Current Perspectives and Scientific Issues in the Study of Prehistoric Cereal Agriculture in Mainland Southeast Asia: A Comprehensive Review

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Abstract

This comprehensive review examines the study of prehistoric cereal agriculture in Mainland Southeast Asia, which has become a focus of research due to its significance in understanding early agricultural practices and complex societies in the region. The review highlights key findings, methodological approaches, and research gaps, with a particular emphasis on rice and millet cultivation, the primary cereal crops in the area. It discusses the origins and diffusion of cereal agriculture, including possible routes of dispersal from China to Mainland Southeast Asia. The limited availability of archaeobotanical data presents a challenge, but the review aims to contribute to ongoing research and provide valuable insights into the agricultural history of the region.

1. Introduction

The cereals are annual common grass members of the grass family (a monocot family Poaceae, also known as Gramineae), which usually have long, thin stalks, such as wheat, rice, maize, sorghum, millet, barley and rye, whose starchy grains are used as food. The term cereal is not limited to these grains, but also refers to foodstuff prepared from the starchy grains of cereal like flours, breads and pasta (Sarwar et al., 2013). Agriculture, marked by the cultivation of plants and domestication of animals. Cereal agriculture has a long history and significance, and it has been a hotspot for agricultural development for thousands of years, with cereal cultivation playing a vital role in the emergence of complex societies and civilizations. The abundance of food provided by cereal crops allowed for population growth and the formation of settled communities. Moreover, cereal agriculture played a central role in shaping the cultural traditions and belief systems of various societies. Due to cereal plants are important sources of carbohydrates, proteins, vitamins, and minerals in the human diet and livestock. They play a crucial role in global food security and provide the foundation for many food products consumed worldwide (e.g. Awika 2011; Zhu and Sang, 2017; Tieri et al., 2020; Garutti et al., 2022).

Researchers suggested that the origin of cereal cultivation dates back thousands of years. Its emerged independently in different parts of the world around during a period known as the Neolithic Revolution. The places of its origin depended on cultivation of different cereals as staple foods. The earliest evidence of cereal cultivation such as emmer wheat, einkorn wheat, and barley can be traced to ancient civilizations in the Fertile Crescent, a region in the Middle East (Western Asia) encompassing modern-day Iraq, Syria, Lebanon, Israel, and Jordan. Rice and millets, on the other hand, began to be domesticated in East Asia. Crops like sorghum and pearl millet and several native grasses were being domesticated in sub-Saharan West Africa. Meanwhile, maize was grown in America, etc. (e.g. Henry and Kettlewell, 1996; Fuller 2007, 2011; Allaby et al., 2010; Zohary et al., 2012).

In mainland Southeast Asia (MSEA), rice in particular has been the primary cereal crop for centuries and continues to be a staple food in the region (Castillo, 2013). It became deeply embedded in the region's cultural practices, rituals, and folklore. The development of rice agriculture in Southeast Asia was driven by various factors, including the availability of suitable ecological conditions such as fertile river valleys and deltas, as well as the region's monsoon climate, which provided abundant rainfall for rice cultivation (Facon, 2000).

The dispersal routes of agriculture by migrating farmers or their crops moved southward from China to Southeast Asia has been open to discussion, with at least three major axes under consideration:

1) a coastal route that started in Taiwan and Fujian in the east coast into Vietnam (e.g. Bellwood, 1991, 1995; Sagart, 2005; Bellwood and Dizon, 2008).

2) a route from the middle Yangtze to the Lingnan and the Pearl River basin in Guangdong and then onwards through Guangxi into Vietnam (e.g. Fuller et al., 2011; Higham, 2017).

3) from the Yangtze River region to Yunnan and then moving down various north-south rivers, such as the Mekong in the east; the Menam Chao Phraya and its tributaries in the centre, and the Salaween and Irrawadi in the west, into Southeast Asia (Higham, 1996, 2002a).

Regarding the arriving period of domestic cultivation in mainland Southeast Asia, there has been substantial evidence indicating that rice and millet agriculture were introduced during the Neolithic period through dispersal processes from the Yangtze Valley region of China (e.g., Higham, 1996; Castillo and Fuller, 2010; Silva et al., 2015; Castillo et al., 2016a, 2016b; Martello et al., 2018). The evolution of domestication in Southeast Asia is a complex and multifaceted process that has occurred over thousands of years. It involves the domestication of various plant and animal species, as well as the development of agricultural practices and social structures to support sedentary lifestyles. The evolution of domestication can then be analysed as a coevolutionary process with human behaviours, technologies and cooking traditions (Fuller, 2021).

The study of prehistoric cereal agriculture in mainland Southeast Asia has become increasingly important in recent years, as researchers aim to understand the origins and spread of agricultural practices in the region. This review aimed to provides an analysis of the current state of archaeobotanical research in mainland Southeast Asia, focusing specifically on the cultivation of rice and millet. The review explores the adoption of cereal agriculture in the prehistoric period and discusses possible routes for the diffusion of rice and millet from China to mainland Southeast Asia. The author examines relevant literature, evaluates existing research, and identifies key themes and areas that require further investigation. One of the challenges faced in this field is the uneven distribution of available archaeobotanical data due to differences in preservation environments and excavation efforts. Despite this challenge, the review aims to contribute to ongoing research efforts and provide valuable insights into the agricultural history in mainland Southeast Asia. It serves as a comprehensive resource for researchers, students, and individuals interested in gaining a deeper understanding of the subject, and it lays the foundation for future studies and research endeavours in this field.

2. Origin of cereal domestication

The advent of cereal agriculture holds great significance in the chronicles of human civilization. The origin of agriculture marks a crucial juncture in human history, signifying the shift from a nomadic hunter-gatherer existence to settled farming communities. As societal complexity, population densities, and subsistence diversity increased, it necessitated various regional populations to adopt resource management strategies, leading to the emergence of rudimentary food production (Smith, 2001; Rowley-Conwy and Layton, 2011). The establishment of permanent human settlements in specific locations can be attributed to the origin of agriculture, driven by escalating population numbers and the limited accessibility of environmental resources during different seasons. Researchers worldwide have shown significant interest in the rise of cereal agriculture. The consensus among scholars points to two primary regions of domestication, namely Western Asia and East Asia. This transition coincided with a period of climate warming from the late Pleistocene to the early Holocene. It is evident that the gradual shift to a sedentary lifestyle associated with agriculture occurred in response to the enhanced nutritional value of cultivated plants (Vostretsov, 2021). Around 11000 to 10000 BP, nomadic hunter-gatherer groups chose to abandon their mobile way of life in favour of crop cultivation, leading to the establishment of sedentary communities. This pivotal transition towards an agrarian lifestyle catalysed the development of intricate political and economic frameworks, as well as technological advancements, laying the groundwork for the rise of notable civilizations that have profoundly influenced human history in more recent times (Zohary et al., 2012).

The question of where and how agriculture first began has been the subject of debate among scholars. Some studies argue that domestication occurred through multiple parallel processes in different locations over an extended period of time (e.g., Allaby et al., 2010; Brown et al., 2009; Fuller 2007, 2011; Nesbitt 2004). Other groups, however, believe that agriculture had a single origin in the Near East within a specific area and a relatively short time frame (Abbo et al. 2010, 2011; Honne and Heun 2009). Archaeologists have focused their attention on various regions in searching for the origins of agriculture. In the 1980s, the Southern Levant in West Asia, particularly the transition from the Natufian to the Pre-Pottery Neolithic period, was the primary area of interest (Henry 1989). Prior to that, researchers studied the hilly flanks of the Zagros and Taurus mountains (Bender 1975). By the late 1990s, the centre of origin shifted to southeast Turkey near the upper Euphrates River and the Karacadag mountains, which were considered the “core area” for the origins of agriculture. This region was characterized by the presence of wild ancestors of various crops (Lev-Yadun et al., 2000). Some archaeologists also proposed another core area along the Upper to Middle Euphrates (Kozlowski and Aurenche 2005; Asouti 2006; Bar-Yosef 2003).

In East Asia, it believed to be another original place of cereal domestication particularly rice and millet. It is widely acknowledged to have multiple centres of independent crop domestication, with at least two being particularly notable (Zhao 2011; Stevens and Fuller 2017). One of these centres is located in northern China near the Yellow River basin and associated with the domestication of millet including the broomcorn (*Panicum miliaceum*) and foxtail millets (*Setaria italica*). The second centre is the Middle and Lower Yangtze valley, where rice (*Oryza sativa*) was domesticated (e.g., Fuller 2010, 2011; Zohary 2012; Choi et al. 2017). In addition, a potential third region of crop domestication is possibly the southern part of in China, including Guangdong and Guangxi, as well as the Pearl River Basin which has long been suggested to have been a region of vegecultural origins of some tuber crops, although clear archaeological evidence remains limited (e.g., Yang et al., 2013; Denham et al., 2018). Due to the rice and millet played a crucial role in the mainland southeast

Asia, the author reviewed some evidence regarding the those crops domestication.

2. 1 The millet cultivation and domestication in northern China

China is one of the main centres for plant domestication and tracing the origins of agriculture (Larson et al., 2014). Millet including foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*) were first utilized in northern China around 10000 BP. (Lu et al., 2009; Yang et al., 2012).

The origins of agriculture during the transition from the Pleistocene to the Holocene, between 12000 and 9000 BP, remain an area of ongoing research. It was during this period that hunter-gatherer communities in Northeast China, the North China plains, and the Middle and Lower Yangtze River regions established the first sedentary villages (Cohen, 2011). Researchers have identified two significant transition periods: one from the Pleistocene to Holocene, approximately 12000-9000 BP, and another during the Middle Holocene, 7000-4000 BP (Larson et al., 2014; Yu et al., 2021). The millet cultivation appears to have been widespread across various northern Chinese cultures by 6000 BC (Liu et al., 2009; Bettinger et al., 2010; Zhao, 2011; Qin, 2012).

Phytolith evidence from the Cishan site in Hebei province suggests that millet cultivation may have even begun earlier, at the start of the Holocene (Lu et al., 2009; Yang et al., 2012). Excavations at various archaeological sites along the Yellow River, such as Yuhuazhai, Peiligang, Shawoli, Yuezhuang have provided valuable insights into the cultivation of millet in ancient China. In addition, the Xinglonggou site in Aohan Banner, Inner Mongolia, China, has yielded millet grains and farming tools dating back approximately 10000 BP. and that the relatively dry condition in the early Holocene may have been favourable for the domestication of common millet over foxtail millet (Lu et al., 2009). Similarly, the Cishan site in Hebei province, also located in the middle Yellow River region, has provided evidence of millet cultivation dating back around 8000 years (Lu et al., 2009). Furthermore, the presence of millet grains and storage pits at the Peiligang culture site, which thrived in the Yellow River region approximately 7000 to 8000 BP, further supports the long history of millet cultivation in the area (Lu et al., 2009).

Archaeobotanical studies such as charred grains, phytoliths, and pollen, have contributed additional evidence to the understanding of millet cultivation in the Yellow River region. Researchers have discovered millet remains in archaeological sites across the Yellow River basin, indicating its widespread cultivation during ancient times (Wang et al., 2018). Regarding the origin of millets, there are two prevailing hypotheses. One suggests that common millet was rapidly domesticated in the central Wei River basin around 8000 BP (Bettinger et al., 2010). The other proposes that common millet was domesticated in Northeast China, specifically around the Liao River basin, during approximately the same period as the first hypothesis (Zhao et al., 2005). However, the taxonomic identification of the remains was problematic because all the so-called millet remains had already decayed to ash when they were discovered (CPAM, Hebei Province, and Handan Relics Preservation Station 1981; Zhao 2011).

So far, there are differing views on the origins of millet with single and multiple origins' proponents. Whether single (e.g., Cohen 1998; Sagart 2008) or multiple origins (e.g., Bettinger et al. 2010; Fukunaga and Kato 2003; Fuller et al. 2008; Weber and Fuller 2008) are considered, the archaeological and genetic evidence indicates the general area of origin in north China (Song, 2011). The millet cultivation, including two primary types, foxtail millet and broomcorn millet. The earliest evidence found in the Neolithic period in the Yellow River region such as Xinglonggou and Cishan, have provided evidence of millet cultivation dating back approximately 10000 to 8000 BP. Archaeobotanical studies have also revealed millet remains in various sites across the Yellow River basin. The exact origin of millets is a subject of debate, with hypotheses suggesting domestication in the central Wei River basin or in Northeast China around the Liao River basin.

2.2 The rice cultivation and domestication in Middle and Lower Yangtze River

Archaeobotanical and genetic evidence, combined with numerous studies conducted in China, provide valuable insights into the timeline and methods of rice domestication. The Yangtze River Valley, located in southern China, is renowned as one of the primary centres of agricultural development in East Asia. Scholars widely believe that the domestication of *Oryza rufipogon*, the ancestral species for *japonica* rice, occurred in this region between 7000 and 4000 BC (Zong et al., 2007). Moreover, the Yangtze River basin, encompassing its middle and lower reaches, along with its tributaries such as the Han and Huai Rivers, is widely accepted as a region where rice domestication took place concurrently with millet domestication which occurred between 7000 and 5000 BC (Cohen 2011; Stevens and Fuller 2017). The exploitation of wild plants, including rice, was observed in the Yangtze River basin, particularly at sites like Chengtoushan, Xiarendong, Shangshan, Liangzhu, Kuahuqiao, Bashingdang and Hemudu, indicating a wider range of plant utilization (Crawford and Shen, 1998; Jiang and Liu, 2006; Zhong et al., 2007). Phytolith analysis conducted in the Diaotonghuan cave confirmed the collection of wild rice during the late Pleistocene period, around 12000 to 11000 years ago. Micromorphological characteristics of early rice phytoliths suggest an initial phase of rice cultivation during the late Pleistocene to early Holocene (Zhang, 2002; Zuo et al., 2017). Subsequently, a combination of wild rice and early domesticated rice harvesting was observed between 10000 and 8000 years ago, followed by a shift towards predominantly domesticated rice utilization around 7000 years ago (Zhao et al., 2005). Specifically, the process of rice domestication took place in the Lower Yangtze region of Zhejiang around 6900 to 6600 years ago (Fuller et al., 2009).

The Shangshan site in Zhejiang, dating between 11000 and 9000 BP., yielded the earliest rice remains, includes charred rice husks and leaves, found in pottery sherds and burnt clays (Jiang and Liu, 2006). Analysis of these remains indicated that rice was likely harvested by cutting the stalks with knives, and stone implements found at the site may have been used as harvesting tools. This method of harvest could have facilitated successful rice domestication (Smith, 1998). Experimental studies with wild rice showed that the use of knives in harvesting led to morphological changes in rice fairly rapidly. The size and shape of the Shangshan rice remains were relatively large compared to later rice remains in the region (Oka and Morishima, 1971). Microscopic observations and phytolith analysis suggested that the Shangshan rice resembled tropical *japonica* more than indica (Zheng and Jiang, 2007; Zheng et al., 2007). The Shangshan rice provided the basis for selecting cultivated types and shifting the rice population (Liu et al., 2007).

The presence of wild rice harvesting at the Kuahuqiao site, which dates between 8200 and 7200 BP, has been a topic of discussion among researchers. Fuller and his team argue that the abundance of empty spikelets in the rice assemblage suggests the collection of wild rice (Fuller et al., 2007). However, Liu and Ah Lee propose alternative explanations that the presence of immature grains, which remain after the threshing of mature grains, possible due to a poor rice growth year or the early stages of rice domestication when maturity rates were inconsistent (Liu et al., 2007). Another possibility is gene exchange between wild and cultivated rice, which could account for the intermediate characteristics observed in archaeological specimens (Yen, 1982). Microscopic analysis of spikelets from Kuahuqiao conducted by Zheng and team reveals that a significant proportion of them exhibit characteristics of domesticated *japonica* rice, while others display features of wild rice (Zheng et al., 2007). This finding indicates that the presence of domesticated characteristics cannot be solely attributed to immature wild spikelets. Other experimental studies were further supporting this argument by demonstrating that naturally disarticulated, green-harvested wild cereals would leave distinct scars on the rachis (e.g., Willcox, 1999; Hillman and Davies, 1999). Therefore, the mixed presence of wild and domesticated rice at Kuahuqiao is likely the result of human intervention rather than natural processes. Additionally, the discovery of rice stalks with attached but empty spikelets in the middle stratum of Kuahuqiao suggests a harvesting method involved cutting the stalks, which can potentially lead to domestication. Based on these observations, it is probable that a certain proportion of the rice at Kuahuqiao was in the process of domestication or had already achieved partial domestication during the middle phase of the site's occupation, at the latest (Liu et al., 2007).

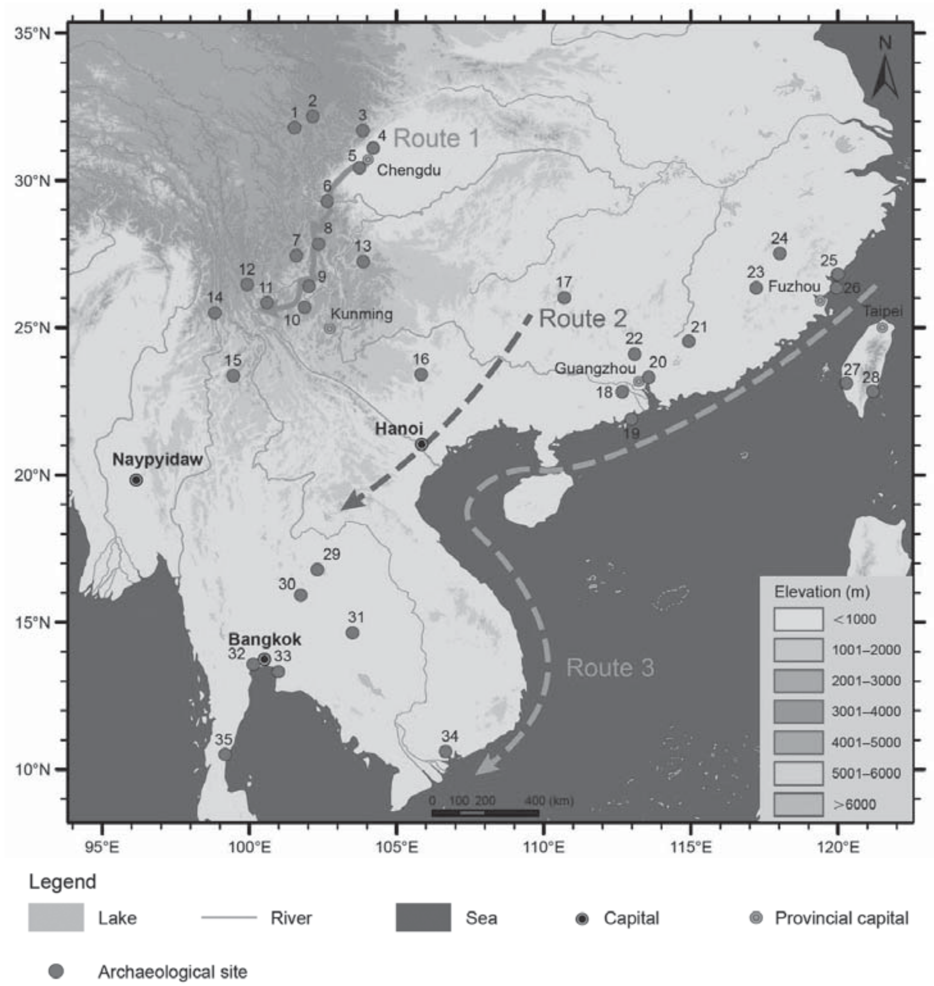
By far, the domestication of rice is believed to have taken place in the Yangtze River Basin between 9000 and 6000 BP. The earliest evidence of rice domestication can be found at sites such as Shangshan and Kuahuqiao, where charred rice remains and harvesting tools have been discovered. These early rice specimens exhibit characteristics of both wild and domesticated rice, indicating a transitional phase of domestication. Over time, human selection and cultivation practices led to the full domestication of rice, resulting in the development of cultivated varieties like *Oryza sativa japonica* and *Oryza sativa indica* rice.

3. Dispersal routes of agriculture from China to Mainland Southeast Asia

Ongoing research are currently investigating the specific routes and mechanisms of dispersal for cereal agriculture, such as rice (*Oryza sativa*) and foxtail millet (*Setaria italica*) (Smith, 2018; Li et al., 2020). Our understanding of cereal agriculture has significantly advanced in the past two decades (Castillo, 2015). In the past, there was a belief that metallurgy was independently developed in Southeast Asia during the 1960s (Pryce, 2009), and it was also thought that this region served as a centre for rice domestication (Gorman, 1977; Sauer, 1952; Solheim, 1972; Chang, 1968, 1970; Chang & Bunting, 1976). However, it is now widely accepted that rice and millets were initially domesticated in China and later spread to other parts of the world, including Southeast Asia (Fuller, 2011; Li et al., 2019). The routes by which migrating farmers and their crops moved from China to Southeast Asia has been open to discussion, with at least three major axes under consideration (Figure 1: from Gao et al., 2020):

(1) a coastal route that started in Taiwan and Fujian (e.g. Bellwood, 1991, 1995; Sagart, 2005; Bellwood and Dizon, 2008; Zhang & Hung, 2010; Gao et al., 2020);

(2) a route from the middle Yangtze to the Lingnan and the Pearl river basin in Guangdong and then



1. Liujiazhai; 2. Haxiu; 3. Yingpashan; 4. Guiyuangqiao; 5. Baodun; 6. Longwangmiao; 7. Guijiabao; 8. Henglanshan; 9. Liantang; 10. Dadunzi; 11. Baiyangcun; 12. Haimenkou; 13. Jigoshan/Wujiadaping; 14. Shilinggang; 15. Shifodong; 16. Gantuoyang; 17. Xiaojin; 18. Guye; 19. Xincun; 20. Chaling; 21. Laoyuan; 22. Shixia; 23. Nanshan; 24. Hulushan; 25. Huangguashan/Pingfengshan; 26. Dapingding; 27. Nanguanlidong; 28. Chaolaiqiao; 29. Non Nok Tha; 30. Ban Non Wat; 31 Non Pa Wai/Nil Kham Haeng/Non Mak La; 32. Khok Phanom Di; 33. Nong Nor; 34. Loc Giang/An Son/Rach Nui; 35. Khao Sam Kaeo.

Figure 1: Three proposed routes with some significant sites regarding the agricultural dispersal from China to Mainland Southeast Asia (after Gao et al., 2020)

onwards through Guangxi into Vietnam (e.g. Zhang & Hung, 2010; Fuller et al., 2011; Gao et al., 2020);

(3) from the Yangtze to Sichuan, Yunnan and then moving down various north-south rivers, such as Salween and Mekong rivers, into Southeast Asia (Higham, 1996, 2002a; 2017).

It is conceivable that two, or even all three, of these routes were pursued concurrently, as indicated by the presence of distinct language phyla in Southeast Asia. This evidence implies the occurrence of multiple agricultural migrations towards both the south and west during prehistoric times (e.g., Higham, 2002b;

Bellwood, 2005; Van Driem, 2005; Stevens and Fuller, 2017).

3.1 Eastern China

In the Southeast Coast of China, archaeobotanical evidence from various sites including Fujian, Guangdong, and Taiwan, suggests the introduction of rice farming to the region around 5,000 BP. This evidence includes charred rice seeds and phytoliths (Ge et al., 2019; Deng et al., 2018a, 2018b; Yang et al., 2016). It confirms that rice cultivation was established in the coastal regions of Southeast China (Fujian Provincial Museum, 2010; Zhang & Hung, 2010). Additionally, phytoliths from the Baitoushan site indicate the presence of millet on the South China Coast at least 5500 years ago (Dai et al., 2021). Some researchers argue that millet arrived in the South China Coast along with rice before spreading into Southeast Asia (Stevens et al., 2017; Yang et al., 2018). Archaeobotanical evidence from sites in Huangguashan and Pingfengshan also suggests the cultivation of millet during the Neolithic period (4300-3500 BP.), in coastal Southeast China, including Fujian (Deng et al., 2017). However, recent findings have challenged the notion that millets were not part of the Neolithic farming system in this region due to the lack of evidence on the south coast of China (Yang et al., 2018). Near the Red River basin, archaeobotanical evidence from the Gantuoyan site on the Vietnam-Guangxi border indicates the cultivation of rice dating back to approximately 4000-3100 BP. Rice was the dominant crop in the region, although millet cultivation was also present (Lu, 2009; Jin et al., 2014). In addition, the site of Gantuoyan in Guangxi provides evidence of both rice and millet cultivation (Lu, 2009). Therefore, a combined rice-millet package may have been introduced to Vietnam through Guangxi during the Neolithic period, as Guangxi is considered a “spread zone” to Southeast Asia during that time (Rispoli, 2007; Higham, 2017; Yang et al., 2017, 2018; Deng et al., 2018).

3.2 Southwestern China

In Yunnan, archaeological research has revealed the coexistence of foxtail millet and rice in sites such as Dadunzi (ca. 4000 BP), Haimenkou (ca. 3700 BP), and Shifodong (ca. 3100 BP) (Jin et al., 2014; Dal Martello, 2021). The dispersal route of millet and rice agriculture suggests a movement from north to southwest Yunnan and potentially into Southeast Asia, possibly through Burma or Laos, before branching into different cereal dispersal routes (Castillo, 2015). Recent findings from archaeobotanical and linguistic data support the contrast in cultivation ecology between wetland regimes in Yunnan and dryland systems in mainland Southeast Asia (Castillo, 2017; Castillo and Fuller, 2010; Fuller et al., 2010; Qin and Fuller, 2019). These findings suggest that previous hypotheses suggesting Austroasiatic speakers as the main source for crop dispersal to the region may need to be reconsidered. Nevertheless, the hilly landscape of the southern China may have facilitated the development of upland rainfed rice varieties, although no archaeobotanical remains have been found to support the hypothesis of dryland rice cultivation in this region (Yang et al., 2018). Further evidence is required to determine the timing and location of dryland rice cultivation and its spread to mainland Southeast Asia (Castillo, 2015). The mountainous terrain in western and southern Yunnan, bordering Burma and Laos, may have posed challenges for the movement of people and cereals, suggesting the possibility of an alternative route (Jin et al., 2014; Higham et al., 2011; Zuo et al., 2017).

Previous theories suggesting a single southward dispersal of cultivated rice associated with Austroasiatic speakers originating in Yunnan and introducing agriculture to mainland Southeast Asia are not well-supported by archaeobotanical evidence (Silva et al., 2015). Instead, recent research indicates that the spread of cereal crops from China to mainland Southeast Asia involved multiple sources and complex interactions over several millennia (fuller et al, 2011; Silva et al., 2015). The available archaeobotanical data provides varying degrees of support for different migration routes of rice cultivation. While all scenarios are consistent with the spatial diffusion of rice from one or two domestication centres in the Middle and Lower Yangtze regions, the southern routes are less compatible with the dispersal of millet (Silva et al., 2015). However, the archaeological sampling has been limited, there is still a need for further research, particularly comprehensive radiocarbon dating and systematic archaeobotanical investigations in both southern China and mainland Southeast Asia, to fill the knowledge gaps and enhance our understanding of this complex process.

4. Evidence of agriculture in Mainland Southeast Asia

MSEA consists of Myanmar, Thailand, Laos, Vietnam, and Cambodia. Archaeobotany in MSEA has focused on investigating the origins of agriculture and the spread of early rice farming communities. The origins and spread of domestic rice and millet cultivation in this region are important topics in scholarly research (e.g., Glover and Higham 1996; Higham 2013). Previous researchers introduced two contrasting theories regarding the issue at hand, known as the theory of local continuity and the “two-layer” hypothesis (Higham, 2017). The theory of local continuity proposes that farming practices in mainland Southeast Asia were adopted and spread by the descendants of indigenous hunter-gatherers without significant changes in language or genetic characteristics (Pietrusewsky, 2010; Higham, 2017; Turner, 1990). This theory finds support in the belief that this region served as a center for rice domestication in the past (Gorman, 1977; Sauer, 1952; Solheim, 1972; Chang, 1968, 1970; Chang & Bunting, 1976). On the other hand, the “two-layer” hypothesis suggests that rice and millet farmers migrated from domestication centers in the north to mainland Southeast Asia (Chang and Goodenough, 1985; Bellwood, 2005; Higham, 2002b; Van Driem, 2005; Stevens and Fuller, 2017; Castillo, 2017). However, there is a gap between the extensive discussions on cultivation and agricultural dispersal and the limited collection of concrete evidence for agriculture (Bellwood 2005, 2007; Higham 1995). Previous statements about agriculture in the region have largely relied on inference and sources of evidence beyond archaeobotany (Castillo 2013). Early literature on agriculture in Southeast Asia focused on rice, and researchers relied on indirect evidence such as associated artifacts and rice impressions found in pottery or brick due to the scarcity of archaeobotanical sampling (Castillo 2013).

4.1 Archaeobotanical evidence

Thailand has been at the forefront of cereal domestication research compared to its neighbouring countries in Southeast Asia. Archaeological excavations in various sites across Thailand have provided evidence of prehistoric cereal agriculture. Rice cultivation has been a prominent focus of study, with significant findings in both southern and north-eastern Thailand. In southern Thailand, excavations at Khok Phanom Di uncovered rice phytoliths and rice husks tempered in potteries. Direct dating of the rice husks yielded calibrated dates ranging from 5039-4646 and 4826-4438 BP (Thompson, 1996; Ramsey et al., 2002). Additionally, nearby Bronze Age cemetery Nong Nor revealed rice husks from potteries buried with the dead, with the earliest dating to 3442-3000 BP (Hedges et al., 1993). In north-eastern Thailand, carbonized rice grains found at Non Nok Tha indicated rice cultivation as early as 4500-3071 BP (Hedges et al., 1991; Kealhofer, 2002; Kealhofer and Piperno, 1994). Other sites such as Ban Non Wat also provided evidence of ancient rice cultivation in the first millennium BC or later (Higham and Higham, 2009; Gao et al., 2020). Other sites like Ban Chiang and Ban Prasat have also yielded evidence of ancient rice cultivation, including rice husks and phytoliths (Castillo, 2017). Thailand has also yielded evidence of early millet cultivation. The Khao Wong Prachan Valley saw the cultivation of foxtail millet and broomcorn millet during its early occupation, transitioning to mixed farming of rice and millets during the late occupation. The earliest foxtail millet was unearthed at Non Pa Wai and directly dated to 4417-4158 BP (Weber et al., 2010; Castillo, 2013). Millet remains were also discovered in southern Vietnam at Rach Nui (3555-3265 a BP) and in the Malay Peninsula at Khao Sam Kaeo (2400-2100 a BP) (Oxenham et al., 2015; Castillo, 2017; Castillo et al., 2018). Studies based on phytolith analysis in Lake Kumphawapi, the Lopburi area, and Khok Phanom Di suggest that rice cultivation may have started as early as the mid-Holocene in the northeast and central plains of Thailand (Kealhofer, 2002; Kealhofer and Piperno, 1994). However, the methods used to differentiate between wild and domesticated rice based on phytolith analysis have been criticized for their limitations (Castillo, 2013). Prominent scholars such as Thompson and Weber have contributed significantly to the understanding of cereal domestication in Thailand. Thompson's research at Khok Phanom Di revealed the first evidence of domesticated rice cultivation in Thailand, dating back to around 4000-3500 BP (Thompson, 1996). Weber's research in the Khao Wong Prachan Valley challenged the prevailing focus on rice and demonstrated evidence of foxtail millet cultivation predating rice adoption by a thousand years (Weber et al., 2010).

Evidence of cereal farming in mainland Southeast Asia between 4500 and 4000 BP is limited, with most of the evidence emerging after 4000 BP (Fuller and Castillo, 2021). The initial agricultural practices established in mainland Southeast Asia were low-yielding and low-input dry rice and millet cultivation. Wet rice cultivation, which is commonly observed today, represents a later development involving labour intensification and increased varietal diversity in rice (Castillo et al., 2018b). The earliest evidence for wet rice cultivation dates back to around 2150 BP at Ban Non Wat (Castillo et al., 2018b). Analysis of rice spikelet base rachilla scars has helped distinguish between domesticated and wild rice (Thompson, 1996; Fuller et al., 2009). Several sites in mainland Southeast Asia have provided evidence of domesticated rice from 4000 BP to the 12th century AD (Castillo, 2013). However, only a few sites have reported foxtail millet, with the earliest evidence of its cultivation dating back to 4420-4150 BP at Non Pa Wai in the Khao Wong Prachan Valley (Weber et al., 2010). Foxtail millet cultivation predates the adoption of rice in the Khao Wong Prachan Valley by over a thousand years, and it continued to be cultivated alongside rice (Castillo, 2013). Other sites, such as Khao Sam Kaeo in the Thai-Malay Peninsula and Rach Nui in southern Vietnam, provide evidence of both rice and foxtail millet cultivation in their dietary practices. The spread of cereal cultivation to Khao Sam Kaeo likely followed a north-south trajectory from central Thailand (Weber et al., 2010). Rach Nui, on the other hand, was a Neolithic site that existed from the second millennium BC and relied on vegeculture, coastal foraging, and exchange activities, with some consumption of foxtail millet and rice (Oxenham et al., 2015). There is no evidence of cereal cultivation at Rach Nui, suggesting that exchange activities played a role in obtaining cereals. The origins of these cereals and the nature of the exchanged products remain unresolved.

Archaeological research conducted in Vietnam has yielded substantial evidence of prehistoric cereal agriculture, particularly within the Red River plains. The Phung Nguyen culture, prevalent in the region, offers valuable insights into subsistence strategies and cultural practices, with the Man Bac site serving as a key resource dating back to approximately 4000 BP (Nguyen, 2009; Huffer and Hiep, 2011; Sawada et al., 2011; Higham, 2017). Compared to other regions in mainland Southeast Asia, the Red River plains in northern Vietnam exhibit an earlier neolithic occupation. Noteworthy sites such as Đa Bút, Cái Bèo, and Quỳnh Văn reveal neolithic occupation dating as far back as 7000-5000 BP, with pottery vessels and tools dating to approximately 4500-3000 BP, and even some artifacts belonging to the Bronze and Iron Ages (Hung, 2016). The Vam Co Dong region is particularly renowned for its concentration of neolithic sites from the late third and second millennia BC, further highlighting the significance of the area (Hung, 2016; Piper et al., 2017). In a comprehensive review by Bùi Vinh, a general model of the neolithic period in Vietnam is presented, emphasizing the northern provinces and discussing various cultures and developmental aspects (Bùi Vinh, 1994). Furthermore, previous research has also identified neolithic sites dating to the late third and second millennia BC in the Vam Co Dong region, including An Son in Long An Province, Loc Giang, and Dinh Ong in Tay Ninh Province (Nishimura 2002; Nishimura and Nguyen 1998). An Son, in particular, has been extensively excavated and provides a comprehensive neolithic sequence in southern Vietnam (Piper et al., 2017). Excavations conducted in 2009 at An Son revealed evidence of a mixed economy, including domesticated pigs and dogs, the cultivation of *Oryza japonica* rice (with husks found in pottery), fish and shellfish from brackish estuarine rivers, and hunted animals (Hung, 2016). Rice chaff was observed in pottery tempers in the later layers of An Son. Other artifacts discovered at the site include ground and polished stone tools, shell beads, bone fishhooks, worked bone/ivory, ceramic roundels or counters, and baked clay pellets (Bellwood et al. 2011; Sarjeant, 2017). Stratigraphic layers at An Son and the Da Kai site have been dated between 4000-3000 BP based on ceramic form and decoration (Nishimura, 2002; Sarjeant, 2017). However, further excavation and a better understanding of site relationships are needed for a more complete understanding of the neolithic sequence in southern Vietnam (Nguyen, 2009).

4.2 Genetic and morphometric studies

Previous research by Castillo (2013) suggests that early rice domestication occurred in two centres, resulting in two genetically distinct subspecies: *Oryza sativa spp japonica* from China and *O. sativa spp indica* from India. Morphometric analysis has been used to distinguish between *japonica*-type and *indica*-type rice grains, but the shape of a grain alone does not confirm its subspecies. In a study analyzing rice grains from seven sites in Southeast Asia, including the Insular Southeast Asia site of Temanggung, morphometric methods were employed. The sites dating from the Bronze Age to the Late Iron Age predominantly showed *japonica*-type rice. Ancient DNA (aDNA) analysis was also performed on rice grains from four of these sites: Ban Non

Wat, Khao Sam Kaeo, Noen U-Loke, and Phu Khao Thong. The results of the aDNA analysis aligned with the morphometric findings, confirming that the rice from these sites was *japonica*. The successful extraction of aDNA from charred remains included both chloroplast and nuclear genetic sequences, although nuclear sequences were less successfully recovered compared to chloroplast DNA. The high success rates of chloroplast DNA confirmed the subspecies of rice (Castillo, 2013). However, the genetic study conducted by Castillo and team does not support the hypothesis that *indica* rice was adopted in Southeast Asia during the initial contact with India. Instead, it suggests that *indica* rice likely arrived during the Historic period (Castillo et al., 2015). Khao Sam Kaeo and Phu Khao Thong in the Thai-Malay Peninsula show evidence of early contact with India based on material culture, but the genetic evidence does not support the presence of indica rice during that time. Furthermore, the evidence of ancient DNA of rice study from Ban Non Wat, Noen U-Loke, Khao Sam Kaeo, and Phu Khao Thong sites suggests the presence of *Oryza sativa* subspecies *japonica* rather than subspecies *indica*. This hypothesis is based on archaeobotanical analysis, including morphometrics, and the archaeological geography of early rice (Castillo and Fuller 2010; Fuller et al. 2010; Castillo 2011). Additionally, the chronological contexts are available from three sites on the Khorat Plateau of Northeast Thailand that evidence early farmer occupation, with initial settlements consistently occurring later than coastal sites: Non Nok Tha 1500-1300 BC, Ban Chiang 1600-1450 BC (Higham, 2015; 2017).

In summary, research indicates that early rice domestication resulted in two genetically distinct subspecies: *O. sativa spp japonica* and *O. sativa spp indica*. Morphometric and aDNA analyses have provided insights into the subspecies present at different time periods in Southeast Asia. While there is evidence of contact with India in certain Southeast Asian sites, the adoption of indica rice in the region appears to have occurred during the Historic period. Further studies are needed to expand our understanding of rice cultivation and subspecies distribution in Southeast Asia throughout history (Castillo, 2013; Castillo et al., 2015; Castillo and Fuller 2010; Fuller et al. 2010; Castillo 2011; Higham, 2015; 2017).

4.3 Farming systems

The archaeobotanical study conducted by Weber and team in the Khao Wong Prachan Valley in central Thailand has provided valuable insights into agriculture and subsistence practices in the region (Weber et al., 2010). The study revealed that millets were the primary staple food before the introduction of rice during the Neolithic and Bronze Age periods. This finding challenges the prevailing focus on rice in archaeological research and has prompted further investigation into the agricultural practices of Prehistoric Thailand. The analysis of weed assemblages in the Khao Wong Prachan Valley, as suggested by Castillo (2013), indicates that dryland cultivation was practiced prior to the adoption of rice, indicating a shift in farming systems. However, when rice became the dominant cereal cultivated in the valley during the first millennium BC, the weed flora became ambiguous, containing both dryland and wetland species. This suggests a possible continuity or "opportunistic farming" approach, where the cultivation practices initially used for millets were adopted for rice. Other archaeobotanical studies focusing on associated weeds of cultivation in mainland Southeast Asia indicate that predominantly dryland rainfed farming systems were prevalent until the Iron Age (Castillo 2011). The earliest evidence for domesticated rice in mainland Southeast Asia comes from the coastal site of Khok

Phanom Di, dating to approximately 2000-1500 BC (Thompson 1996). Extensive archaeobotanical research conducted at this site did not find any evidence of foxtail millet cultivation. It is likely that rice was cultivated in nearby swamps using a décrue cultivation system that relied on natural flooding episodes. The presence of millet evidence in the Khao Wong Prachan Valley predates even the earliest domesticated rice from Khok Phanom Di (Castillo, 2015). Further research is needed to understand the routes of arrival for both cereals and their associated farming systems.

Moving to the Thai-Malay Peninsula, two Metal Age entrepôt sites, Khao Sam Kaeo (KSK) and Phu Khao Thong (PKT), indicate a subsistence regime centered around rice. Other crops consumed or cultivated in these sites include foxtail millet (only in KSK) and Indian pulses such as mungbeans and horsegram (in both KSK and PKT). Historical records from the early twentieth century also indicate that foxtail millet was cultivated during rice scarcity, highlighting its secondary importance compared to rice (Burkill 1935; Castillo, 2017). It is worth investigating whether millets were cultivated in the Thai-Malay Peninsula prior to rice, similar to the Khao Wong Prachan Valley. If so, the shift from one cereal to another, while maintaining the same farming technique, could explain the transition to rice cultivation at Khao Sam Kaeo (Castillo, 2017). The weed taxa associated with rice cultivation at Khao Sam Kaeo and Phu Khao Thong come from dryland systems (Castillo 2013), and other crops cultivated in these sites, such as pulses, are grown under dryland agricultural regimes. The current hypothesis in the Thai-Malay Peninsula is that cultural differentiation occurred within the same population from the second millennium BC due to competition for land (Bulbeck, 2017; Bellina et al., 2022). However, the issue of land exploitation is difficult to tackle due to limited botanical data available in Thai-Malay Peninsula research for this period (Goh et al., 2019; Bulbeck, 2014). Further research is needed to shed more light on the agricultural practices and subsistence strategies in the region.

5. Discussion

The origins of rice and millet cultivation in East Asia have long been a topic of scholarly debate. Based on archaeobotanical and genetic evidence, it is widely believed that rice and millet were independently domesticated in multiple centres. One centre associated with the domestication of millet is located in northern China near the Yellow River basin, this domestication estimated to have occurred between 10000-7000 BP (e.g., Lu et al., 2009; Yang et al., 2012; Gao et al., 2020). On the other hand, the domestication of rice is associated with the Middle and Lower Yangtze valley, rice domestication in this region is estimated to have taken place between 9000-6600 BP (Zhao et al., 2005; Fuller 2010, 2011; Zohary 2012; Choi et al. 2017). Some evidence suggesting a third region in southern China, including Guangdong and Guangxi, where the origins of some tuber crops are suggested but lack clear archaeological evidence (e.g., Yang et al., 2013; Denham et al., 2018).

Previous research provided the direct dating of rice and millet remains has been valuable for understanding the origins of early agriculture in mainland Southeast Asia. However, to gain a comprehensive understanding, it is important to explore archaeological sites in adjacent areas. Evidence of earlier rice and millet cultivation has been found in South and Southwest China. Analyzing the regional archaeological background is crucial to determine the origin of prehistoric agriculture in mainland Southeast Asia. A chronological table (Table 1) is provided below, outlining the major milestones in the domestication routes of rice and millet from China to mainland Southeast Asia.

Table 1: Some crop evidence from sites in along the dispersal routes proposed by researchers.

Region	Site	Date (BP)	Main remains	Referene
Mainland Southeast Asia (Thailand)	Khok Phanom Di	5039-4646 3500	Rice husks millet	Thompson, 1996; Ramsey et al., 2002
	Non Nok Tha	4500-3071 BP	Rice (No millet)	Hedges et al., 1991; Kealhofer, 2002; Kealhofer and Piperno, 1994
	Non Pa Wai	1st millennium BC 4417-4158 BP	Rice Millet	Weber et al., 2010
	Non Mak La	1st millennium BC 2nd millennium BC	Rice Millet	Weber et al., 2010
	Nil Kham Haeng	2756-2492 BP 2nd millennium BC	Rice Millet	Higham and Higham, 2009
	Ban Non Wat	2746-2459	Rice (No millet)	Higham 2009a, 2009b, 2009c; Higham and Kijngam 2011; Higham and Wiriyaromp 2011a, 2011b
	Nong Nor	3442-3000	Rice hush in sherd	Higham and Thosarat 1998a, 1998b; O'Reilly 1998; Hedges et al., 1993
Mainland Southeast Asia (Vietnam)	Loc Gian	4000-3300	Rice spikelet bases in sherds	Barron et al., 2017
	An Son	4250-3150	Rice spikelet bases in sherds	Bellwood et al., 2011; Barron et al., 2017; Castillo et al., 2016; 2018
	Lach Nui	3555-3265	Rice	Castillo, 2018
Yunan-Guizhou	Baiyangcun	4574-4424 4818-4523	Rice Millet	Martello et al., 2018
	Dadunzi	4139-3928 4144-3880	Rice Millet	Jin et al., 2014
	Haimenkou	3692-3571 3966-3706	Rice Millet	Min, 2013
	Jigoshan	3444-3219	Rice No millet	Martello, 2018; Gao et al., 2021
	Wujiadaping	3471-3166	Rice No millet	GZICRA et al., 2006a; Gao et al., 2021
	Shifodong	3358-3066	Rice-millet coexist	YICRA et al., 2010; Martello, 2018
	Shilinggang	2724-2384	Rice-millet coexist	Zheng et al., 2017; Gao et al.,2021
	Gantuoyan	3859-3596	Rice-millet coexist	Martello, 2018; Gao et al., 2021
Guangxi-Guangdong	Xiaojin	4500	Rice No millet	ATGZ and ZCRC, 2004; Zhang and Hung, 2009
	Chaling	4526-4418	Rice (No millet)	Xia et al., 2019
	Laoyuan	4690-4246	Rice (No millet)	Yang et al., 2018

	Shixia	4348-4091	Rice (No millet)	Yang et al., 2016
Fujian-Taiwan	Nanshan	4974-4846	Rice-millet coexist	Yang et al., 2018
	Hulushan	3842-3649	Rice-millet coexist	Ge et al., 2019
	Huangguashan	3980-3846	Rice-millet coexist	
	Pingfenshan	3826-3632	Rice-millet coexist	Deng et al., 2018a
	Nanguanlidong	5000-4300 5000-4300	Rice Millet	Tsang et al., 2017
	Chaolaiqiao	4200-4000	Rice (No millet)	Deng et al., 2018a

In Southern China, particularly coastal Fujian and Guangdong, according to archaeological records, the indigenous hunter-gatherer communities had existed prior to the introduction of agriculture during the Neolithic Age (Gao et al., 2020). These regions experienced a mixed hunter-gatherer culture influenced by the Middle Yangtze Valley when farming was introduced. In contrast, Guangxi and western Guangdong developed independently without external influence. Therefore, it is reasonable to assume that rice farming initially reached the coastal areas, as supported by existing archaeobotanical evidence (e.g., Yang et al., 2018; Gao et al., 2020).

In the Guangxi-Guangdong region, rice remains have been unearthed at several sites such as Xiaojin, Chaling, Laoyuan, and Shixia, dating between 4690-4246 BP. However, no evidence of millet cultivation has been discovered in this region yet. The timeline for the spread of rice from the middle Yangtze to the Lingnan and Pearl River basins in Guangdong, and subsequently into Vietnam and the upland valleys of Laos, remains unclear. This issue has been highlighted by previous researchers (e.g., Zhang and Hung, 2010; Fuller et al., 2011; Gao et al., 2020).

In the Fujian-Taiwan region, evidence of both rice and millet cultivation has been found at the Nanguanlidong site, dating between 5000-4300 BP. The coexistence of rice and millet has been observed at the Hulushan, Huangguashan, and Pingfenshan sites, dating between 3980-3632 BP. Valuable insights into subsistence strategies and cultural practices dating back to approximately 4000 BP have been provided by evidence from northern Vietnam, particularly the Phung Nguyen culture and the Man Bac site (Nguyen, 2009). Rice spikelet bases have also been discovered in sherds from several sites in Vietnam, such as Loc Gian, An Son, and Lach Nui, dating between 4250-3150 BP. Excavations at An Son in southern Vietnam have revealed evidence of a mixed economy, including the cultivation of *Oryza japonica rice*, domesticated animals, and hunting (Nguyen, 2009; Huffer and Hiep, 2011; Sawada et al., 2011; Higham, 2017). However, there are still limitations in the archaeobotanical evidence to confirm the timeline along the coastal route.

It is important to consider the cultural relationships between these regions and mainland Southeast Asia. Guangxi, which is adjacent to northern Vietnam, shares similar geographical environments and human settings, including a hunter-gatherer subsistence during the middle Neolithic Age. However, thus far, only rice and no millet remain have been found in prehistoric Guangxi and western Guangdong. Therefore, the most we can deduce is that rice farming may have originated from inland areas of Guangdong and Guangxi (Gao et al., 2020). Considering the similarities in material culture along the coast and the impressive navigational abilities of prehistoric groups, it is plausible that an ocean route existed along the coastal areas (Bellwood, 2011). Given the earlier appearance of millet farming in mainland Southeast Asia compared to rice farming and the absence of millets in coastal Guangdong, it is possible that the ocean route originated from coastal Fujian, where both rice and millet were cultivated. Archaeological sites in the southern Indo-China Peninsula, such as Loc Giang, An Son, and Rach Nui in southern Vietnam, have indeed unearthed rice remains dating back to earlier than 3,000 BP. Unfortunately, there is still a lack of evidence for millet agriculture in the coastal areas earlier than Non Pa Wai in Thailand.

In Southwest China, the process of Neolithization began in the mid-fourth millennium BC and was significantly influenced by Northwest China through the "Crescent-Shaped-Cultural Communication Belt" (Gao et al., 2020). The earliest evidence of rice cultivation in the Yunnan-Guizhou region comes from the Baiyangcun site, dated between 4574-4424 BP. This followed by the Dadunzi site (4139-3928 BP), the Haimenkou site (3692-3571 BP), and other more recent sites. Millet evidence has also been discovered at the Baiyangcun site, dated between 4818-4523 BP, which predates the evidence for rice cultivation. However, several sites such as Dadunzi, Haimenkou, Shifodong, Shilinggang, and Gantuoyan show evidence of the coexistence of rice and millet, dated between 3859-2384 BP. In comparison, various sites across Thailand have provided evidence of prehistoric cereal agriculture, including rice phytoliths and rice husks tempered in pottery. These findings date back to different periods, ranging from 5039 BP to 3,000 BP or later. Foxtail millet evidence has been discovered in a few sites, such as Non Pa Wai (4417-4158 BP), Non Mak La (4000 BP), and Khok Phanom Di (3500 BP), supporting the conclusion that rice cultivation predate the foxtail millet adoption. However, the chronological dates raise questions about the timeline for the dispersal routes of rice and foxtail millet from southern China into mainland Southeast Asia. The dates of rice and millet evidence found in the southern margin of China indicate a younger age compared to those found in Central Thailand. Further evidence is required to determine the timing and location of dryland rice cultivation and its spread to mainland Southeast Asia (Castillo, 2017). The mountainous terrain in western and southern Yunnan, bordering Burma and Laos, may have posed challenges for the movement of people and cereals, suggesting the possibility of an alternative route (Jin et al., 2014; Higham et al., 2011; Zuo et al., 2017).

Regarding the agricultural expansion into mainland Southeast Asia, the migration of farmers and their crops from China to Southeast Asia has been a subject of discussion, with three main routes being considered: a coastal route originating in Taiwan and Fujian, a route from the middle Yangtze River to the Lingnan and Pearl River basin in Guangdong, and a route from the Yangtze River region to Sichuan, Yunnan, and then into Southeast Asia (e.g., Bellwood, 1991; 2005; Sagart, 2005; Zhang and Hung, 2010; Fuller et al., 2011; Higham, 1996; 2017; 2002; Castillo, 2017; Gao et al., 2020).

In the early sites of the Yunnan-Guizhou Plateau and coastal Fujian, rice and millet crops were consistently cultivated together. However, this crop combination was not found in mainland Southeast Asia. The available evidence suggests that millet farming was introduced first in this area, while rice was not present during the southward movement. The absence of rice cannot be solely attributed to excavation omissions, as millet grains are smaller and more challenging to preserve and find than rice. This raises the question of whether a crop package still existed when early agriculture spread to mainland Southeast Asia (Gao et al., 2020).

The earliest millets in mainland Southeast Asia were found in the Kao Wong Prachan (KWP) Valley. This area had favourable conditions for dry farming, with relatively fertile clay in the river terrace and silty soil with good water seepage in the piedmont zone where archaeological sites were located. Paleoenvironmental studies indicate that the region was less forested and more herbaceous during the late Neolithic period, making it conducive to dry farming in terms of climate (Kealhofer, 2002). Therefore, millet farming in the KWP Valley may have been a survival strategy employed by local inhabitants to adapt to the natural environment. Furthermore, Neolithic mainland Southeast Asia primarily cultivated upland rice instead of wet rice, which differed from the wet rice cultivation in China (Fuller et al., 2011; Castillo et al., 2017; Martelloa et al., 2018). The transition from wet to upland rice can be seen as an adaptation to the local environment and as a result of the inadaptability of wet rice from China. This difference in rice cultivation practices is one of the reasons why rice farming was introduced at a later stage. It is believed that the introduction of wet rice cultivation in mainland Southeast Asia was likely a result of cultural exchanges and interactions with the Dong Son culture in northern Vietnam, which had advanced agricultural techniques and sophisticated bronze casting technology (Bellwood, 2005; Higham, 1996; 2017).

The spread of agriculture, including rice and millet cultivation, from China to mainland Southeast Asia was a complex process that involved multiple routes and interactions between different cultures. The timing and specific routes of this spread are still subjects of ongoing research and debate, and further archaeological, botanical and genetic studies are needed to provide a more comprehensive understanding of this agricultural expansion.

6. Conclusion

The study of prehistoric cereal agriculture in mainland Southeast Asia offers valuable insights into the origins and spread of agricultural practices in the region. Cereal agriculture, with a focus on rice and millet cultivation, played a vital role in the development of complex societies and civilizations. It contributed to population growth, the formation of settled communities, and the establishment of cultural traditions and belief systems.

Scholarly debates have revolved around the origins of rice and millet cultivation in East Asia. Current evidence suggests that they were independently domesticated in multiple centres. The domestication of millet associated with northern China, specifically near the Yellow River basin, while the domestication of rice associated with the Middle and Lower Yangtze valley. There are indications of a possible third region in southern China, although clear archaeological evidence is lacking. Previous archaeobotanical publications has primarily provided the information on direct dating of rice and millet remains in mainland Southeast Asia. However, to gain a comprehensive understanding, it is crucial to explore archaeological sites in adjacent areas. Earlier evidence of rice and millet cultivation has been discovered in South and Southwest China, implying that the spread of agriculture into mainland Southeast Asia was a complex process involving multiple routes.

In Southern China, particularly coastal Fujian and Guangdong played a significant role in the dissemination of rice farming. It is likely that rice farming initially reached the coastal areas and later expanded to other regions. However, the timeline for the spread of rice to the Lingnan and Pearl River basins in Guangdong, as well as into Vietnam, remains unclear. In the Fujian-Taiwan region, evidence of both rice and millet cultivation has been found, indicating the coexistence of these crops. Valuable insights into subsistence strategies and cultural practices have also been provided by evidence from northern Vietnam. Nonetheless, the timeline along the coastal route lacks sufficient archaeobotanical evidence. Guangxi and western Guangdong developed independently, and so far, only rice remains have been discovered in these regions. It is plausible that rice farming originated from inland areas of Guangdong and Guangxi. The existence of an ocean route along the coastal areas is also possible, given the similarities in material culture and the navigational abilities of prehistoric groups.

In Southwest China, the Neolithization process was influenced by Northwest China, and evidence of both rice and millet cultivation has been found in the Yunnan-Guizhou region. However, the timing and location of dryland rice cultivation and its spread to mainland Southeast Asia are still uncertain. The mountainous terrain in western and southern Yunnan, including present-day Myanmar and Laos, may have presented challenges for the movement of people and cereals, suggesting the possibility of an alternative route.

The migration of farmers and their crops from China to Southeast Asia involved three main routes: a coastal route originating in Taiwan and Fujian, a route from the middle Yangtze River to the Lingnan and Pearl River basin, and a route from the Yangtze River region to Sichuan, Yunnan, and further into Southeast Asia along rivers, particularly the Mekong and Salween Rivers. The available evidence suggests that millet farming was introduced first in mainland Southeast Asia, while rice cultivation occurred at a later stage. The transition from wet to upland rice cultivation in mainland Southeast Asia can be seen as an adaptation to the local environment and as a result of cultural exchanges with neighbouring regions.

Based on the available archaeobotanical evidence from mainland Southeast Asia, it is indicated that rice was introduced during the 3rd millennium BC according to the site of Khok Phanom Di. Notably, the presence of millet in Thailand later arrived by several centuries. It is worth noting, however, that the discovery of millet remains in the mainland Southeast Asia is quite scarce, with only a limited number of sites yielding such evidence. However, the spread of agriculture, including rice and millet cultivation, from China to mainland Southeast Asia was a complex process influenced by various factors such as geographical conditions, cultural interactions, and adaptation to local environments. Further research is necessary to uncover more evidence and provide a clearer understanding of the timing, routes, and cultural dynamics involved in this agricultural expansion.

By far, this paper consolidates existing knowledge, identifies research gaps, and offers a comprehensive understanding of prehistoric cereal agriculture in mainland Southeast Asia. It establishes a foundation for future studies and research endeavours in this field, thereby advancing our knowledge of ancient agricultural practices and their societal implications.

7. Perspectives

One particular area of concern pertains to the lack of concrete archaeobotanical evidence along specific routes, particularly the western regions of China along the routes via Salween and Mekong rivers. These areas have yet to undergo thorough archaeobotanical investigations, resulting in a dearth of comprehensive data regarding the cultivation and dispersal of rice and millet. Interestingly, in Laos, the exact arrival time of rice farming is unclear due to the lack of rice cultivation-related materials. Insufficient botanical and archaeological research have hindered our understanding. It remains uncertain whether rice cultivation originated in southern China and was introduced to Laos or if it developed domestically. Although wild rice exists in the region, there is no botanical evidence from prehistoric sites in Laos to verify this hypothesis. Archaeological records from neighbouring countries such as Vietnam and Thailand suggest transmission of rice and foxtail millet from China, but the exact transmission route is unclear due to the lack of information from Laos.

To establish a precise chronology of prehistory in Laos, interdisciplinary approaches and evidence from different sites are required. While the study of archaeobotany has made significant contributions to the archaeology of various regions, research in the Middle Mekong River region, including Laos, has been relatively undeveloped compared to adjacent regions. Additionally, another significant region encompasses the border region between Guangxi and Vietnam, extending through upland valleys such the mountain range along the border between Laos and Vietnam is called the Annamite Mountain Range where is known for its dense forests, rugged terrain, and rich biodiversity with abandon prehistoric cave sites and human presences since the late Pleistocene to the Holocene (e.g. Pa Ling cave site, Hang cave site, Plain of jars, etc.). Further research is necessary to elucidate the extent and dynamics of rice and millet cultivation along this particular pathway.

Based on available sources of literatures, there are still notable research gaps and scientific issues that remain unresolved as can be identified as follows:

- Limited evidence and research on cereal cultivation in the middle Mekong River region.
- Understanding the domestication process and origins of cereal cultivation in the middle Mekong River region.
- Dispersal routes and migration patterns of cereal cultivation in the middle Mekong River region.
- Methodological approaches and interdisciplinary studies in studying prehistoric cereal agriculture.
- Socio-cultural aspects and agricultural practices related to cereal cultivation in the middle Mekong River region.

Therefore, further investigations using a multidisciplinary approach, including archaeobotanical research, genetic analysis, and socio-cultural studies, would help shed light on the history, domestication process, migration patterns, and socio-cultural dynamics of cereal cultivation in this region.

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本土東南アジアにおける先史時代の穀物農業の研究における現在の視点と科学的課題 : 包括的なレビュー

シントン　ソムマーイ

近年、本土東南アジアにおける先史時代の穀物農業の研究が注目されています。この研究は、初期農業の進展や地域社会の形成における重要な役割を果たしています。本稿では、本土東南アジアにおける先史時代の穀物農業研究の現状と科学的な課題について包括的に検討します。重要な発見、方法論的アプローチ、研究課題が示され、今後の研究の方向性を特定することを目指します。また、このレビューでは、本地域における主要な穀物作物である米と粟の栽培に焦点を当て、中国から本土東南アジアへの穀物農業の拡散経路についても考察し、起源と拡散について探求します。考古植物学的データの収集の不均衡な状況には課題もありますが、このレビューは継続的な研究に貢献し、本土東南アジアの農業史に貴重な示唆を提供することを目指しています。先史時代の穀物農業に関心のある研究者、学生、一般の方々にとって、このレビューは包括的な情報源となり、さらなる研究や活動の基盤となるでしょう。