;Yang, H. and Yang, Y. 1983).

Table 9. 2 Plant remains in the Pearl River Delta after 4,500 BP

Site	Date (BP)	Plant remains			Source
		Macro remains	Starch grains	Phytoliths	
Sha Ha-Neolithic layer	c. 4,500-4,000	Rice seed		Cucurbitaceae (possibly domesticated), Oryzoideae	Lu 2007
Haogang-3	4,500-4,000		Acorn 23%; geophytes 33%		Data in this thesis
Yuanzhou	c. 4,500		Acorn 36%; geophytes 36%		Data in this thesis
Chaling	4,500-3,700	*Oryza sativa; Leguminosae, Solanaceae, Amaranthaceae ; Canarium sp*		*Oryza*; Arecaceae; Cucurbitaceae; Annonaceae; Fagaceae?	Xia et al. 2019; Yang et al. 2018
Yinzhou	c. 4,500		Acorn 29%; geophytes 33%		Data in this thesis
Hengling	4,000-3,000		Acorn 26%; geophytes 31%		Data in this thesis
Cuntou	4,100-3,000		Acorn 34%; geophytes 27%		Data in this thesis

However, some changes in local subsistence in the Pearl River Delta could be observed according to materials of the six study sites in my thesis. I firstly reorganized the starch data recovered in this thesis (Figure 9.1 a and b) and the published materials of grinding/pounding tools (Figure 9.1 c). The starch results in this thesis indicate that after between 4,500 BP to 3,000 BP, a regionally recognized starch foodstuff assemblage in the Pearl River Delta has been formed, which were composed of acorns/oak-chestnuts and geophytes (Figure 9.1 a), probably suggesting a long-term intensifying exploitation of these two kinds of plants in the late Neolithic Pearl River Delta. Besides gathering, some attempts at cultivation of indigenous plants at that time. For example, the possible domesticated-type phytoliths of Cucurbitaceae found at the Sha Ha Site (c. 4,500 BP) (Table 9.2) were interpreted as suggestive that cultivation had emerged in Hong Kong (Lu 2005).

The changes in plant use were accompanied by the decrease in the average counts of starch granules recovered on each stone tools in the late Neolithic period (Figure 9.1 b), which is probably suggestive of declining use of those grinding or pounding tools. Meanwhile, these grinding and pounding tools at the study sites not only were less used in processing starch plants but also reduced in proportion (Figure 9.1 c). As I did not get specific data of the stone tool counts at Hengling site and Yinzhou site, Figure 9.1 c only presents the data from four sites, shown in Table 9.3. The comparisons among these four sites indicate that in the late Neolithic period, the ratio between grinding/pounding tools and other formal tools, including woodworking tools: axes and adzes, is lower than those in the middle Neolithic period (Figure 9.1 c). Without considering the outlier of the third phase of the Hoangang site, these ratios between the grinding/pounding tools and other formal tools can correspond to the changes in the combination of starch granules (Figure 9.1).

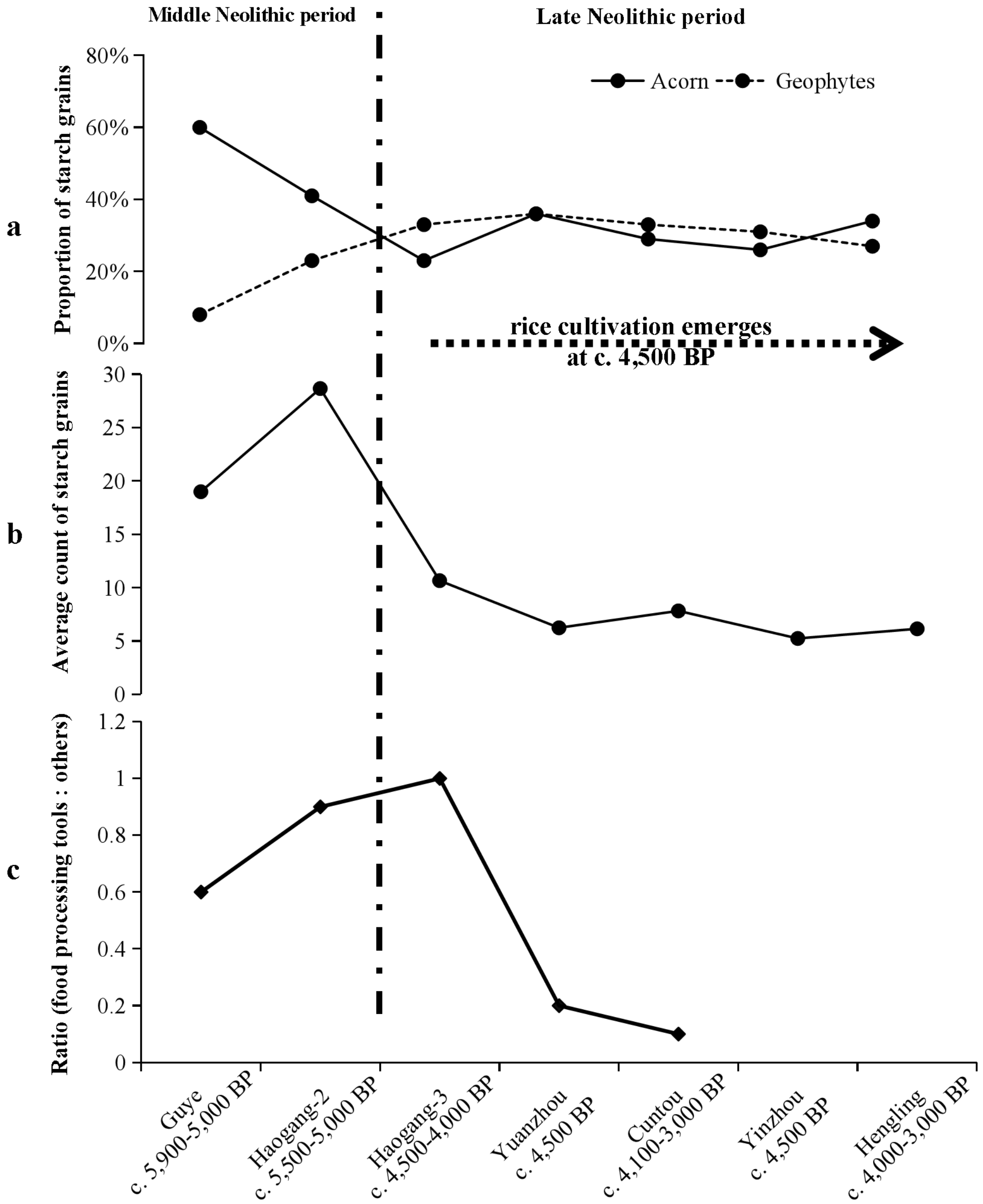

Figure 9. 1 Subsistence transition in the Pearl River Delta revealed by starch grains and use of grinding and pounding tools from the middle Neolithic period to the late Neolithic period. a, the proportion of acorn and geophyte starch grains; b, the average count starch grains recovered from each sampled tools; c, the ratio between grinding and pounding tools and other tools.

Table 9. 3 Tool kits unearthed in the Pearl River Delta during the middle and late Neolithic period (He et al. 2012; Li et al. 2005; Liu 2007; Shenzhen Cultural Relics and Archaeology Institute 2013; Wen and Chen 1990)

	Site	Xiantouling		Longxue		Dahuangsha		Xincun[1]-layer A		Guye site[2]		Haogang[3]-2	
	Date (/BP)	7,000-6,000		c. 6,000		c. 6,000		c. 6,000		5,900-5,000		5,500-5,000	
	Site type	sand dune		sand dune		sand dune		sand dune		shell midden		shell midden	
		count	proportion	count	proportion	count	proportion	count	proportion	count	proportion	count	proportion
Food processing tools	Hammerstone	4	2%	9	8%	1	1%	7	8%	118	27%	0	0%
	Handstone	46	27%	52	48%	16	21%	0	0%	0	0%	13	43%
	Netherstone	52	31%	32	30%	31	40%	42	49%	39	9%	1	3%
	Pestle	17	10%	0	0%	0	0%	9	10%	0	0%	0	0%
	total	119	71%	93	86%	48	62%	58	67%	157	36%	14	47%
Other formal tools	Adze	36	21%	4	4%	20	26%	21	24%	278	64%	7	23%
	Axe	0	0%	9	8%	8	10%	0	0%	0	0%	8	27%
	Chisel	13	8%	0	0%	1	1%	3	3%	0	0%	0	0%
	Knife	0	0%	2	2%	1	1%	4	5%	0	0%	1	3%
	Shovel	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
	total	49	29%	15	14%	30	38%	28	33%	278	64%	16	53%
	Ratio (food processing tools: formal tools)	2.4		6.2		1.6		2		0.6		0.9	

1 Xincun site in Hong Kong

2 Data of Guye site are from preliminary statistics (He and Li, 2012). Some handstones maybe misclassified as hammerstone. Specific data should be based on the forthcoming report

3 The data of Haogang site are provided by Haogang Museum in Dongguan City.

Table 9.3 Tool kits unearthed in the Pearl River Delta during the middle and late Neolithic period (continued) (Chen and He 1984; Guangdong Museum and Foshan Museum 2006; Lou and Huang 2009; Mo 2003; Wu 2000; Yang 1985)

	Site	Sha Ha[1]		Haogang-3		Yuanzhou		Hedang-甲		Zaogang		Maogang		Cuntou	
	Date (/BP)	c. 4,500-4,000		4,500-4,000		c. 4,500		4,300-3,500		c. 4,000		c.3,500		4,100-3,000	
	Site type	sand dune		shell midden		shell midden		shell midden		shell midden		shell midden		shell midden	
		count	proportion	count	proportion	count	proportion	count	porportion	count	proportion	count	proportion	count	proportion
Food processing tools	Hammerstone	17	12%	5	8%	0	0%	0	0%	2	4%	0	0%	0	0%
	Handstone	3	2%	8	13%	0	0%	0	0%	0	0%	0	0%	11	2%
	Netherstone*	5	4%	17	27%	4	15%	24	25%	5	10%	32	59%	18	3%
	Pestle	0	0%	1	2%	0	0%	0	0%	0	0%	0	0%	30	4%
	Total	25	18%	31	49%	4	15%	24	25%	7	15%	32	59%	59	9%
Other formal tools	Adze	113	80%	20	32%	22	81%	66	69%	38	79%	10	19%	616	89%
	Axe	3	2%	7	11%	0	0%	1	1%	1	2%	7	13%	11	2%
	Chisel	0	0%	2	3%	1	4%	4	4%	0	0%	5	9%	2	0%
	Knife	0	0%	3	5%	0	0%	0	0%	0	0%	0	0%	0	0%
	Shovel	0	0%	0	0%	0	0%	0	0%	2	4%	0	0%	0	0%
	Total	116	82%	32	51%	23	85%	71	75%	41	85%	22	41%	629	91%
	Ratio (food processing tools: other formal tools)	0.2		1.0		0.2		0.3		0.2		1.5		0.1	

1 only data of C02 and DII02 excavated in 2002 is included.

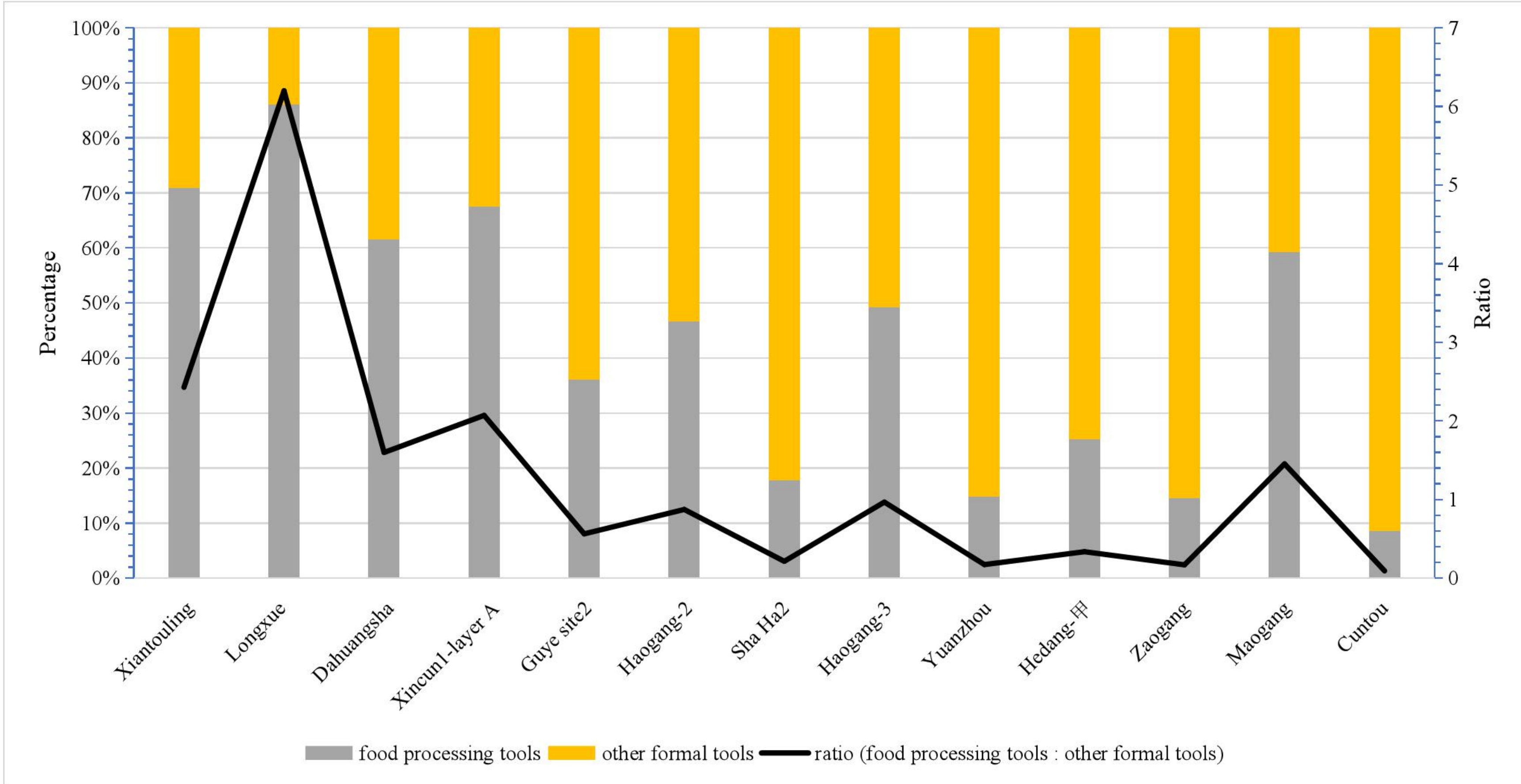

Figure 9. 2 Proportion and ratio between food processing tools and other formal tools in the Pearl River Delta (data are from Table 9.3).

This toolkit changes in the study sites also corresponded to regional trends in the Pearl River Delta. As shown in Figure 9.2, the tool kit ratios dropped from the middle Neolithic period to the late Neolithic period. In the middle Neolithic period, when no evidence of cultivation activities in coastal Guangdong were found (see Section 9.1), the ratios between grinding/pounding tools and other formal tools are relatively high, which could be up to 6.2 at Longxue site (c. 6,000 BP), where *Lithocarpus* remains were identified (Table 9.1) (Yang et al. 2015).

The changes in the ratio between grinding/pounding tools and other formal tools involved two aspects. First is increasing proportions of woodworking tools: adzes and axes (Table 9.4 and Figure 9.2). Based on the data I have collected, the ratio at Guye site (c. 5,900-5,000 BP) is lower than those at Xiantouling culture sites (Figure 9.2). It was the time when the double-shouldered stones, especially adzes, emerged in the Pearl River Delta (see Section 2.2). While with the development of those woodworking tools, including the emergence of the new form which combined the features between stepped adzes and double-shouldered adze (see Section 2.2), the ratio further reduced in the late Neolithic period, which value is around 0.2, except for some outliers, such as 1.0 at the third phase of Haogang site (c. 4,500-4,000 BP), and 1.5 at Maogang site (c. 3,500 BP). This tendency also corresponded to the fluctuation of the oak forest in the Pearl River Delta. For example, the pollen sequence GY1 presents a declining trend of oak forest. Besides the fire caused by dry climate (Ma et al. 2018), the reason for this fluctuation is probably related to changes in the use of forest resources, especially the use of timber, probably for house construction (some wooden structures were unearthed at Maogang site, see Section 2.2) and use as firewood. According to Flora of China (2004), the dark oak timbers are high-quality for buildings and light-colored ones could be used for farming tool producing or as firewood. Besides, it is also possible that some management of trees and tree crops was undertaken as well as small-scale crop cultivation.

The second is the declining grinding/pounding tools, indicating that the food processing technology changed. As reviewed in Section 3.3, in terms of plant processing, the evidence indicates that the grinding and pounding tools are more likely to be related to wild plant processing rather than cereals (Table 3.8). Hence, this declining tendency may suggest the reduced dependence on wild plants.

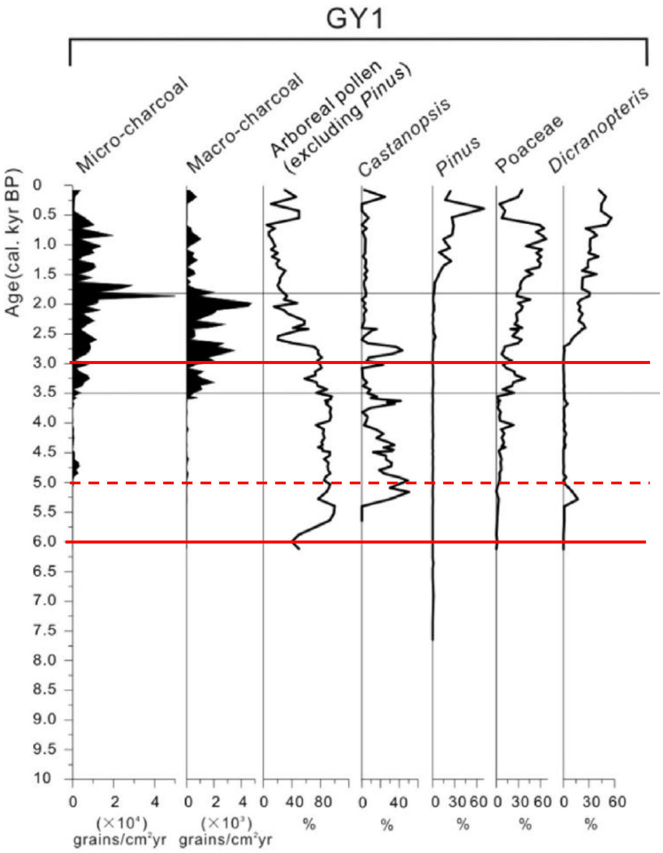

Figure 9. 3 Microscopic charcoal and macroscopic charcoal influxes and selected pollen taxa in cores GY1 (modified after Figure 4 in Ma et al. 2018, the red line intercepts the study time of this thesis).

9.3 External impacts on the plant-related subsistence in the Pearl River Delta

Beside the possible domesticated-type phytoliths of Cucurbitaceae found at the Sha Ha Site (c. 4,500 BP) (Table 9.2), there is no more direct evidence which could reflect the local cultivation practice in the Neolithic Pearl River Delta. Nevertheless, the exotic rice farming that emerged in the late Neolithic period provided more information of the cultivation practice across the delta. In this section, I reviewed and discussed the external factors, especially rice farming, on the indigenous subsistence in the delta.

9.3.1 Inception of rice cultivation

Increasing discussions suggested that rice farming was introduced to south subtropical China, although the possibility of indigenous rice cultivation cannot be entirely ruled out, as the wild rice (*Oryza rufipogon*) widely distributed in this region (e.g. Fan et al. 2000; Huang et al. 2012; Yang et al. 2017; 2018; Zhao et al. 2005). Recent studies at Chaling site (4,500-3,700 cal. BP) in the Pearl River Delta firstly detect that rice farming had arrived no later than 4,500 BP, based on the domesticated *Oryza* phytolith records and charred rice seeds (*Oryza sativa*) (Table 9.1) (Xia et al. 2019; Yang et al. 2018). The charred rice seed, together with Oryzoideae phytoliths, also recovered at Neolithic Sha Ha site (c. 4,500 BP) (Table 9.1), but so far, there is no report clarified if rice was included into the cultivation system in Hong Kong, as whether these findings are domesticated type is uncertain (Lu 2005).

The diffusion of rice farming should related to cultural interactions with other regions. As reviewed in section 2.2, in the late Neolithic period, the culture in the Pearl River Delta was affected by farming communities from other regions, such as Shixia (c. 5,000-4,100 BP), the first confirmed community which had rice farming in north Guangdong (Figure 2.25). And the object features at Chaling site presents close similarities to those of Shixia site (Zhang 2018), suggesting that rice farming is probably introduced during the cultural interaction with Shixia people.

But the interaction with farming communities has taken place no later than 5,300 BP, as the third phase of Guye site has been influenced by Liangzhu culture, at which improved agricultural technology has been identified, including irrigation system, completed domestication of rice, and the enlarged scale of production (e.g. Li 2019; Li and Cui 2018; Liu et al. 2017; Pan and Yuan 2018; 2019; Zheng et al. 2019). However, there is no evidence indicating that Guye people had adopted rice cultivation (Yang et al. 2017).

The reason for the inception of rice cultivation in the Pearl River Delta at c. 4,500 BP may involve several aspects. Firstly, the subsistence development, discussed in section 9.2, may pave the way to adopt rice farming in the region. The indigenous cultivation attempts may help the natives to be familiar with managing plants and their habitats. The inadequacy of acorn or oak-chestnuts may push the adoption of rice farming. The pollen records indicate that the *Castanopsis*, a dominant genus of the local subtropical forest, fluctuated after 5,000 BP (Figure 9.3), which possibly cannot provide stable oak-chest nut resources. As the starch analyses in Section 7.2, across the Pearl River Delta, the oak-chestnuts (*Castanopsis*) seems to be the most important nut sources between 6,000 BP and 3,000 BP (Figure 7.25). And the regional decline of acorn consumption was also possibly related to the decline of *Castanopsis*, for example, the starch analyses in Dongguan city (Figure 7.19). Hence, cultivated rice may be accepted as one substitute to fill up the shortage of oak-chestnuts at that time. Besides, the gradual deltaic progradation (Figure 2.3) and the development of forest swamps no later than around 4,900 years ago (Figure 2.4 and Figure 2.5) (e.g. Huang et al. 2016; Ma et al. 2018; Peng et al. 2015; Zong et al. 2012; 2013) provided suitable landscape for rice cultivation. A similar landscape is argued to benefit the initial rice cultivation in the lower Yangtze River (e.g. Chen 2008; Zong et al. 2007).

9.3.2 Implications for delay of intensive rice cultivation

However, rice cultivation was only part of a Neolithic subsistence economy that centered on fishing, hunting, and gathering, before c. 2,500 BP. When the open disturbed landscape dramatically replaced the oak forest, the acorn and oak-chestnuts are presumably abandoned, together with the complete adoption of new subsistence forms, involving the cultivation of rice and other crops (e.g. Peng et al. 2016; Ma et al. 2018; Zheng et al.2004).

The first possible reason that delay the rice cultivation is the limited space suitable for rice cultivation. Although the forest swamps developed, the region was largely covered by dense evergreen forest (Figure 9.3) (e.g. Huang et al. 2012; Peng et al. 2015; Wang et al. 2009). This high forest cover caused the large-scale rice cultivation almost impossible since the inadequacy of open wetlands suitable for rice farming. The human intervention of landscape transformation did not conduct immediately, indirectly suggesting the unimportance of rice cultivation at that time. The frequent fires and deforestation occurred after around 3,500 BP, revealed by charcoal records (GY1) and pollen records (e.g. GY1 and GZ-2) (Figure 9.3), suggesting the enhanced human intervention, which may be related to the slash and burn cultivation method (e.g. Ma et al. 2018; Peng et al. 2015; Wang et al. 2009).

Another barrier for the delay of rice cultivation is that the abundant local starch-rich plants, like acorns and geophytes, may have higher return rates (kcal/h) than rice (Table 8.3 and Table 9.4). These data based on modern observations and tests can provide some references. Zhao et al. (2005) evaluated the return rate (kcal/h) of wild rice collection (*Oryza rufipogon*), which is only 116 kcal/h. This value is much lower than the mean rate of tubers (1,296 kcal/h) (Table 9.4), and that of non-toxic nuts (609-1,700 kcal/h) (Table 8.3). Hence, in the Pearl River Delta where diverse starch-rich plants were available, wild rice collection was not an optimal choice. On the other hand, Barton (2009) reported that the return rate of swidden rice ranges from 400 to 1,500 kcal/h, according to the yield data of hulled rice from dry rice fields from Strickland (1985). Although it is close to the acorn or geophyte collection, compared to the rice crop, which production may be impacted by several factors, these plants are relatively less risky. Analogue with these, rice would not have been an irreplaceable crop in the prehistoric Pearl River Delta.

Table 9. 4 Some return rates obtained in Yongning, Guangxi, South China (Zhao et al. 2005)

	Freshwater snail	**Starch-rich geophytes***	**Wild rice (*Oryza rufipogon*)**
Average acquisition (g/h)	459	1,800	33
Energy per 100g (Kcal)	69	75	350
Reture rate (Kcal/h)	317	1,296	116

The authors tested the return rates of yam (*Dioscorea* sp.) collection from the hill in Yongning, Guangxi, and then estimate the mean values between yam (*Dioscorea* sp.) and “wild” taro (*Colocasia* sp.), common in the tested region here.

9.4 Subsistence and its changes in the Pearl River Delta between 6,000 BP and 3,000 BP

In the later phase of middle Neolithic period (c. 6,000-5,000 BP), when the grinding and pounding tools were widely used for wild plant processing, the plant-related subsistence was a heavy dependence on gathering, mainly acorns, at shell midden sites. But the starch-rich geophytes only accounted for a small proportion of the total. Combined with the other plant and animal evidence, the subsistence at that time in the Pearl River Delta should center on gathering, hunting, and fishing.

In late Neolithic period, the gathering still seemed to be a significant part of the local subsistence. The plant exploitation strategy in the previous period was further expanded. The starch results in my thesis indicate that the proportion of acorn declined, but was not abandoned. At the same time, the proportion of geophytes increased to a similar level as those of acorns. Meanwhile, the toolkit changes and domesticated plant remains suggest that forest management and cultivation have been already involved in the local subsistence practices. However, these activities need more diagnostic evidence. On the other hand, exotic rice farming was introduced in the Pearl River Delta, through the cultural interactions with other farming communities, such as Shixia people in north Guangdong. However, the cultivation practices should be small-scaled, forming the minority of the local plant-related subsistence. Overall, the plant-related subsistence in the late Neolithic Pearl River Delta still relied on gathering, supplementary with a small-scale cultivation practices.

Chapter 10: Conclusion

From the research presented in this thesis, I can draw two main conclusions about prehistoric subsistence practices during the three millennia from 6,000 BP to 3,000 BP., Firstly, through the identification of starch granules on pounding and grinding tools from the study region, I can show that acorns (primarily from wild oaks) and geophytes were staple foods in diets of communities around the Pearl River Delta during the Neolithic and into the early Bronze Age. This finding differs slightly from previous hypotheses about diets in South China, that geophytes alone were likely to be the primary staple food source of hunter-gatherer communities before the adoption of rice cultivation (e.g. Li and Lu 1987; Yan 2005; Zhao 2005). This research shows that wild oaks were once of significant importance in the local diets during the Holocene, and probably earlier, which reflects similar findings from research along the lower Yangtze River and Northern China, where tree nuts were consumed in large quantities, and sometimes stored as a delayed-return food, prior to the emergence of cereal agriculture (e.g. Fuller and Qin 2010; Liu et al. 2011a; 2011b; Norshiro 2016; Tushingham and Bettinger 2013). Together with the previous evidence of sago consumption at the Xincun site, my findings further enrich our knowledge of plant use and of the types of plant foods that were likely consumed on a daily basis.

Secondly, my research shows that there exists an important temporal shift in the regional diet, from acorn dominance in the middle Neolithic period (6,000-5,000 BP) to a balance between acorns and geophytes in the late Neolithic period and early Bronze Age (4,500-3,000 BP). This change probably suggested the regional subsistence transition from foraging to to small-scale cultivation that may have included tuberous plants. Other evidence of cultivation practices occur in the region during the Bronze Age with the earliest remains of domesticated pigs, domesticated rice, and phytoliths from Cucurbitaceae (Guangdong Museum and Foshan Museum 2006; Lu 2007; Xia et al. 2019; Yang et al. 2018). Based on this evidence I argue that some form of ‘vegeculture’ the cultivation of some vegetative propagated plants, especially some tuberous plants, and probably ‘arboriculture’, involving the cultivation or management of wild oaks, may have emerged by the late Holocene. The aboriginal plant-related subsistence in the delta seem to be more complex than previously thought.

These results lead to further thinking of the subsistence practices in this delta. The first is that when subsistence systems based on trees in delta spanned the Neolithic archaeological sequence, whether the woodlands of the Pearl River Delta were managed. The forest transformation process is complex and subtle, rather than the binary evolution from impact-free exploitation to large-scale deforestation and destructive ‘agricultural’ practices. In the initial 4,000 years of human settled on the Pearl River Delta from around 7,000 BP to 3.000 BP, the vegetation cover showed few indications of deforestation and the oak forest remained dominant according to the pollen sequences (see Section 2.1), but that does not preclude the possibility of small-scale forest management practices, such as planting, transplanting, maintaining and/or protecting certain trees, and the selective cutting and burning of potential plant competitors. For example, using an analogy with the horticultural systems across Oceania (Dotte-Sarout 2016), the indigenous Neolithic subsistence practices in the delta may be based on the forest management but avoiding large-scale forest clearance. Since the late Neolithic period, there is an increase in the frequency and diversity of woodworking tools, such as shouldered stone and stepped adzes, suggesting concomitant increases in woodland exploitation. Together with the cultivation needs and the preservation of complicated wooden constructions, it could be inferred that forest management has occurred.

Another area that this research can contribute to is the observation of a slow adoption of agricultural activities in Southern China (see Yang et al. 2013). Although we still cannot rule out such a possibility of native rice cultivation (Huang et al. 2012; Lu 2013), the widely accepted view is that the south subtropical China was the first region into which rice-farming immigrants spread prior to entering into Southeast Asia, along with their cultural packages and unique pottery forms, domesticated pigs and rice at around 5,000 BP (Bellwood et al. 2011; Castillo et al. 2016; Fuller 2011; Silva et al. 2015; Yang et al.

2017; Zhang and Hung 2012). The indigenous foraging subsistence in South China were influenced or replaced by this external cultivation tradition accompanied by the cultural transformation under the effects of superior culture (e.g. Bellwood et al. 2011; Yang et al. 2017; Zhang and Hung 2012). However, in the Pearl River Delta, one key region of south subtropical China, the inception of rice cultivation seems to be later than the emergence of interaction with the rice farmers from lower Yangtze River. After the emergence of domesticated rice in the delta, the start of its large-scale cultivation may not be earlier than 3,000 years ago, when the vegetation transformed significantly as palynologists reported (Huang et al. 2016; Ma et al. 2018; Peng et al. 2015). Geng (2019) argued that this transition that sago-type palms began to be gradually excluded from the major staple food in south subtropical China was not a spontaneous process, but occurred with the intervention of the central government since Qin and Han Dynasty. So far, further research on the start, southward diffusion pathways, slow adoption, and even possible resistance of rice farming in south subtropical China is still ongoing, as the data accumulation is insufficient.

Besides, the lack of samples at sand dune sites in the Pearl River Delta limits the complete understanding of the subsistence economy in the Pearl River Delta. As reviewed in section 2.2, two types of archaeological sites: shell middens and sand dune sites, widely distributed in the Pearl River Delta at the same time. It is argued that features of sand dunes and shell middens in the Pearl River Delta during the middle Neolithic period can be generalized into the same archaeological culture, such as Xiantouling culture (c. 7,000-6,000 BP). But by the late Neolithic period, two distinct styles could be identified at coastal sand dunes and shell middens located in the hinterlands (e.g. Kuang 1998; Xiao 2004). There are two isolated archaebotanical case study in the Pearl River Delta during middle and late Neolithic separately, indicating that the sago type palms, together with geophytes, were consumed by Xincun people (5,300-4,400 BP) in middle Neolithic (Yang et al. 2013) and the starch diet involved similar percentages of acorns and geophytes in the late Neolithic period at Lujingcun (c. 4,000-3,500 BP) (Wang 2017), which values are close to those recovered in my thesis.

Whether there were differences in woody starch plant selection between shell midden sites and sand dune sites in the Neolithic period, further comparisons are needed.

Overall the analysis undertaken in this thesis shows that from the middle Neolithic to the Early Bronze Age, sedentary village communities were heavily engaged in complex seasonal gathering and storage of wild acorns. As well, these communities were consuming roots and tubers. It remains to be determined if people were actively managing oak forests to ensure a reliable annual harvest, but it remains a distinct possibility. After 4,500 BP there are significant directional changes in the palaeoenvironmental data that indicate a major shift in subsistence practices was occurring, with a decline in the use of forest oak, and eventually of large scale clearance. This landscape transformation may well be related to the rise of slash and burn dryland agriculture and the cropping of rice and millets.

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Appendix

Table 1 The dates of some Chinese Dynasties.

Dynasty			Date
Xia			c. 2070-1600 BC
Shang			c. 1600-1046 BC
Zhou	Western Zhou		c. 1046-771 BC
	Eastern Zhou	Spring and Autumn period	770-476 BC
		Warring States period	475-221 BC
Qin			221-207 BC
Han	Western Han		202 BC-9 AD
	Xin		9-23
	Eastern Han		25-220
Three Kingdom period			220-280
Jin	Western Jin		266-316
	Eastern Jin		317-420
The period of Southern and Northern Dynasties			420-589
Sui			581-619
Tang			618-907
The period of Five Dynasties and Ten Kingdoms			907-979
Song	Northern Song		960-1127
	Southern Song		1127-1279
Yuan			1271-1368
Ming			1368-1644
Qing			1644-1912

Glossary

Latin Name		Common name	
Genus	Species	English	Chinese
	Aegilops speltoides	Goatgrass	
	Aegilops tauschii		节节麦
Aesculus		Horse chestnut	七叶树
	Agropyron cristatum		冰草
	Alisma plantago-aquatica	Water plantain	泽泻
	Alopecurus aequalis	Shortawn foxtail	棒棒草
	Alpinia japonica		山姜
	Alpinia officinalis		野山葵
	Alsophila spinulosa	Spinulose tree fern	蕨树
	Amaranthus hypochondricus	Amaranth	天雄米
	Amomum villosum		砂仁
	Amorphophallus konjac	Konjac	魔芋
	Amorphophallus paeoniifolius	Elephant yam	大魔芋
	Amorphophallus xiei		谢军魔芋
	Amorphophallus ximengensis		西蒙魔芋
	Amorphophallus yuloensis		攸落魔芋
	Amorphophallus yunnanensis		滇魔芋
	Angiopteris esculenta		小叶观音座莲
	Angiopteris fokiensis		马蹄蕨
	Angiopteris yunnanensis		云南观音座莲
	Antiaris toxicaria	Bark cloth tree	见血封喉/药树
	Aphanamixis grandifolia	Shan lian	苦柏木
	Aquilaria sinensis		沉香
	Arenga pinnata	Sugar palm	桄榔
	Arenga westerhoutii		桄榔
	Arenga engleri		鱼骨葵/矮桄榔
	Asparagus cochinchinensis	Chinese asparagus	天门冬
	Asparagus filicinus	Fern asparagus	土百部
	Avena nuda	Naked oat	裸燕麦
	Beilschmiedia bancroftii	Yellow walnut	
	Bombax ceiba	Red silk cotton tree	木棉
	Botrychium lanuginosum		云南阴地蕨
	Boussingaultia gracilis		田三七
	Bromus japonica		雀麦
	Cajanus cajan	Pigeon pea	木豆
	Canarium album	Chinese white olive	橄榄

Canavalia gladiata	Sword bean	刀豆
Caryota maxima		鱼尾葵
Caryota mitis	Fishtail palm	短穗鱼尾葵
Caryota monostarchya		
Caryota obtusa		董棕
Castanea crenata		日本栗
Castanea henryi		锥栗
Castanea mollissima	Chinese chestnut	栗
Castanea sativa	Sweet chestnut	
Castanea seguinii	Chinese chinquapin	茅栗
Castanopsis argyrophylla		银叶锥/满登
Castanopsis carlesii		米槠/白橼
Castanopsis ceratacantha		瓦山锥/刺栗子
Castanopsis echidnocarpa		短刺锥
Castanopsis eyrei		甜槠
Castanopsis faberi		罗浮锥/狗牙锥
Castanopsis fargesii		栲
Castanopsis fleuryi	Chinquapin	小果栲
Castanopsis fordii		毛锥/南岭栲
Castanopsis hystrix		红锥
Castanopsis kweichowensis		贵州锥
Castanopsis platyacantha		扁刺锥
Castanopsis sclerophylla		苦槠
Castanopsis tibetana		钩锥/野板栗
Castanopsis platyacantha		扁刺锥
Cayratia japonica		乌蔹莓/五爪龙
Cerbera manghas		海杧果/香军树
Cibotium baromet		金毛狗
Cicer arietinum	Chick pea	鹰嘴豆
Cinnamomum camphora	Camphor	樟
Claoxylon indicum		白桐树
Cocculus laurifolius		樟叶木防己
Cocculus orbiculatus	Queen coralbead	木防己
Codonopsis convolvulacea		鸡蛋参
Coix lacryma-jobi	Job's tear	薏苡
Colocasia esculenta	Taro	芋头
Colocasia tonoimo		野芋
Coniogramme		凤丫蕨
Cordia dichotoma		破布木
Crinum flaccidum	Murray lily	
Cyanotis vaga		土贝母
Cycas panzhihuaensis	Cycad	攀枝花苏铁

	Cycas pectinata		篦齿苏铁
	Cycas revoluta		苏铁
	Cyclobalanopsis chapensis		扁果青冈
	Cyclobalanopsis gambleana	Oak	毛曼青冈
	Cyclobalanopsis glauca		青冈
	Cyclobalanopsis phanera		亮叶青冈
	Delonix regia		凤凰木
	Dendrotrophe frutescens		寄生藤
	Digitaria sanguinalis	Crabgrass	马唐/蹲倒驴
	Dioscorea alata	Water yam	参薯/脚板薯
	Dioscorea bulbifera	Aerial yam	黄独/零余薯
	Dioscorea esculenta	Chinese yam	甘薯/山药
	Dioscorea esculenta var. spinosa		刺山药
	Dioscorea japonica	Glutinous yam	日本薯蓣/土淮山
	Dioscorea opposita	Yam	薯蓣
	Dioscorea pentaphylla		五叶薯蓣
Diospyros		Persimmon	柿
	Drynaria baronii		秦岭槲蕨
	Drynaria fortunei		槲蕨
	Echinochloa colonum	Barnyard grass	光头稗/扒草
	Echinochloa crusgalli	Narnyard grass	稗
Elaeocarpus		Woodland elaeocarpus	杜英
	Eleocharis dulcis	Chinese water chestnut	荸荠/马蹄
	Elephantopus scaber		地胆草/磨地胆
	Eleusine coracana	Finger millet	穇/鸭距粟
	Eleutherine plicata		红蒜
	Endiandra palmerstonii	Walnut bean	
	Eriochloa villosa		野黍
	Fagopyrum esculentum	Buckwheat	荞麦
	Fagus engleriana		米心水青冈
	Fagus grandifolia	American beech	
	Fagus longipetiolata	Beech	水青冈
	Fagus lucida		光叶水青冈
	Fagus orientalis	Oriental beech	
	Fagus sylvatica	Common beech	
Fallopia			何首乌
	Ficus microcarpa	Chinese banyan	榕树
	Foeniculum vulgare	Fennel	茴香
	Fritillaria cirrhosa	Chuan bei mu	川贝母
Ginkgo		Ginkgo	银杏
	Glyptostrobus pensilis	Chinese swamp cypress	水松
Hemsleya			雪丹

	Hordeum vulgare	Common barley	大麦
	Houttuynia cordata	Chameleon	蕺菜/鱼腥草
	Ipomoea batatas	Sweet potato	番薯
Juglans		Walnut	胡桃
	Lablab purpureus	Hyacinth bean	扁豆
	Lagenaria siceraria	Bottle gourd	葫芦
	Lasia spinosa		刺芋
	Lathyrus sativus	Grass pea	家山黧豆
	Lens culinaris	Lentil	兵豆
	Leymus chinensis	Guinea grass	羊草
	Lilium brownii	Lily	百合
	Lithocarpus amygdalifolius		杏叶柯
	Lithocarpus balansae		猴面柯
	Lithocarpus chrysocomus		金毛柯
	Lithocarpus cleistocarpus		包果柯
	Lithocarpus corneus	Oak	烟斗柯
	Lithocarpus fohaiensis		勐海柯
	Lithocarpus glaber		柯
	Lithocarpus litseifolius		胖椆/甜茶
	Lithocarpus pachyphyllus		厚叶柯
	Lolium perenne	Ryegrass	黑麦草
	Luculia intermedia		滇丁香
	Manihot esculenta	Cassava	木薯
	Matteuccia struthiopteris	Ostrich fern	荚果蕨
	Melia azedarach	Bead tree	苦楝
	Melica scabrosa		臭草
	Milium effusum	Wood millet	粟草
Musa		Banana	芭蕉
	Myrica rubra	Chinese bayberry	杨梅
	Nelumbo nucifera	Lotus	莲
	Nephrolepis auriculata		肾蕨
	Oryza rufipogon	Wild rice	野生稻
	Oryza sativa	Rice	水稻
	Osmunda japonica	Zenmai	紫萁
	Pachyrhizus erosus	Yam bean	沙葛
	Panax notoginseng		三七
	Panicum bisulcatum		糠稷
	Panicum miliaceum	Broomcorn millet	黍
	Phaseolus coccineus	Runner bean	荷包豆
	Phaseolus lunatus	Lima bean	棉豆
	Phaseolus vulgaris	Kidney bean	菜豆
	Pinus massoniana	Red pine	马尾松

Piper		Pepper	胡椒
	Pisum sativum	Garden pea	豌豆
	Poa annua	Annual bluegrass	早熟禾
	Potentilla anserina	Silverweed	蕨麻
	Pteridium aquilinum	Brackenfern	欧洲蕨
	Pteridium revolutum		毛轴蕨
	Pueraria montana	Kudzu vine	葛
	Quercus acutissima	Sawthorn oak	麻栎
	Quercus cocciferoides		大理栎
	Quercus dentata	Daimyo oak	槲树
	Quercus fabri		白栎
	Quercus franchetii		椎连栎
	Quercus mongolica	Mongolian oak	蒙古栎
	Quercus oxyphylla		尖叶栎
	Quercus semecarpifolia		高山栎
	Quercus variabilis	Cork oak	栓皮栎
Ricinus		Castor-oil plant	蓖麻
	Sagittaria trifolia	Chinese arrowroot	慈姑
	Schizocapsa plantaginea		裂果薯
	Secale cereal	Rye	黑麦
	Setaria chondrachne		莩草
	Setaria faberil	Giant foxtail	
	Setaria italica	Foxtail millet	小米
	Setaria parviflora		幽狗尾草
	Setaria plicata		皱叶狗尾草
	Setaria pumila		金色狗尾草
	Setaria viridis	Green foxtail	狗尾草
	Smilax china	China Root	菝葜
	Smilax glabra		土茯苓
	Smilax glaucochina		黑果菝葜
	Solanum tuberosum	Potato	土豆
	Sorghum bicolor	Sorghum	高粱
	Stahlianthus involucratus		土田七
	Tinospora capillipes		金果榄
	Trapa natans	Water chestnut	菱角
	Trichosanthes kirilowii	Snakegourd	栝楼
Trigonobalanus		Oak	三棱栎
	Triticum aestivum	Common wheat	小麦
	Vernicia fordi	Tung tree	油桐
	Vicia faba	Horsebean	蚕豆
	Vigna angularis	Adzuki bean	红豆
	Vigna cylindrica	Black-eyed pea	短豇豆/眉豆

	Vigna radiata	Mung bean	绿豆
	Vigna umbellata	Rice bean	赤小豆
	Woodwardia japonica	Chain fern	狗脊
	Woodwardia unigemmata		顶芽狗脊
	Xanthium sibiricum		苍耳
	Zea mays	Corn	玉米
	Zizania caduciflora	Manchurian wild rice	茭白
Ziziphus		Jujube	枣