Post-Neolithic broadening of agriculture in Yunnan, China: Archaeobotanical evidence from Haimenkou

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Abstract: We report archaeobotanical results from systematic flotation obtained during the 2008 excavation of the site of Haimenkou, in Northwest Yunnan, dated to c. 1600-300 BC. Haimenkou is thus far the largest prehistoric settlement excavated in Yunnan, its long occupation across the second and first millennium BC bridges a gap from the Neolithic to the Bronze Age, and its location close to bronze smelting sites and the core area of the 1st millennium BC polity of the Dian makes it an important site to investigate the early development of the province. It is also the earliest site with evidence for wheat and barley in Yunnan and provides essential data for tracing the spread of the two crops into Yunnan, as well as for understanding the agricultural production developments in the province from the second millennium BC onward. People at Haimenkou were practicing a mixed-crop farming strategy based first on rice and millet, and with the addition of wheat from c. 1450 BC. Between c. 800-300 BC archaeobotanical remains attests to a general decrease of millet and rice production in favour of wheat, possibly linked with a drying climate. Other important cultivars present include large quantities of *Chenopodium* (associated with other cereal crops remains such as rice and millets), *Perilla* (Shisoo) seeds, and a few grains of buckwheat, all possibly utilized as crops. Additionally, *Cannabis* seeds have also been retrieved. Several fruits species have also been retrieved, including peaches (*Amygdalus persica*), apricots (*Armeniaca vulgaris*), although these are present in minor quantity in relation to crops and might indicate that local plant resource collection had a secondary role to crop cultivation.

Keywords: Paleoethnobotany, Wheat, Buckwheat, Bronze Age, Domestication, Yunnan

Word count: ~9,000

1. Introduction

Yunnan province in Southwest China lies on the crossroads of the Yangtze basin, the rivers of mainland Southeast Asia (the Salween and the Mekong), the Tibetan Plateau, and mountain tracts leading to the Indian subcontinent. The topographic variability contributes to high biodiversity (Qian et al. 2020; Li and Yue 2020), and the region is also an ethnolinguistic diversity hotspot (Chirkova 2017). It has been seen as a pivotal area in the spread of cultural traditions, including perhaps agriculture and likely bronze working into mainland Southeast Asia (i.e. Higham 1996; Yao et al. 2020). Yunnan may be involved with several south/west dispersal events, including rice between China to India (cf. van Driem 2017; Silva et al. 2018), and likely buckwheat and barley varieties associated with Tibetan and Bodic speakers (Hyslop and D'Alpoim Guedes 2020). In terms of west to east movements into Yunnan, there is a hypothesised dispersal route of barley from India into East Asia through Yunnan (Lister et al. 2018; Liu et al. 2017). Until recently, however, archaeobotanical evidence for early farming in the region has been limited.

Yunnan also lies at the heart of the Dian Culture (formerly known as the Shizhaishan Culture) which occupied the region around the present-day Lake Dian, Kunming. This early Kingdom state was conquered by the Han in 109 BC but saw its beginnings within the Bronze Age from around 800 BC (Allard 1999). As such, Yunnan can potentially provide a comparison for agricultural developments leading to early "state-type" formations in Bronze Age East Asia or Southeast Asia, such as those seen within central China (e.g. Liu and Chen 2012; Higham 2014; 2002).

With the increasing deployment of flotation during archaeological excavations in China, it has become increasingly possible to assess when various crops were introduced to the region, including those originating elsewhere within China (such as rice, millets, soybean or hemp), those that originated outside China, such as wheat, barley, and finally potentially locally domesticated taxa (indigenous to Yunnan or adjacent areas), such as buckwheat (*Fagopyrum esculentum*), *Chenopodium album* or even soybean. The site at Haimenkou produced an outstanding assemblage that included waterlogged and by virtue of the waterlogged conditions exceptionally well-preserved charred remains. As often is the nature of waterlogged material this category of plant remains related predominately to local environmental conditions, while only the charred element included crop species. For this reason, this paper focuses on the charred assemblage rather than the waterlogged, which is drawn up for elements such as fruits and some wild resources, although these formed a relatively minor component of the overall assemblage.

While earlier sites with archaeobotanical remains are known that document the Neolithic dispersal of agriculture within Yunnan from 2600 BC (Dal Martello et al. 2018) and later Bronze Age sites that document agricultural systems within the Dian period (i.e. Dal Martello et al. 2021; Li and Liu 2016; Wang 2014; Yang 2016), few sites with archaeobotanical data are available in Yunnan for the intermediate period from 2000 to 800 BC. The site of Haimenkou, spans the mid-second to the first millennium B.C, corresponding to the Late Neolithic through the Bronze Age of the province, it therefore represents an important resource with which to examine changes in agricultural practices within the early to middle Bronze Age of Yunnan, including the movement and potential domestication of crops, and their relationship to the development of bronze metallurgy and an insight into the potential origins of the agriculture that underpinned the Dian Kingdom within the region.

2. Haimenkou site and excavations

Haimenkou is located in the Dali Bai Autonomous Prefecture in Jianchuan County, Northwest Yunnan (26.466914 N, 99.919778 E; Fig. 1). Jianchuan County belongs to the wider Jinsha River Basin, a tributary of the Yangtze River, presenting a mountainous landscape, with elevations reaching between 3600-1000 m asl; the site of Haimenkou itself lies at 2190m asl (Min 2013). After its discovery in 1957, the site was excavated in March-April 1957 (YPM 1958); in April 1978 (Xiao 1991; Xiao 1995), and in January-May 2008 (YIPCRA et al. 2009). Since 2016, further excavations (still undergoing) have been led by Sichuan University. Detailed excavation reports for any excavation campaign are yet to be published. The site extends over ~5 ha, and is regarded as the largest prehistoric site in Yunnan (Yao 2010) built in or adjacent to wetland on the Heihui River as it flows into Jianhu Lake. The region is under the influence of the subtropical monsoon, with distinct rainy (between May and October) and dry (between November and April) seasons. Annual precipitation in this area is about 1000-1200ml, with only 5% of it occurring during the dry season (Zhao 1994), and annual average temperature is about 12-15 °C (Li and Walker 1986). The site was occupied at a time of general monsoon activity change, with overall environmental conditions becoming cooler and drier than the previous millennium and a climatic event associated with a sharp drop in the monsoon intensity at c. 1500 BC brought climatic conditions in the region close to those of present day (i.e. Dearing et al. 2008; Shen et al. 2006; Shen et al. 2005; Dykoski et al. 2005).

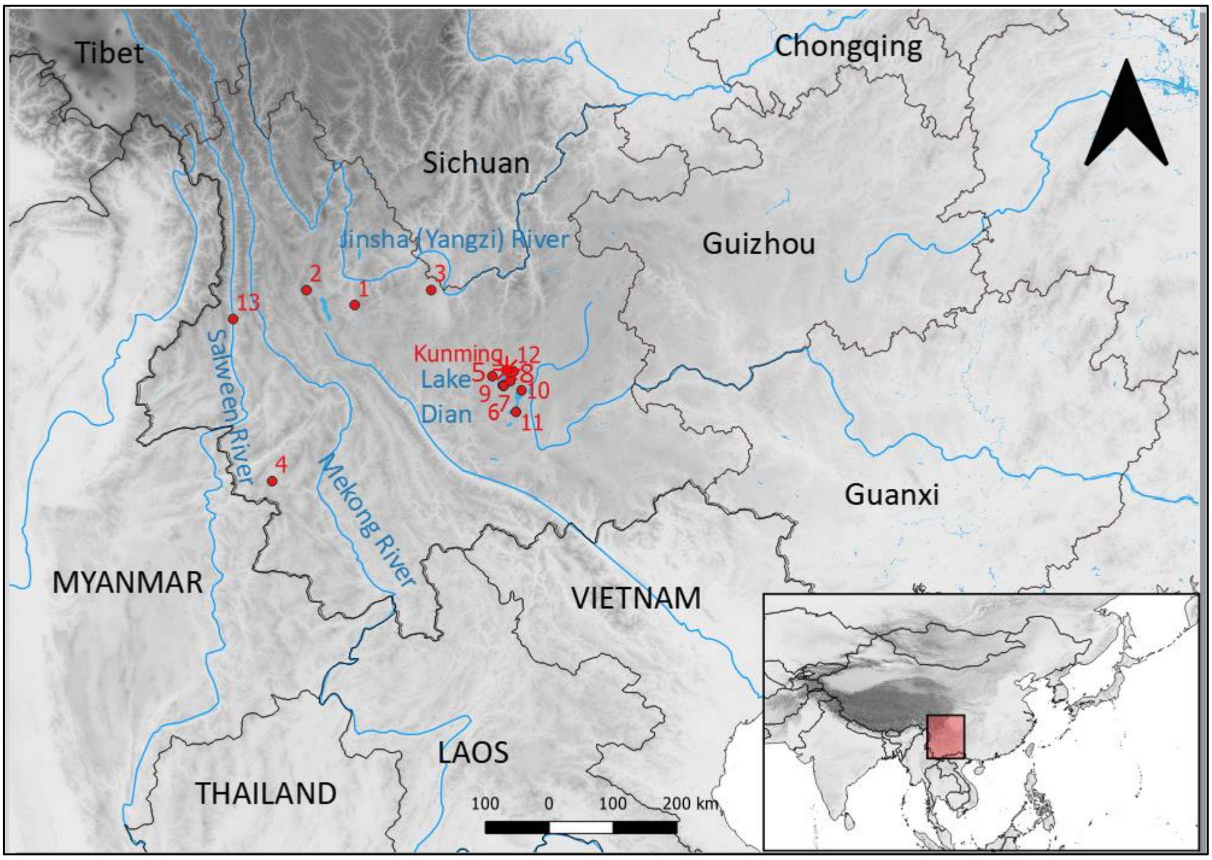


Figure 1. Map showing location of study area and sites mentioned in text: 1. Baiyangcun; 2. Haimenkou; 3. Mopandi; 4. Shifodong; 5. Shizhaishan; 6. Hebosuo; 7. Shangxihe; 8. Anjiang; 9. Dayingzhuang; 10. Xueshan; 11. Guangfentou; 12. Xiaogucheng; 13. Shilingang. Made with QGIS.

Excavations at Haimenkou revealed numerous rectilinear pile dwellings, with the bases of posts, mostly of pine, preserved by waterlogging (Yao 2010; Gao et al. 2014). One especially large wooden structure may have been as large as 2 ha, the largest structure attributed to the Chinese Neolithic to date (Yao 2010). Bronze objects have been reported from the site since its first excavation campaign, leading to debates on its chronology (see Table 1 for a list of all published radiocarbon dates from Haimenkou; Fig. 2).

During the 2008 campaign, a total area of 1395 m^2 divided in 27 trenches of 5*10m size was excavated (Fig. 3). Ten cultural layers were individuated throughout the site, with bronze objects found from layers 6 to 4, and iron objects in layer 3; no metal objects have been reported from the earlier layers (see Li and Min 2014 for an analysis on the composition of metal objects from Haimenkou, and a discussion on early metal production in Yunnan).

During the 2008 excavations, faunal remains were collected and revealed the presence of both domesticated and wild animals (Wang 2018). Domestics included pig (*Sus domesticus*), the most prevalent species through the occupation of the site, along with sheep/goat (*Ovis/Capra* sp.), dog (*Canis familiaris*), and potentially gaur (*Bos gaurus*). Wang (2018) hypothesized that *Bos gaurus* was also under human management. Today, gaur presence is limited to Southern Yunnan and nearby areas; the domesticated form, gayal (*Bos frontalis*), today only sporadically found amongst minority people across Northeast India and Myanmar (Simoons and Simoons 1968; Shaller 1967; Larson and Fuller 2014; Murphy and Fuller 2018: fig. 8).

Charred annual plant remains obtained from flotation samples from trenches T1003, T1004, T1005 (see Fig. 3) were submitted for AMS radiocarbon dating, establishing the following chronology (from Xue 2010):

1. Phase I (Neolithic) 1600- 1450 cal BC layers 10-9-8;
2. Phase II (Neolithic/Bronze Age Transition) 1450-1100 cal BC layer 7-6;
3. Phase III (Bronze Age) 800-300 cal BC layers 5-4-3.

There is apparently a hiatus between Phases 2 and 3, at least within the excavated areas of the site. The significance of this in terms of regional settlement patterns deserves further study. It is also possible that this hiatus relates to fluctuating lake levels locally. Phase III can be associated with the Dian culture.

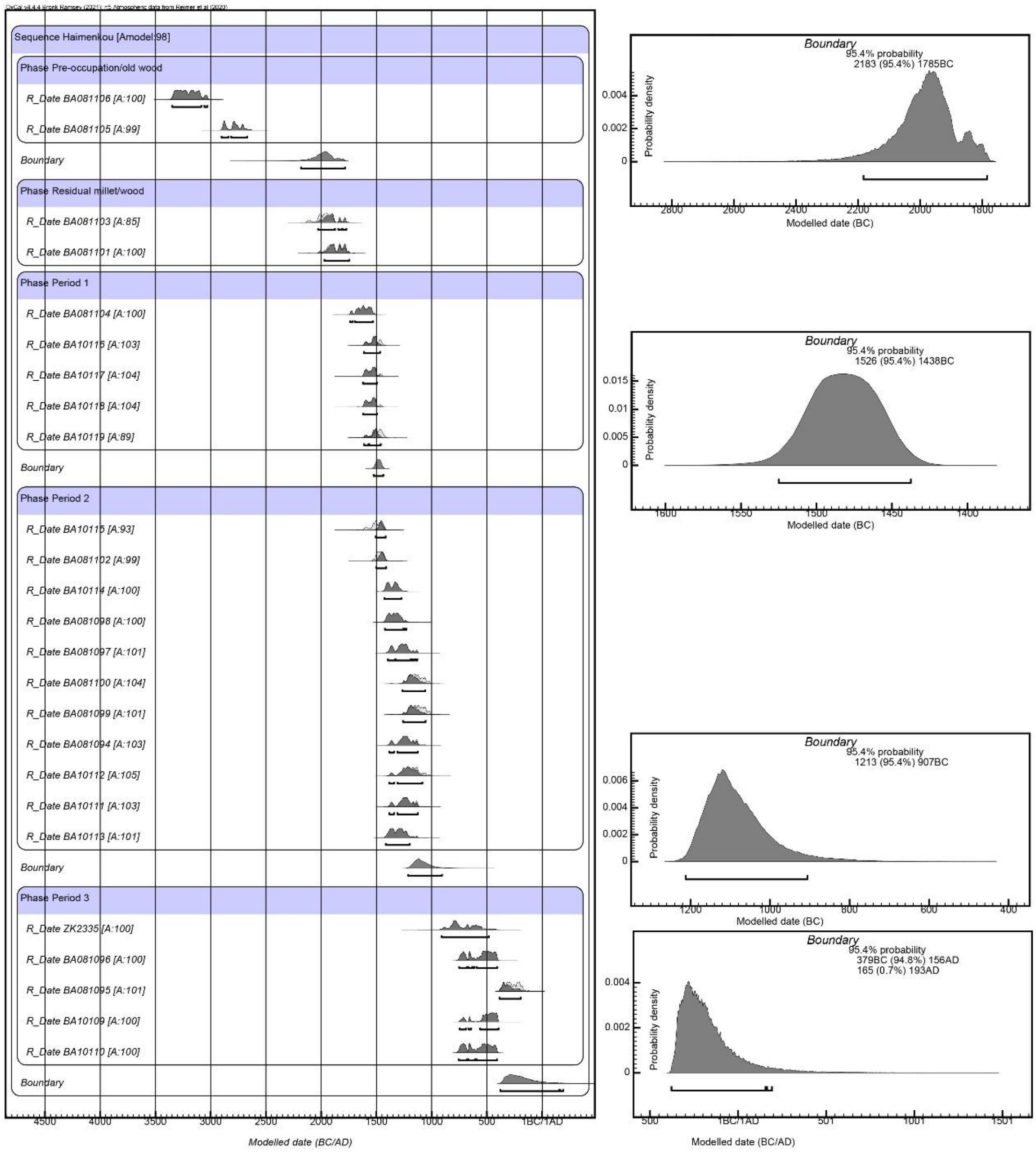


Figure 2. Bayesian model of the calibrated radiocarbon dates from Haimenkou. Made with Oxcal (OxCAL v. 4.4. with the IntCal20 curve: Bronk Ramsey 2009; Reimer et al. 2020)

We report here predominately on the charred archaeobotanical evidence, incorporating initial sorting carried out by QL & DF to obtain dating samples, work by Xue (2010), and further work by Dal Martello (2020). A previous archaeobotanical assessment of Haimenkou was completed by Jin (2013) who studied additional subsamples from trenches DT1003, DT1004, DT1005 (see Supplementary Material S1); those data counted waterlogged and charred seeds together. We consider many of the waterlogged remains, especially from Layer 6, as likely to be post-depositional in relation to the cultural activities in Phase II, and we therefore exclude these from quantitative analyses, although they are included in supplementary data tables (Supplementary Material S1).

Context	Material	Lab Code	date BP	68.20%	95.40%
1958 exc.					
n/a	Wood charcoal	n/a	3115±90		1150±90 BC
1990 exc.					
n/a	Wood charcoal	n/a	2595±75		645±75 BC
Trench 2, Layer 4	Wood charcoal	ZK2335	2520±75	800-540 BC	910-482 BC (a=99.9%)
2008 exc.					
T1003-4-s2	Wheat grain	BA10109	2405±35	520-400 cal BC	747-396 cal BC (a=99.6%)
2008JHAT2121-5	Plant rhizome	BA081095	2200±35	357-203 cal BC	386-194 cal BC (a=100.5%)
2008JHAT2002-5	Wheat grain	BA081096	2435±35	730-415 cal BC	752-406 cal BC (a=99.6%)
T1003-5-s2	Wheat grain	BA10110	2445±35	740-410 cal BC	755-409 cal BC (a=99.6%)
2008JHDT1304-5	Seed	BA081094	3000±35	1288-1131 cal BC	1384-1125 cal BC (a=102.5%)
2008JHAT2003-6	Rice grain	BA081099	2930±35	1196-1057 cal BC	1260-1055 cal BC (a=101.3%)
T1003-6-s2	Wheat grain	BA10112	2975±45	1262-1124 cal BC	1384-1085 cal BC (a=104.7%)
T1003-6-s1	Wheat grain	BA10111	3000±35	1290-1130 cal BC	1383-1125 cal BC (a=102.5%)
2008JHDT1005-5	Charred plant	BA081097	3020±35	1374-1214 cal BC	1396-1130 cal BC (a=101.1%)
T1004-6-s3	Soybean (wild)	BA10113	3045±40	1390-1230 cal BC	1416-1201 cal BC (a=100.5%)
2008JHDT1304-6	Plant fibre	BA081098	3075±35	1397-1292 cal BC	1424-1230 cal BC (a=100%)
2008JHAT2003-7	Foxtail millet grain	BA081100	2940±35	1214-1088 cal BC	1264-1060 cal BC (a=104.1%)
T1003-7-s2	Rice grain	BA10115	3240±40	1610-1450 cal BC	1507-1417 cal BC (a=92.8%)
2008JHAT2505-7	Foxtail millet grain	BA081101	3550±40	1949-1780 cal BC	1971-1748 cal BC (a=99.9%)
T1005-8-s2	Rice grain	BA10116	3250±35	1610-1460 cal BC	1613-1468 cal BC (a=1-2.5%)
2008JHDT1205-8	Plant rhizome	BA081102	3205±35	1502-1440 cal BC	1502-1412 cal BC (a=99.1%)
T1003-8-s2	Foxtail millet grain	BA10117	3275±35	1610-1460 cal BC	1623-1494 cal BC (a=104.2%)
2008JHDT1205-8	Wood charcoal	BA081103	3605±40	2023-1916 cal BC	2030-1773 cal BC (a=84.9%)
T1003-9-s2	Rice grain	BA10118	3275±35	1610-1500 cal BC	1623-1494 cal BC (a=104.4%)

T1003-9-s2	Foxtail millet grain	BA10119	3230±40	1600-1440 cal BC	1612-1461 cal BC (a=89%)
2008JHDT1005-9	Wood charcoal	BA081104	3345±35	1688-1565 cal BC	1738-1530 cal BC (a=100%)
2008JHDT1004-9	Wood charcoal	BA081105	4210±35	2891-2706 cal BC	2902-2670 cal BC (a=99.4%)
2008JHDT1003-10	Plant rhizome	BA081106	4485±35	3331-3099 cal BC	3348-3031 cal BC (a=99.9%)

Table 1. List of published radiocarbon dates for Haimenkou. Data from Xue (2010); Jin (2013); Li and Min (2013); Min (2013); YPM (1958).

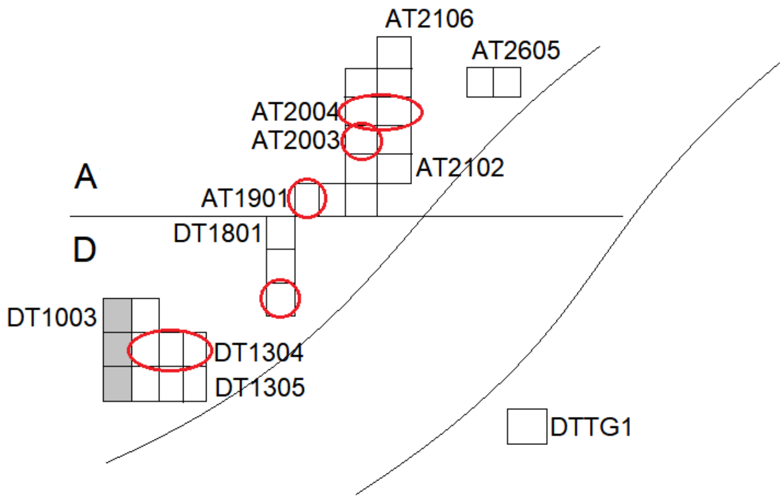


Figure 3. Excavation area and provenance of archaeobotanical samples from Haimenkou; systematically collected samples from trenches DT1003, DT1004, DT1005 shown in filled light grey; trench location of arbitrarily collected samples indicated in red circles. Map redrawn from YPICRA (2009).

3. Materials and Methods

Over the course of the 2008 excavation season, flotation was carried out and archaeobotanical samples were systematically taken covering a complete stratigraphic sequence from layer 3 (most recent) to layer 10 (oldest) from the bulks of trenches DT1003, DT1004, and DT1005 on the western side of the excavation. A number of additional arbitrary samples were taken where the excavators encountered contexts rich in plant remains across the entire site. Of these, 9 were selected with the aim of obtaining higher taxa diversity through the sequence (Fig. 3, Supplementary Materials S1 Tables S1A and S1B); these are reported separately in the quantitative analysis (Fig. 5) as arbitrarily collected samples are biased towards large plant remains that are visible to the naked eye during excavation, and therefore provide only a partial picture in comparison to systematically collected samples. Further well-preserved hand-picked material comprising larger charred and waterlogged remains visible during excavation are provided as supplementary material (S4).

This paper presents the results from 58 analysed samples, from 36 archaeological contexts, including systematically collected (subsamples from trenches DT1003/1004/1005, henceforth referred to as the sampled sequence, see Fig. 3) and 9 selected arbitrary samples (contexts DT1104, DT1204, DT1304, DT1803, AT1901, AT2003, AT2004, see Fig. 3); systematically collected samples were 5L on average (Table 2, Xue 2010). Flotation samples were collected using a 0.3mm mesh, dried naturally and then sieved to obtain fractions of 2mm; 0.9mm; 0,45mm; and a fine fraction of >0.3mm.

The samples presented in this paper were sorted at Peking University, Beijing, and the UCL Institute of Archaeology, London. Macro-botanical remains were extracted from each fraction, and analysed under a low power stereo binocular microscope, with magnification up to 40x. Identifications were recorded following the nomenclature of the revised *Flora of China* (Wu et al 2013; www.efloras.org). Selected specimens were photographed or imaged by scanning electron microscope. While all studied samples are listed in Table S1A, quantified data reported here (seed counts, relative frequency) include those studied by Xue (2010), Dal Martello (2020) and some additional arbitrarily collected samples (Tables 2 and 3), as those reported in Jin (2013) did not differentiate charred and waterlogged specimens.

Many waterlogged remains, especially small-seeds of aquatic plants, are probably post-depositional and washed into the site after human abandonment, especially during the hiatus between Phases II and III, and therefore have been excluded from our analysis. Some larger waterlogged remains, such as fruit stones, were likely transported to site by human occupants. Full data on waterlogged remains can be found in Supplementary Material S1.

Quantitative analysis of the relative frequency of individual taxa and taxonomic groups was conducted on charred material from systematically collected samples to look at changes overtime and differences between contexts. Relative frequency results presented below include only results from systematically sampled sequence, whereas results from both systematic and arbitrary datasets, are included in the ubiquity index.

1. Results:

3.1. General features of the assemblage and key economic taxa

A total of 117,857 charred identifiable remains from some 20 families and over 30 species were recovered from the analysis of the Haimenkou samples (Tables 2, 3, and 4). Charred identifiable remains were divided into the following categories: crops, seeds of field weeds and other weedy species, pulses, fruits, and other potential economic plants (Supplementary Material S2; Fig. 10-11). Uncharred, waterlogged taxa have been quantified and reported separately (see Supplementary Material S1, Table S1B and Fig. S1A).

	No. of samples contexts	Total ID remains	Density (items/L)	Sampling Strategy
Phase 1	8	13,144	202.2	Systematic
	1	4	n/a	Arbitrary
Phase 2	9	7794	103.9	Systematic
	7	84,263	n/a	Arbitrary
Phase 3	8	2304	25.6	Systematic
	3	10,342	n/a	Arbitrary

Table 2. Summary of Haimenkou charred archaeobotanical assemblages.

Phase	1 1600- 1450 cal. BC	2 1450-1100 cal. BC	3 800-300 cal. BC
Volume floated (litres)	c. 65 L	c. 75 L	c. 90 L
No. of contexts	8	9	8
Field crops			
Oryza sativa **(grains)**	1319	570	13
Oryza sativa (fragments)	158	18	8
Oryza sativa (spikelet bases)	333	534	9
Oryza sativa (culms and husks)	14	26	-
Triticum aestivum (grains)	*11*[1]	129	370
Triticum aestivum (fragments)		35	235
Triticum aestivum (rachises)		17	
Hordeum vulgare	--	6	7
Setaria italica **(syn.** ***Setaria italica*** subsp. ***italica*****)**	2990	735	216
Panicum miliaceum	46	12	1
Indet. Millets	21	2	--
Fagopyrum cf. *esculentum*	1	1	2
Other inferred crops			
Cannabis sativum	16	31	--
Chenopodium album sensu lato	6330	1754	7
Perilla sp.	--	--	--
Pulses			
Glycine cf. max	7	66	19
Fruits and nuts			
Prunus sp.	4	2	1
Amygdalus persica	--	--	--
Armeniaca vulgaris	--	--	--
Rubus sp.	3	34	21
Vitis sp.	--	2	--
Cucurbitaceae	--	--	--
Cucumis melo	--	--	--
Acorn indet.	--	--	--
Nut shells	1	--	--
Euryale ferox	--	--	--
Grasses			
Setaria viridis (syn. *Setaria italica* subsp. *viridis*)	108	54	3
Setaria cf *verticillata*	--	18	--
Echinochloa sp.	--	38	--
Digitaria sp.	30	140	4

[1] Eleven wheat grains recovered from layer 8 have been excluded in the quantitative analyses as direct radiocarbon dating revealed they were intrusive from later periods (see section 3.2.3 in text).

Avena cf	--	--	--
Other weedy species			
Indet. Poaceae	34	46	3
Verbena officinalis	20	205	11
Galeopsis sp.	2	56	1
Leonurus sp.	--	48	--
Stellaria sp.	2	16	--
Oxalis sp.	4	2	--
Torilis japonica	--	--	--
Sedges and other wetlands			
Cyperus sp.	48	105	7
Juncellus sp.	21	116	3
Juncaceae	--	--	--
Carex sp.	425	698	109
Polygonum sp. (sensu stricto)	70	101	87
Persicaria sp.	5	55	57
Scirpus sp. Type A	48	362	237
Scirpus sp. Type B	4	--	40
Scirpus juncoides	9	14	1
Scirpus triangulates	--	11	--
Indet. Sedge	442	624	41
Najas sp.	--	--	2
Butomus sp.	3	--	--
Mosla sp.	23	88	--
Brassicaceae	--	--	168
Other species			
Bombax sp.	--	22	--
Hibiscus sp.	--	--	--
Apiaceae	2	12	14
Asteraceae	22	34	14
Convolvulaceae	94	87	20
Fabaceae	--	--	--
Lamiaceae	9	33	13
Unidentified remains	134	433	408
Total charred macro-remains	**13,144**	**7794**	**2304**

Table 3. Summary of charred remains from systematically collected flotation samples from trenches DT1003/1004/1005, with total counts of the main crops and species represented by macro-remains.

Phase	1 1600- 1450 cal. BC	2 1450-1100 cal. BC	3 800-300 cal. BC
No. of contexts	1	7	3
Field crops			
Oryza sativa (grains+fragments+spikelet bases)	--	220	2577
Triticum aestivum (grains+fragments+rachises)	--	262	17
Hordeum vulgare	--	2	1
Setaria italica (syn. *Setaria italica* subsp. *italica*)	3	81,941	239
Panicum miliaceum	--	43	--
Fagopyrum cf. *esculentum*	--	2	--
Other inferred crops			
Chenopodium album sensu lato	--	788	7032
Cannabis sativum	--	769	--
Perilla sp.	--	130	456
Pulses			
Glycine cf. max	--	3	--
Fruits and nuts			
Prunus sp.	--	3	--
Amygdalus persica	--	3	--
Armeniaca vulgaris	--	4	--
Rubus sp.	--	6	--
Cucurbitaceae	--	1	1
Cucumis melo	--	--	1
Acorn indet.	--	--	1
Nut shells	--	2	1
Euryale ferox	--	1	1
Grasses			
Setaria viridis (syn. *Setaria italica* subsp. *viridis*)	1	9	6
Setaria cf *verticillata*	--	5	--
Echinochloa sp.	--	1	--
Digitaria sp.	--	2	3
Avena cf	--	4	--
Other weedy species			
Indet. Poaceae,	--	14	1
Verbena officinalis	--	1	--
Galeopsis sp.	--	--	1
Leonurus sp.	--	4	--
Torilis japonica	--	1	--
Sedges and other wetlands			
Cyperus sp.	--	15	--
Juncaceae	--	1	--
Carex sp.	--	4	--
Persicaria sp.	--	11	1
Najas sp.	--	1	--
Butomus sp.	--	2	--
Hibiscus sp.	--	1	--
Asteraceae	--	4	--
Fabaceae	--	--	1
Lamiaceae	--	--	1
Unidentified remains	--	2	1
Total charred macro-remains	4	84,263	10,342

Table 4. Summary of charred remains from arbitrary samples from trenches DT1104, DT1204, DT1304, DT1803, AT1901, AT2003, AT2004.

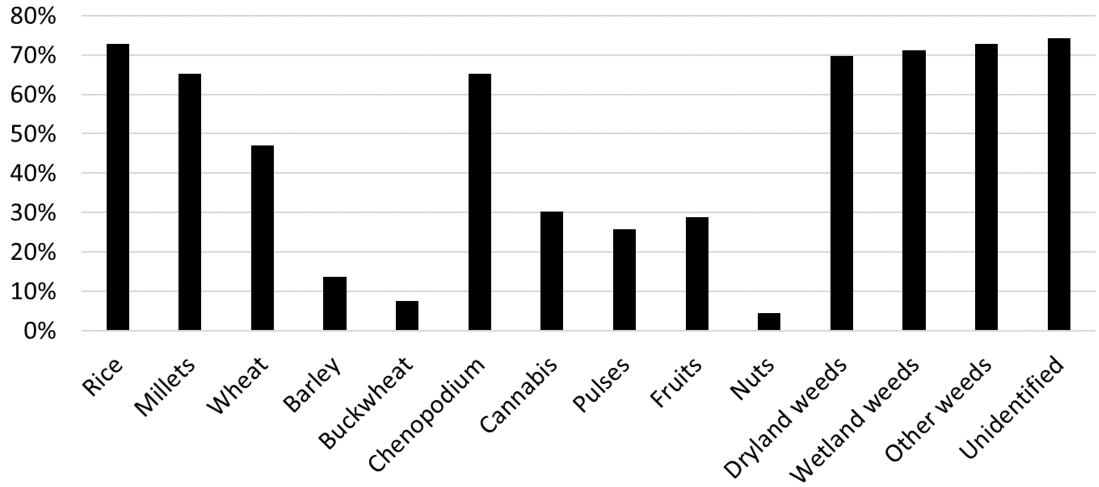
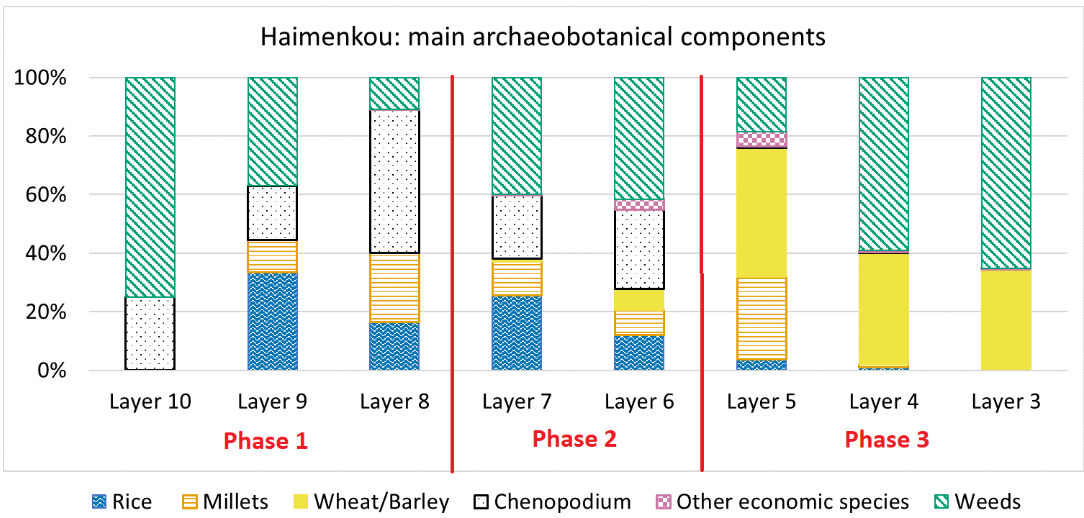


Figure 4. Ubiquity index of main archaeobotanical remains from all analysed samples (including systematically and arbitrarily collected samples) from Haimenkou. Data from Xue (2010); Jin (2013); and Dal Martello (2020).



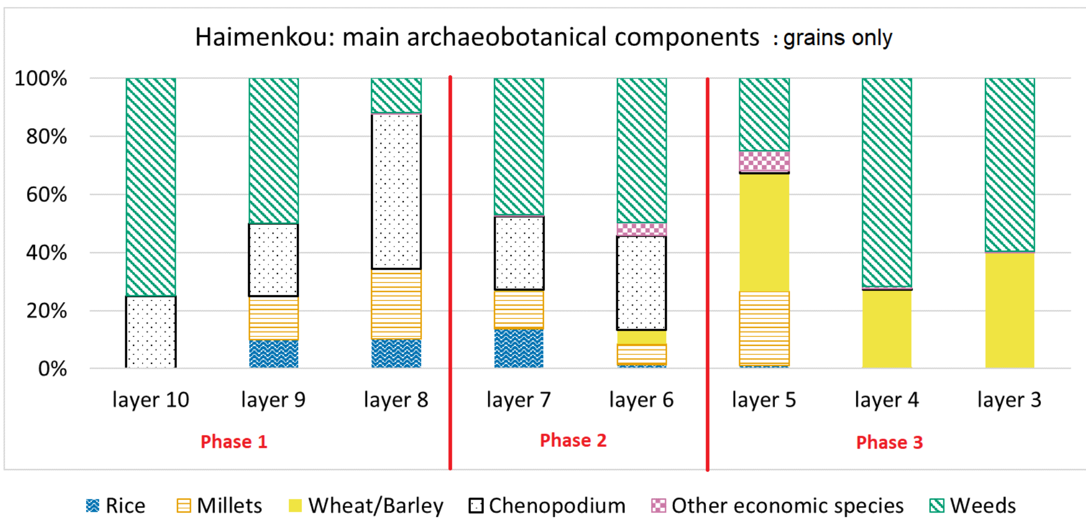


Figure 5a. Top: Relative frequency of main archaeobotanical categories from systematically collected samples at Haimenkou plotted by layer, indeterminate remains have been excluded. Sample sizes: Phases 1: 8 samples (n=12989 seeds); Phase 2: 9 samples (n=7359 seeds); Phase 3: 8 samples (n=1896 seeds). All plants component for crops, including chaff (NIPS). Bottom: Relative frequency of main archaeobotanical categories, chaff excluded, grains only included (MNI). Sample sizes: Phases 1: 8 samples (n=11856 seeds); Phase 2: 9 samples (n=6207 seeds); Phase 3: 8 samples (n=1563 seeds).

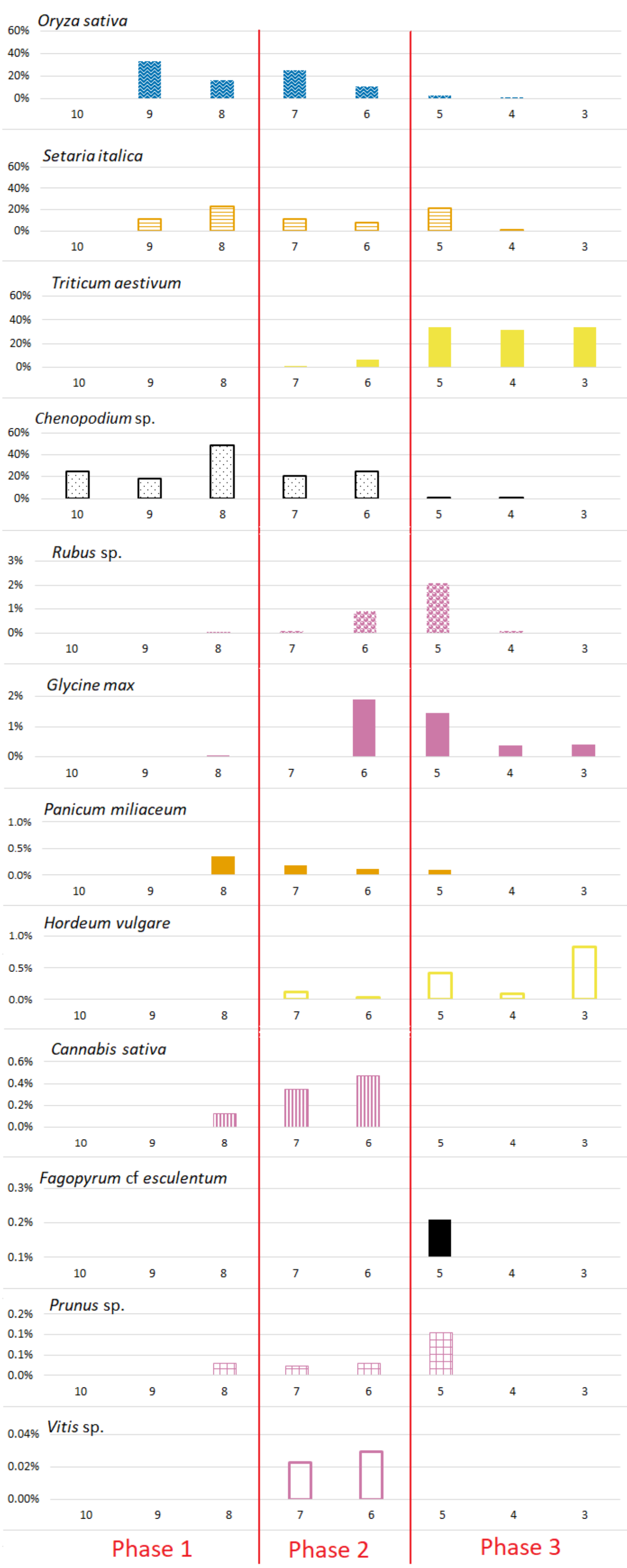


Figure 5b. Relative frequency of main archaeobotanical species from systematically collected samples plotted by layer (see Supplementary Material S2 for absolute counts).

Figure 6a. Top: Relative frequency of main archaeobotanical species from arbitrary samples plotted by layer. Sample size: Phase 1: 1 sample (n= 4 seeds); Phase 2: 7 samples (n= 84259 seeds); Phase 3: 3 samples (n= 10349 seeds). All plants component for crops, including chaff (NIPS). Bottom: Relative frequency of main archaeobotanical categories, chaff excluded, grains only included (MNI). Sample sizes: Phases 1: 1 sample (n=seeds); Phase 2: 7 samples (n=seeds); Phase 3: 3 samples (n=seeds).

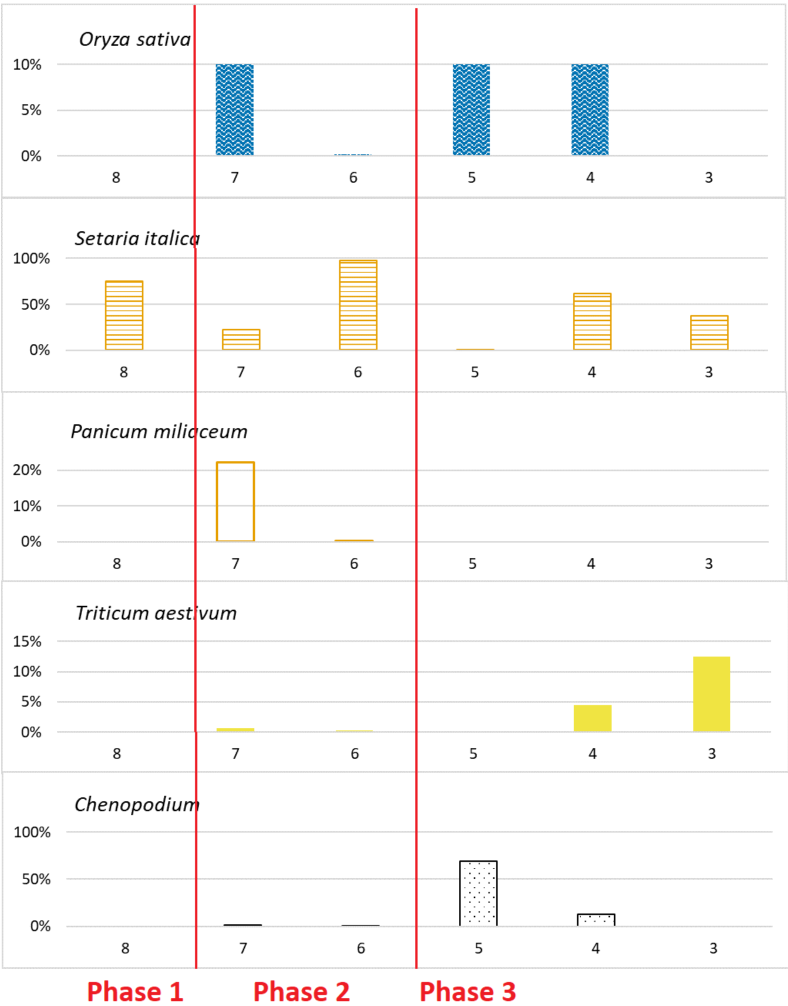


Figure 6b. Relative frequency of main archaeobotanical species from arbitrary samples plotted by layer (see Supplementary Material S2 for absolute counts).

3.2. Field Crops

Annual crops are well represented at Haimenkou and include: rice (*Oryza sativa*), foxtail millet (*Setaria italica; syn. Setaria italica subsp. italica*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), broomcorn millet (*Panicum miliaceum*) and buckwheat (*Fagopyrum* cf *esculentum*). *Chenopodium album* likely also represents a cultivated crop, showing a high relative frequency, especially from layer 8 (Fig. 5a), and a ubiquity comparable to that of cereal crops (Fig. 4). Crop remains are especially prevalent in arbitrarily collected samples, and are the second most numerous categories after seeds of weedy taxa in the systematically collected samples from DT1003, DT1004, DT1005 (Tables 3 and 4, Fig. 6a). The high prevalence of crops in arbitrary samples may indicate that that these concentrations of seeds came originally for stored materials that were displaced (e.g. fallen from upper layers of buildings).

3.2.1. Rice- *Oryza sativa*

Rice remains included whole and fragmented grains, half of which had visible husks, and over 1600 spikelet bases, mainly of the domesticated type (Supplementary Material S2). Rice was most well represented in during the first and second phases from 1600-1100 BC declining in the third phase (Fig. 5a and 5b), although a potentially later context (DT1304⑤) contained high numbers of rice grain and hence the differences might reflect a spatial rather than a temporal pattern.

In several contexts (DT1304⑥, DT1304⑤, and AT1901⑥) large "lumps" of charred rice were recovered (Figs. 7; S4A; S4B); as well as straws bundles (AT2004⑥) (Fig. S4K), although whether or not the latter represent rice straw is unclear.

Ninety-eight rice grains were measured; average width 2.8mm (stdev 0.3mm); average L/W ratio 1.7mm (stdev 0.19mm). All measured grains but one had a L/W ratio <2.2mm (Supplementary Material S3), and can therefore be classified as *Oryza sativa* subsp. *japonica* (as per Castillo et al. 2016). The dimension of rice grains from Haimenkou match those of rice remains dating to prior and around this period, both in Yunnan, as well as other parts of China and Southeast Asia, which have also been identified as *japonica* by other scholars working in these regions (e.g. Fuller et al. 2010; Deng et al. 2015; Castillo et al. 2016; Dal Martello et al. 2021)

Figure 7. Charred lumps of rice from context DT1304⑤. Photos by Rita Dal Martello (From Dal Martello 2020).

3.2.2. Millets- *Setaria italica* and *Panicum miliaceum*

Both *Setaria italica* (syn. *Setaria italica* subsp. *italica*; foxtail millet), and *Panicum miliaceum* (broomcorn millet), were found at Haimenkou, although the latter is only present in very low quantity (less than 0.3%), suggesting it was cultivated as a minor crop or persisted as a weed. Around half of all the millet grains recorded were husked, and charred lumps comprising whole millet panicles were also found from Phase 1 and 2 contexts (Fig. 8; DT1003⑧and DT2004⑥), an indication that they were charred before threshing. This could be indicative that harvested millets (*Setaria italica*) were sometimes stored unprocessed on the spike. One traditional method for storing panicles of foxtail millet selected for propagation rather than consumption is to hang them in bundles and only thresh them the following spring before sowing (Li and Wu 1996). It might be noted that a further sample contained an extremely high quantity of foxtail millet grains (AT2006⑥) potentially representing a storage unit.

A total of 54 grains of *Setaria italica* from Haimenkou were measured, averaging 1.30mm in length (stdev 0.10mm), 1.33mm in width (stdev 0.11mm), and 1.15mm in thickness (stdev 0.15mm); average L/W ratio was 0.98mm (stdev 0.11mm). These measurements are comparable to domesticated foxtail millet reported from sites in Central China (e.g. d'Alpoim Guedes et al. 2013; Stevens, unpublished data), and later periods in Yunnan (e.g. Yang 2016; Dal Martello et al. 2021). Moreover, two grains of *Panicum miliaceum* were also measured: average length was 1.66mm, width 1.98mm, and thickness 1.40mm; average L/W was 0.09mm (Supplementary Material S3); these fit amongst domesticated *P. miliaceum* grains from central China from the Late Neolithic (Stevens et al. 2021).

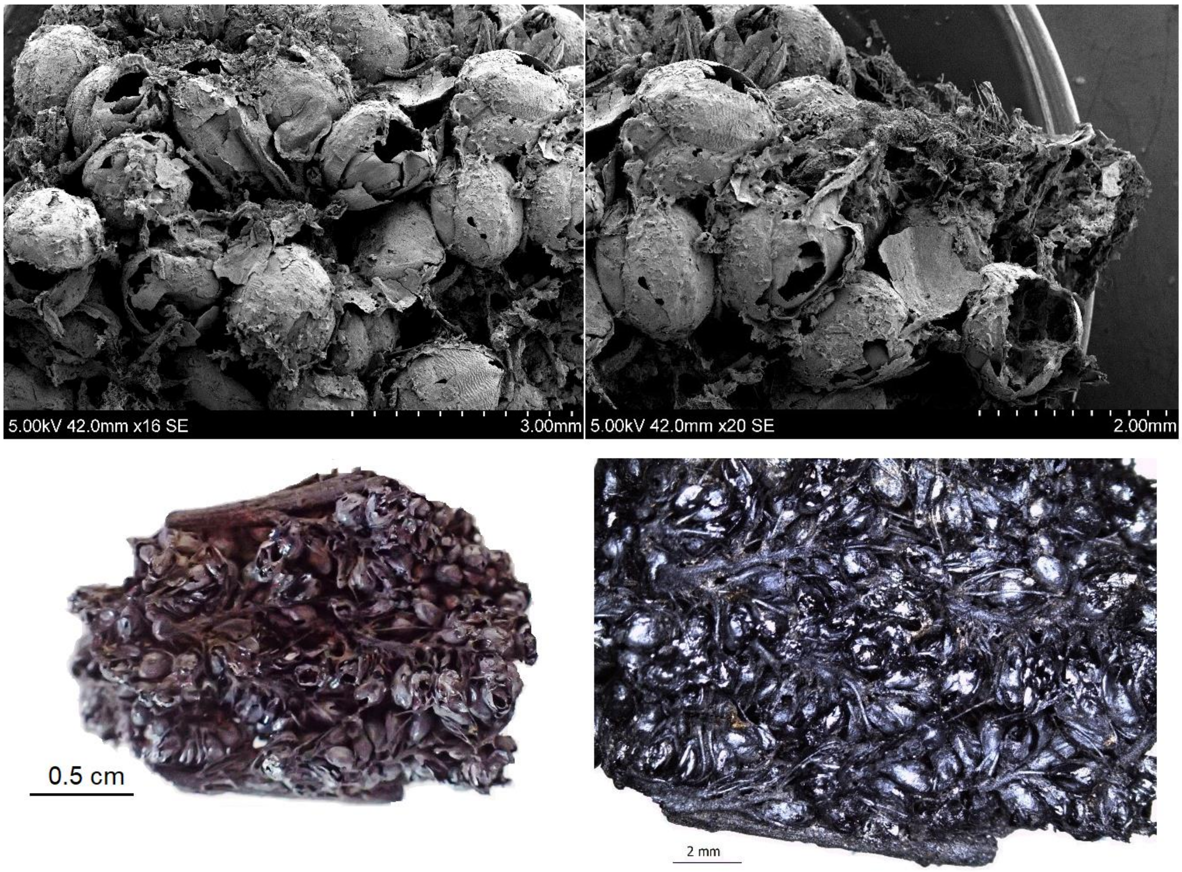


Figure 8. Top: SEM pictures of charred foxtail millet spike from context DT1003⑧. Bottom: Photo and close-up of charred foxtail millet spike from context AT2004⑥. Photos by Rita Dal Martello; from Dal Martello (2020).

3.2.3. Wheat- *Triticum aestivu*m

Securely stratified wheat remains are present from the second phase of occupation (from c. 1400 BC, layer 7) and show an increasing trend in relative frequency (Figs. 5a, 5b). Although some grains of wheat were recovered from layer 8 (DT1005⑧, DT1005⑦) direct AMS dating showed them to be intrusive (Xue 2010), highlighting the importance of directly dating grains to establish the true antiquity of specific cereals (Lee et al. 2007; Long et al. 2018; Deng et al. 2020). Among the hand-collected samples there were no wheat-rich examples; this may indicate that a free-threshing cereal, such as wheat, was less likely to be lost in bulk in contrast to rice or millets that require bulk dehusking on a regular basis. Millets and rice are also more likely to be stored in the spiker or panicle, which can be for example hung from the ceiling or walls; such storage is likely to account for many of crop-rich hand collected samples.

Forty-one grains of wheat were measured (Supplementary Material S3). Their average width was 3.37mm (stdev 0.37mm); L/W ratio was 1.46mm (stdev 0.17mm).

3.2.4. Barley- *Hordeum vulgare*

Only sixteen grains of barley were found in the samples, all from the latter half of Phase 2 and from Phase 3 (layers 6 to 3) (Supplementary Material S2, Fig. 5b). These appear to be naked barley, based on rounded grain profiles (Fig. 10-F), unlike the hulled barley found at the later Dian era site of Dayingzhuang (Dal Martello et al. 2021).

3.2.5. Buckwheat- *Fagopyrum esculentum*

Six nutlets of buckwheat were found spread across all phases of occupation at Haimenkou (Supplementary Material S2; Fig. 10-H). This are regarded as cultivated buckwheat. The nutlets are wide in comparison to the wild progenitor of *Fagopurum esculentum* and as such are thought more likely domesticated. Furthermore, buckwheat's wild progenitor as known today lies in the hills of Northwest Yunnan and Southwest Sichuan (Ohnishi and Matsuoka 1996; Ohnishi and Konishi 2001; Ohnishi 2004; Konishi et al. 2005; Konishi and Ohnishi 2007), supporting Southwest China as the centre of buckwheat domestication. Haimenkou lies within this natural range.

Pulses

3.2.6. Soybean- *Glycine* cf. *max*

A total of 65 whole soybean grains, 18 half grains and 9 hilums were recovered at Haimenkou. The majority (45) coming from just one sample (DT1004⑥), belonging to Phase 2 (c. 1400-1100 BC; Supplementary Material S2; Fig. 10-J).

Soybean remains from early sites in Southwest China are rare, and in Yunnan only found from one other site, Baiyangcun, which is located close to Haimenkou in the Jinsha Basin, and dated to 2600-2050 cal BC (Dal Martello et al. 2018). The finds from Baiyangcun are in terms of morphology and size analogous with wild soybean, which are still known in Southwest China (Dong et al. 2001) and interpreted as a disjunct from the core native wild distribution in central and northern China. At Haimenkou, however, soybean remains are consistent with domesticated morphology and their larger size (Supplementary Material S3, Fig. 10-J), comparable to finds from the Yellow River, confirm their likely domesticated status (see Lee et al. 2011; Fuller et al. 2014).

Other inferred crops

3.2.7. Hemp- *Cannabis sativa*

Cannabis remains were not retrieved in great quantities, with 700 out of the 800 or more grains being recovered from a single Phase 2 context (1450-1100 BC) (1204⑥; Table S2), and no hemp seeds recorded from Phase 3 (c. 800- 300 BC).

A recent review of the available archaeological evidence relating to *Cannabis* use proposed that this species might have been domesticated multiple times across the Old World, as evidenced by early remains in both Europe and East Asia (Long et al. 2017).

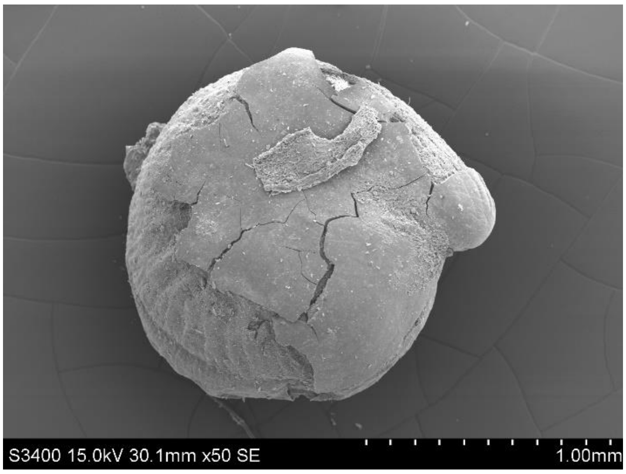
For China, North China is traditionally considered the most likely centre of origin, where *Cannabis* grains and hemp fibre impressions have been reported from as early as the fifth millennium BC (Long et al. 2017) and recent genomic evidence supports this theory (Ren et al. 2021).

3.2.8. *Chenopodium album* sensu lato

Over 15,000 charred *Chenopodium* seeds were recovered from the Haimenkou samples, making this species amongst the most prevalent (Figs. 4 and 5a). Not only is *Chenopodium* present in higher quantities than cereal crops from many samples in the earliest two phases (Fig. 5a), but charred lumps of *Chenopodium* were recovered from the same sample (DT1304⑤) as similarly preserved remains of rice, suggesting their combined presence in a burnt Phase 3 storage context (Fig. 9).

Varieties of *Chenopodium album* (syn. *C. giganteum*) are cultivated today in the Indian Himalayan region, as well as in Tibetan villages in southern Gansu as a minor crop (Partap and Kapoor 1985a; Partap and Kapoor 1985b; Partap and Kapoor 1987; Kang et al. 2014; Kang et al. 2013). *Chenopodium* cultivation is also attested among the Formosan tribes of highland Taiwan, where it is grown for both its leaves and seeds (e.g. Fogg 1983).

Domesticated *Chenopodium* varieties often have larger seeds with thinner coats, (Partap and Kapoor 1985a; 1985b; 1987; Fuller and Allaby 2009) and many of the *Chenopodium* seeds from Haimenkou appear larger and more rounded in profile than typical Chenopodium seeds recovered from central Chinese sites where they are likely present as weeds. These observations together the sheer quantity of *Chenopodium* in crop rich contexts, alongside rice and millet grains then suggests its identification as a cultivated crop (Table S2). Several sites across Sichuan and Yunnan have also been noted to have produced substantial quantities of *Chenopodium* (Gao 2021), as well as from western Han tombs from the Yangling mausoleum (Yang et al. 2009), supporting the theory that this species was under cultivation in the later prehistory of Southwest China.



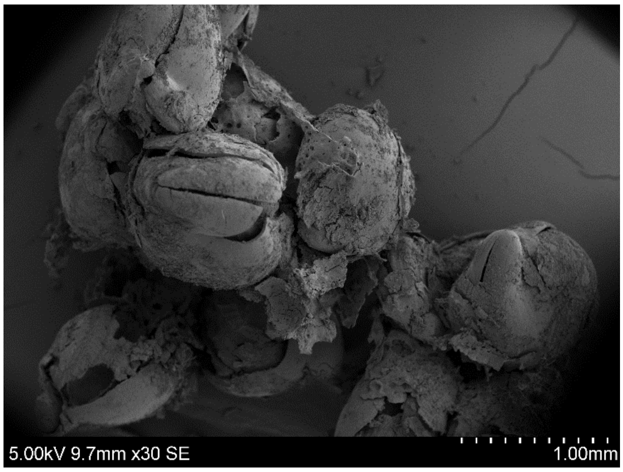


Figure 9. SEM pictures of charred *Chenopodium* grain from Layer 6 (left), and a charred lump of *Chenopodium* remains (right) from context DT1304⑤. Photo by Rita Dal Martello (from Dal Martello 2020). These seeds have a prominent "nose", truncate margin and relatively thin seed coat, in contrast to typical *Chenopodium* seeds encountered on many archaeological sites, suggesting a domesticated form.

3.2.9. Sishoo- *Perilla frutescens*

Seeds of *Perilla frutescens* occurred in large quantities from some Phase 2 and 3 contexts, suggesting they came from cultivated plants, although this species is known also to grow as a weed. The wild form (*P. frutescens* var *purpurascens,* and related wild diploid *Perilla* spp.) occurs throughout southern China, as well as Japan, Korea and the Indian Himalaya (Nitta et al. 200, 2005; Hedge 1990). Cultivated forms include var. *crispa* (Chinese *zisu* 紫苏), which is grown for its aromatic leaves, and var. *frutescens* (Chinese *baisu* 白苏) grown for its seeds, which are significantly larger and softer (Lee and Onishi 2001). While this species is considered to have been domesticated in China, the possibility of more than one origin of cultivation is suggested by the separation of northern and southern oilseed varieties in some genetic investigations (e.g. Ma et al. 2019), while finds from Jomon Japan, at least as early as those in China, suggest a separate domestication there (Crawford 2011).

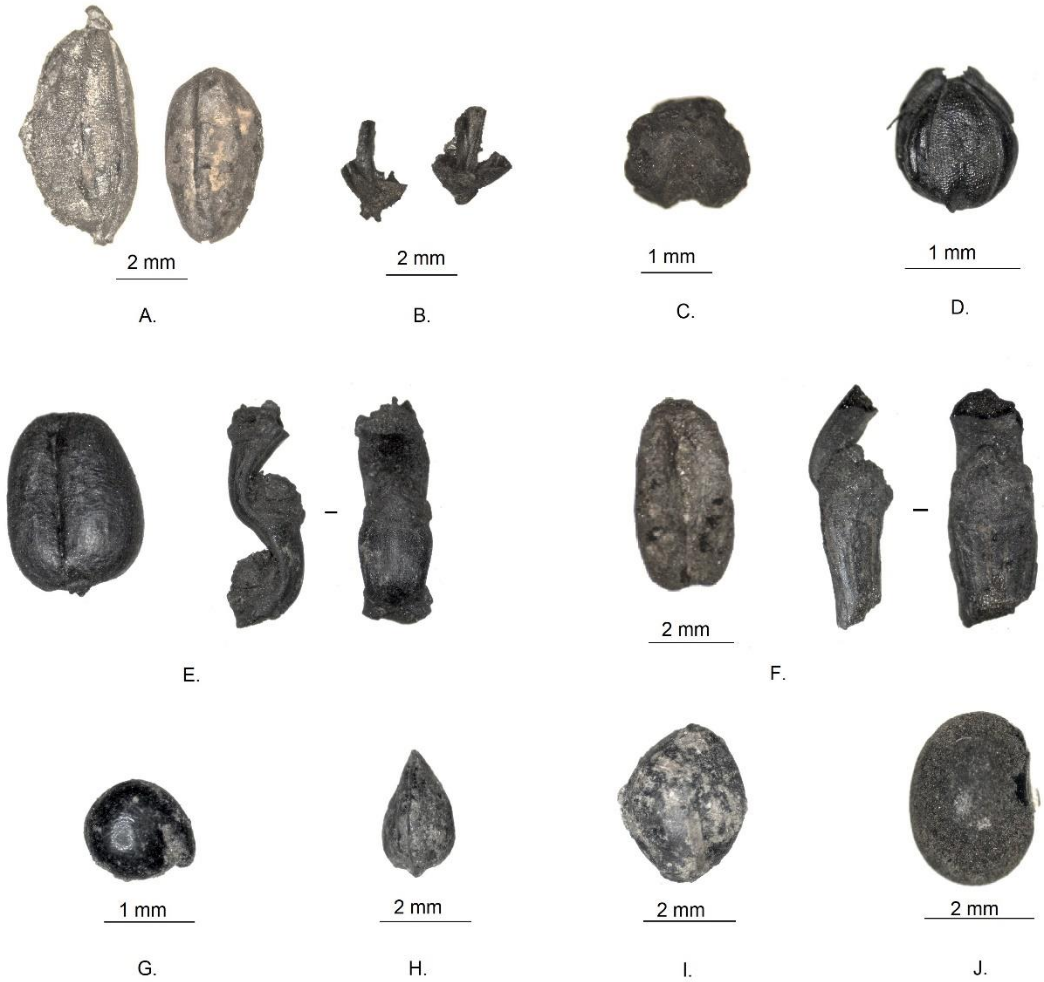


Figure 10. Archaeobotanical remains from Haimenkou: A: *Oryza sativa* grains; B. Rice spikelet bases; C. *Panicum miliaceum*; D. *Setaria italica* (husked); E. *Triticum aestivum* grain and rachis fragment; F. *Hordeum vulgare* grain and rachis fragment; G. *Chenopodium* grain. H. *Fagopyrum* cf *esculentum* grain; I. *Cannabis* grain; J. *Glycine max*.

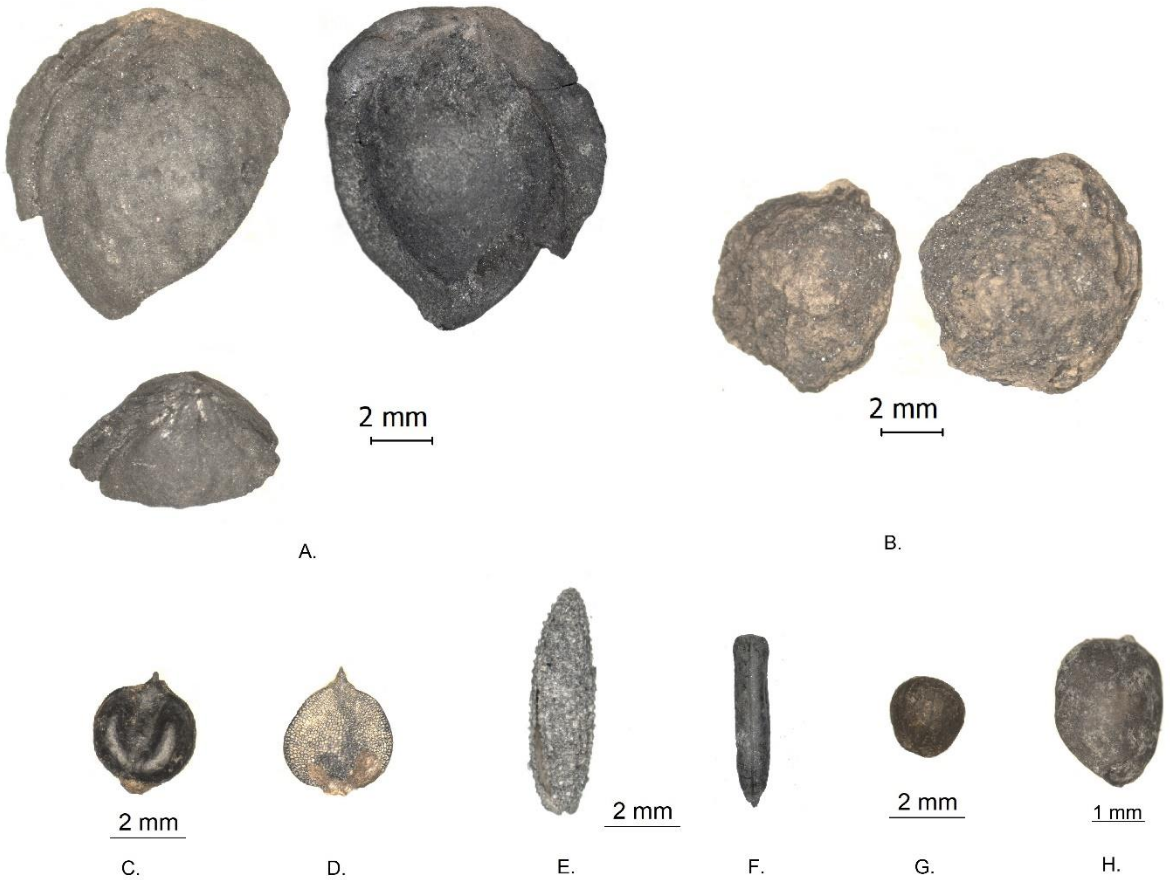


Figure 11. Archaeobotanical remains from Haimenkou: A. *Prunus* cf *persica*; B. *Prunus* cf *armeniaca*; C. *Polygonum persicaria*; D. *Carex* sp.; E. *Najas* sp.; F. *Butomus* sp.; G. *Perilla* sp.; H. *Galeopsis* sp.

3.3. Field weeds

Remains of several field weed species were found at Haimenkou, where they account for c. 22% of the total identified remains (Supplementary Material S2, Fig. 5a). Such species were most prominent in the Phase 1 and the earlier Phase 2 contexts, 9, 7) as well level 4 in Phase 3. *Carex* sp. is the most frequently found of field weed species, followed by *Scirpus* sp. Both are damp to wetland weeds, which are often associated with rice agriculture. These two species together account for c. 8% of the total identifiable remains from systematically collected samples, and for c. 37% among all the weeds remains. Other wetland type of weeds found at Haimenkou include *Polygonum* spp. and *Najas* sp.

Weed species commonly associated with dryland cultivation, at Haimenkou represented by either millet or wheat cultivation, include *Setaria viridis* and *Digitaria* sp. and other wild type Poaceae,, *Galeopsis* sp., and *Leonurus* sp.; these are found primarily between layer 8 and 5, account for the 6% of the total weed remains. Furthermore, a third category has been applied to weed remains, that of "intermediate" weeds, which represent those weed taxa that can be found in a variety of ecological conditions, from wet to dry. At Haimenkou intermediate weeds include *Echinochloa* sp., *Cyperus* sp. and *Mosla* sp.

As expected, arbitrarily collected samples, which were taken during excavation due to visible concentrations of rice and millets, especially in form of lumps (see Supplementary Material S4), have negligible quantities of seeds of field weeds (c. 3%, see Fig. 6a).

3.4. Fruits and Nuts

Several species of fruit were recovered from the Haimenkou samples including numerous charred seeds of *Rubus* sp. (raspberry), along with lesser numbers of charred *Prunus* sp. (wild plum/peach), *Vitis* sp. (wild grape), and *Cucumis melo* (melon) (Table S2). Many additional fruit remains were recovered from the arbitrarily collected samples, including waterlogged stones/stone fragments of *Prunus* sp., including two waterlogged stones of *Prunus* cf. *salicina* (Chinese plum, Fig. S4G). A waterlogged fragment of a jujube (*Ziziphus jujuba*) fruit (Fig. S4J), might represent a cultigen given the wild progenitor (*Ziziphus jujuba* var. *spinosa*) distribution unlikely extends so far south (Fuller and Stevens 2019). Further, likely cultigens include *Armeniaca vulgaris* (apricot, Fig. S4H in Supplementary Material S4), and *Amygdalus persica* (peach, Fig. S4I) whose remains were found from Phase 2 contexts (1450-1100 BC).

Fruit remains represent less than 0.3% of the total identifiable remains and this low occurrence in the analysed samples might indicate that fruit was a relatively minor dietary component. Nevertheless, regional syntheses suggest the apricots and peaches at Haimenkou are likely domesticated forms that had dispersed from Central China (Fuller and Stevens 2019). An increase in the length of peach stones in the Lower Yangtze region suggests the evolution of domesticated, larger-fruited forms began in the third millennium BC (Fuller 2018; Zheng et al. 2014), and the peach stones from Haimenkou measuring 26-27mm (Fig. S4I) are comparable to domesticated peaches from the second millennium BC. The grapes from Haimenkou, which have short stalk typical of wild species, are presumably a locally gathered wild species, along with those of raspberry (*Rubus* sp.).

There is also evidence for some use of wild nuts, but these remains are very minor. In the charred assemblage, seeds of aquatic foxnut (*Euryale ferox*) were recovered, while hand-collected samples included acorns of *Lithocarpus* and cones of *Pinus yunnanensis,* which might have used for its oily edible seeds (pine nuts) (see Figs. S4C, S4D, S4L).

Of some interest was a section of rolled bark retrieved from Phase 1 (DT1305⑧ Fig. S4M). Similar, rolled plant remains have been reported from Hulijia, a 3rd millennium BC site in Qinghai, western China, where it has been hypothesized it was consumed as a famine food (Wang et al. 2015). Early Chinese texts, such as the second century AD *Sheng Nong Beng Cao Jing* (The Classic of Herbal Medicine), report the use of bark (especially of *Eucommia ulmoides* and *Magnolia officinalis;* i.e. Forrest 1995; Hu 1979) for medicinal purposes. Historical and ethnographic traditions from Scandinavia and North America, also attest to bark exploitation as a subsistence strategy (i.e. Östlund et al. 2004; Östlund et al. 2009; Bergman et al. 2004; Rautio et al. 2014; Swetnam 1984).

4. Comparative Discussion

4.1. Agricultural practices in Yunnan during 2nd millennium BC

Flotation has been increasingly deployed in archaeological investigation in China in the last 20 years. Among the pioneering works emplying this method and making Chinese archaeobotany accessible in the English language has been the work done by Crawford and colleagues at the site of Liangchengzhen (Crawford et al. 2005), which provided systematic data on plant use including intrasite spatial variation of plant use, highlighting the importance of the sampling and analysis methodology adopted also at Haimenkou. Moreover, the work at Liangchengzhen also showed a similar archaeovbotanical assemblage to that found at Haimenkou with a mixture of dryland and wetland weeds. Numerous similar studies have been published for northern and central China since (e.g. Lee et al. 2007; d'Alpoim Guedes et al. 2013; Deng et al. 2015; Song et al. 2019), however, similar scholarship in Yunnan has been lacking. To date, Haimenkou is the only second millennium BC site in Yunnan that has undergone systematic archaeobotanical investigation; two more sites, Mopandi and Shifodong (Fig. 1), dated to the second millennium BC through cultural association, have limited, non-systematically retrieved archaeobotanical results. At Shifodong, a cave site located on the Mekong basin in western Yunnan, remains of rice and millets have been reported (Zhao 2010; Liu and Dai 2008), as well as two tree legumes, one of which has been identified as *Tamarindus* cf. *indicus* (Dal Martello 2020). At Mopandi, rice remains were hand-picked during excavation, but no systematic flotation was conducted (YPICRA 2003; Zhao 2003).

Archaeobotanical analyses at Haimenkou, along with the limited results from the aforementioned sites, attest to a broadening of agricultural diversity through the growing of additional crops over the course of the second millennium BC. While Neolithic sites such as Baiyangcun witness the first agricultural settlements in Yunnan, demonstrating a subsistence based largely on rice and millets, supplemented by some wild foods (Dal Martello et al. 2018), Haimenkou provides a chronology for the development of agricultural systems during the second millennium BC that lead to those of the first millennium BC, as seen on a number of sites described below.

4.1.1. Agriculture within the early mid-2nd millennium BC (Phase 1)

Within the earliest phase from 1600-1450 BC, alongside rice and millet, buckwheat, soybean, cannabis and *Chenopodium* all appear as likely cultigens, supplementing subsistence strategies of farming communities at Haimenkou.

While the soybean at Haimenkou appears domesticated, its origin is unclear. In Sichuan, soybean remains of unclear status are reported from just one site, Yingpanshan, dating to about 3300 BC (Zhao and Chen, 2011). The lack of similar finds from the surrounding regions (Sichuan and Middle Yangzi Basin) therefore makes it challenging to investigate whether soybean came to Southwest China together with rice and millet as part of a Neolithic package. However, Yunnan could represent a distinct centre of domestication, given that there is a disjunct cluster of wild populations are known from the region (Dong et al. 2001; Li et al 2010), and the occurrence of morphologically wild soybean were recovered at Neolithic Baiyangcun (Dal Martello et al. 2018). The Haimenkou finds, therefore, raise interesting questions regarding the possibility of either a local domestication process from local wild populations, or a dispersal process of this crop in post-Neolithic times and later than the spread of rice and millets.

Chenopodium likely constituted an important starchy staple, a pseudo-cereal, especially during Phases 1 and 2 alongside rice and millet. *Chenopodium* seeds are often present in higher absolute quantity than any other species (Supplementary Material S2; Fig. 5a), and show a ubiquity comparable to cereal crops rice, millets and wheat, especially during the earlier phases of the site (c. 1600- 1100 BC; Fig. 4). This prevalence and association with rice and millets supports its identification as a food crop.

Buckwheat (*Fagopyrum esculentum*), another pseudo-cereal, is also present throughout the site's occupation was, although the very small quantities mean we cannot infer it to have been very important at Haimenkou.

Reports of buckwheat (*Fagopyrum*) from archaeological contexts in China are rare. A recent review by Hunt and colleagues (Hunt et al. 2018) individuated a total of 26 occurrences in the published literature, of which 16 referred to pollen remains or in two cases starch. Just 10 reports of macro-fossils came from archaeological sites in North and South China. On these data Hunt et al. (2018) suggest that buckwheat was probably initially domesticated at the margins of its native distribution in North China by the fourth millennium BC, earlier than the inference of third millennium BC domestication prosed by other scholars (Weisskopf and Fuller 2013). However, the earlier date is based on inferred dates associated with pollen studies, often from off-site locations, and starch finds (Hunt et al. 2018). As such questions remain as to whether they are securely identified to domesticated, as opposed to wild, *Fagopyrum,* and how secure the associated dating is. At present, the Haimenkou remains represents the earliest macro-fossil remains found so far of domesticated buckwheat from archaeological sites in China.

Early Chinese texts such as the *Shi Jing* (Book of Odes) and *Zhou Li* (Rites of Zhou) have references in the use of *Cannabis* as food, fibre, and for medicinal and/or recreational purposes since at least the early first millennium BC (Li 1974a; Li 1974b; Huang 2000; Clarke and Merlin 2013; Ren et al. 2019). The hundreds of *Cannabis* seeds from Haimenkou, especially from one rich sample, suggest its cultivation as an edible oilseed at this site, although other uses cannot be ruled out, and one unidentified textile fragment and a rope bundle have also been found (AT2003⑥) (Figs. S4E and S4F).

There is also evidence for the exploitation of a small number of wild remains including raspberry (*Rubus* sp.), foxnut (*Euryale ferox*), and local wild plums/peaches (*Prunus* sp.) during the earliest phase.

4.1.2. Agriculture within the later 2nd millennium BC (Phase 2)

From 1450 to 1100 BC, while rice and millet continue to be the most important crops on the site, we see the first appearance of wheat in Yunnan, although at this time it appears of lesser importance in comparison to rice and milletThe initial date of the appearance of wheat at Haimenkou is confirmed through the presence of directly dated wheat grains from Phase 2 (the earliest from T1005-7-s1 furnished a date of 3170±25 BP; 1500-1410 cal. BC). The co-occurrence of small numbers of barley grains with wheat at this time suggests that it was a minor crop or even a contaminant that accompanied wheat into Yunnan around 1450-1100 BC.

The origin of wheat and barley in Yunnan initially is most likely from the northern route via Central Asia. After initial domestication in southwest Asia these crops spreads eastwards from exaploid forms of wheat (*Triticum aestivum*) first occurring in northern Iran c. 6400-5700 BC. They then reached northern Central Asia after 3000 BC (Spengler et al 2016; Stevens et al 2016; Liu et al. 2016; Liu et al 2017; Zhou et al. 2020). However, it might be noted however some native wild barley populations do occur in Central Asia (Morrell and Clegg 2007; Fuller and Weisskopf 2014).

In northern and eastern China wheat appears generally after 2500 BC (Lee et al. 2007; Liu et al. 2017; Deng et al. 2020; Chen et al. 2020). However, it is rarely accompanied by barley in the Early Bronze Age (Boivin et al. 2012), and on the basis on modern genetic diversity patterning, it has been suggested barley could have also come to China from India (Lister et al. 2018; Liu et al. 2017).

On the northern edge of the Tibetan Plateau, to the north of Yunnan, wheat first appears around 1600-1500 BC, along with barley and sheep pastoralism (Chen et al. 2015). It is noted that barley is especially well-suited to the higher elevation of Qinghai and the Tibetan plateau, where it became a prominent crop from 1600-1500 BC (i.e. Chen et al. 2015; Lu et al. 2020).

At 1400 BC Haimenkou is the earliest site in Yunnan where wheat remains have been found, being near contemporary to wheat and barley from Ashaonao site in western Sichuan (1400–1000 BC, d'Alpoim Guedes et al. 2015) and a few centuries earlier than other finds in Southwest China, such as Changguogou in Tibet (c. 1450-800 BC; Fu 2001). Stylistic similarities in ceramics, as well as an increase of sheep/goat animal bones in conjunction with the introduction of wheat and barley at Haimenkou suggests that both species initially came into Yunnan from Northwest China (Li and Min 2013), although a second later possible introduction of barley is discussed below.

Sheep/goat remains, while present within Phase 1 show an increasing trend from c. 1450 BC onward, in conjunction with the appearance of wheat and barley at the site (Wang 2018). However, given their earlier presence at both Haimenkou, and even earlier at nearby Baiyangcun (YPM 1981) dated from 2650- 1690 cal BC (Dal Martello et al. 2018) implies that domesticated caprines were likely introduced to Yunnan before wheat and barley.

As well as wheat, it is also during Phase 2 that we see the first evidence for cultivated peach and apricot, alongside the continued collection and consumption of a similar array of wild taxa to that of Phase 1. However, how such wild remains contributed to the early forest exploitation and management in Yunnan and broader China in prehistory is an issue that deserves further study. *Euryale* and acorns were both recovered from earlier Neolithic samples from Baiyangcun (Dal Martello et al. 2018) and their presence, together with fruits like *Vitis* and *Rubus,* indicates some continuity of gathering of wild forest products from the earliest Neolithic into the Bronze Age, probably focused on later summer or early autumn, but these were at most a minor supplement to economy focused on grain agriculture.

4.2. Agricultural practices in Yunnan during the 1st millennium BC

Our knowledge of the agricultural strategies in Yunnan during the first millennium BC is comparatively better than the previous millennium, as more sites have recently undergone systematic archaeological research, including archaeobotanical analyses.

At Haimenkou the nature of the mixed-crop economy can be seen to generally shift from rice-millet based agriculture during the initial phases of occupation (c. 1600-1200), to a wheat-millet based one by the latest phase (c. 800-300 BC) (Fig. 5a) following the hiatus of 300 years at the end of Phase 2.

In contrast to Haimenkou, most other sites with archaeobotanical data are located in the surroundings of Lake Dian in central Yunnan, and associated with the Dian Culture, including Shizhaishan (779-488 cal BC; Yao and Jiang 2012), Hebosuo (1186-674 cal BC; Yao et al. 2020; Yang 2016; Yao et al. 2015; Yao and Jiang 2012), Shangxihe (1212-208 cal BC; Yao et al. 2020), Anjiang and Xiaogucheng (770-430 cal BC, Yao et al. 2015), Dayingzhuang (750-390 cal BC; Dal Martello et al. 2021), Xueshan (700 BC- 100 AD; Wang et al. 2019; Wang 2014), and Guangfentou (700-300 BC; Li and Liu 2016), (Fig. 1).

At these sites, archaeobotanical investigations show a high diversity of plant resources, including annual crops, rice, foxtail millet, and wheat, as well as several other economic species, such as *Prunus* fruits, soybean, and nuts. At all of these sites, cereals crops represent the majority of the remains retrieved, although high quantities of *Chenopodium* are reported from Guangfentou (Li and Liu 2016), and also form a significant part of the assemblages from Anjiang and Xiaogucheng (Yao et al. 2015). Further some 149 grains of buckwheat have been found at Xueshan (Wang 2014), supporting Southwest China as forming an important region for the investigation of past human use for these two species.

The archaeobotanical assemblages at the Dian sites show that a highly mixed farming strategy was carried out, incorporating rice, millets, and wheat, taking full advantage of the vertical landscape zonation peculiar of Yunnan and possibly implementing a two-season agriculture, with the cultivation of summer rice in the lowlands, and a rotation cycle of summer millets and winter wheat in the surrounding hills (Dal Martello et al. 2021).

Two other aspects are notable for these sites that lie at the heart of the Dian Kingdom. One is that millets, are not well represented on the majority of these sites, forming a very minor crop. The second is that wheat forms a much larger part of the assemblage than millet in most of these sites, and in some cases, e.g. at Xueshan, Dayingzhuang and Anjiang also than rice.

On the western edge of Yunnan province along the Mekong River, research at the site of Shilingang (723-339 cal BC; Li et al. 2016) has revealed people living there relied on a mixed, rice-millet economy, attested by the presence of rice and millet grains, with some input of *Chenopodium*. However, the δ13C stable isotope signatures from human bones at the site (Li et al. 2016; Zhang et al. 2017; Ren et al. 2017) were in the majority of cases lower than −17.5% indicating a diet predominately attained from C3 plants, rather than millets (cf. Liu, R. et al. 2021). Notably wheat was however, absent from this site while micro-botanical analyses further attested that tubers, roots, palms and acorns also contributed to the economy of the site.

Haimenkou lies at the periphery of the area traditionally associated with the Dian Kingdom. Given it was occupied for a long period of time between the second and first millennia BC, its occupation predates this development of strong hierarchical societies in Yunnan, which are attested during the Dian (Yao and Jiang 2012). However, Haimenkou shows a connection with bronze making technology in the province, being located in the close vicinity of at least two bronze smelting sites, Wasezhen (Zou et al. 2017; Li and Han 2011) and Yinsuodao (Min and Wan 2009). Research on archaeological settlement distributions show that the development of the hierarchical society seen during the Dian cultural period in Yunnan province, is reflected by a shift of occupation from the lowland wetlands to the hills (Yao et al. 2015). This shift seems to be a response to a changing climate that provided less water availability/ precipitation, and possibly favoured the relatively rapid incorporation of wheat into the agricultural production soon after its introduction to the region, as attested both by the archaeobotanical sequence at Haimenkou, as well as sites in the Dian basin.

The evidence from Haimenkou can be compared to other sites in western and northwestern China where wheat also rapidly became a significant crop, in contrast to central China. It seems clear that in central and eastern China (Shaanxi, Henan, Shandong), wheat was a minor crop and a minor component of diet from the Late Neolithic through to the Early-Middle Bronze Age, where millet dominated (Crawford et al. 2005; Crawford & Stark 2006; Li et al. 2007; Boivin et al. 2012; Deng et al. 2020). However, wheat certainly grew in importance on some sites within the Central Plains during the Early Shang (Lee et al. 2007) but more notably during the Western and Eastern Zhou (1050-770 BC and 770-256 BC), sometimes becoming of equal importance to millet, although this was not widespread and on many sites millet continued to dominate (Deng et al. 2020).

This situation contrasts with northwest China (e.g. Gansu) where wheat appears to have made rapid inroads into agriculture and diet from its first appearance (Liu et al 2014; Ma et al. 2016). Some of the peoples of Southwest China, those who were ancestral to the Dian Kingdom of first millennium BC Yunnan, also appear to have taken strongly to wheat, as seen by the evidence so far at Haimenkou from the second millennium BC. One further aspect of note is that the distinction between naked barley at Haimenkou (ca. 1400 BC) and hulled barley at later sites, including Dayingzhuang (ca. 400 BC) (Dal Martello et al. 2021) and Guangfentou (Li and Liu 2016), might suggest at least two introductions of different barley varieties, suggesting that the region still witnessed further crop introductions during the first millennium BC.

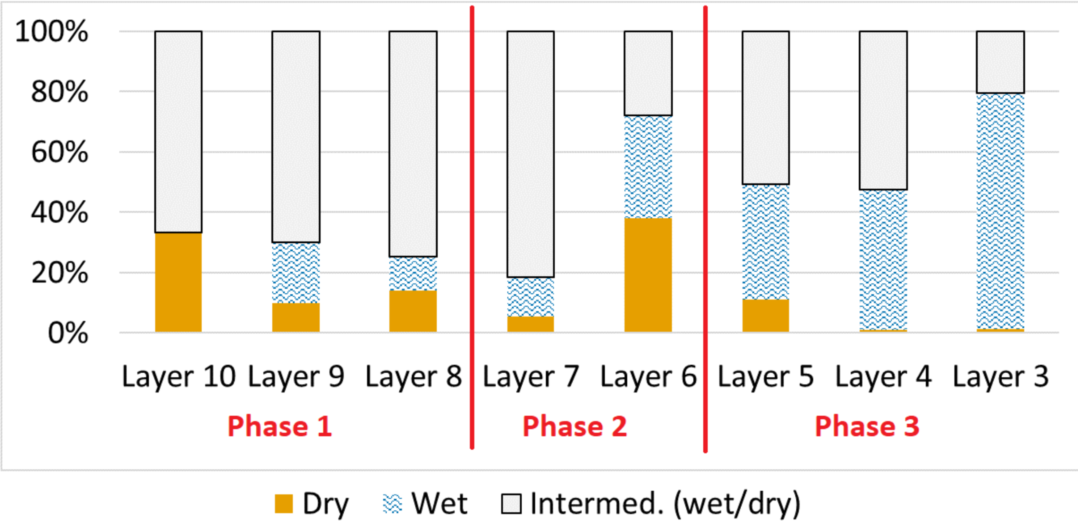


Figure 12. Comparison of field weeds category from systematic collected samples at Haimenkou plotted per layer. Sample sizes: Phases 1: 8 samples (n= 1452 seeds); Phase 2: 9 samples (n= 2985 seeds); Phase 3: 8 samples (n= 835 seeds).

4.3. Changes in weed flora over time

Archaeobotanical analyses at Liangzhengzhen represents one of the first studies to infer the cultivation ecology of rice from archaeobotanical assemblages and to highlight the potential to separate dry vs. wet conditions (Crawford et al. 2005). Seeds of wild herbaceous species interpreted as field weeds were present throughout the occupation of Haimenkou. While they can provide potential information about cultivation ecology their interpretation is hampered by the degree of certainty to which they can be assigned to any specific crop. In all phases there is a mix of dryland and wetland weeds, while those classified as “intermediate” can occur in both wet or dry systems (Fig. 12). Wetland weeds are most likely from rice cultivation in low lying wetlands, or irrigated fields, while “intermediate” weeds might also be associated with such systems. With increasing intensification of irrigated rice, we might expect increasing wet weeds and fewer intermediate types (as per the pattern seed in Iron Thailand: Castillo et al 2018). Dryland weeds are more probably associated with millets, barley or wheat.

Stratigraphically, at the transition between Phases 1 and 2 (layers 8 and 7), rice is the most prevalent crop species and seeds of wetland field weeds are slightly more numerous than dryland weeds, suggesting a generally suitable environmental for rice production in the wetlands of the river valley and lake basin. The high diversity of sedges and Polygonaceae, as well as a few charred examples of true aquatics, such as *Butomus,* argue for their association within wet, flooded rice cultivation. A shift in the weed spectrum then occurs from the transition from Phase 2 to 3 (from Layer 6), where wheat remains first appear, and seeds of dryland field weeds can be seen to increase (Fig. 12). This transition is also associated with a decline in rice (Fig. 5a), where after a hiatus in occupation of around 300 years wheat and to a lesser extent millet become the prevalent crops as seen from the sampled sequence. However, field weed remains are mostly represented by wet and intermediate types (Fig. 12), possibly indicating that although the general production of rice decreased in favour of wheat, irrigation was likely practiced, and this is represented by overall higher quantities of wetland weed remains. One possible contributing factor for the decreased prominence of rice was the inferred drying of the monsoon in this period that might have affected rice productivity and resulted in an increased emphasis on wheat production (d'Alpoim Guedes and Butler 2014). Nevertheless, the evidence for wetland rice weeds in the upper levels suggests some intensification of rice production via water management, which could have served to offset reduced rainfall levels.

Weeds such as *Galeopsis* and *Verbena* were likely hitchhikers with the introduction of wheat. Of note, is the appearance of oats (*Avena* sp.) in Phase 2, the same horizon as wheat and barley, as this genus (*A. sterilis* and *A. fatua*) is native to the Mediterranean through western Asia and likely spread east as a weed of wheat or barley (Baum 1977; Loskutov 2008). Although *Avena* was found only in arbitrarily collected samples, its presence is significant as marker the translocation of the wild/weedy form to this region. *Avena* cf. *fatua* type oats are also reported from Xishanping in Gansu as early as 4000-5000 BP. The establishment of *A. fatua* is important, as in due course it is secondarily domesticated to become the hexaploid Chinese naked oats (*Avena chinensis*), not to be confused with the diploid naked oats of western Europe (*A. nuda*). *A. chinensis* eventually became an important crop across parts of Mongolia, northwestern China and Tibet (Nakao 1951; Zheng and Zhang 2011).

5. Conclusion

Archaeobotanical remains at Haimenkou suggest people were practicing a mixed-crop farming strategy, initially based on rice and millets from around 1600 BC. Wheat is first present on the site during the mid-second millennium BC onward, where it appears to have been of much greater importance than within Central China where millet still dominated in the site. The importance of wheat increases during the latest phase, c. 800-300 BC, a pattern also seen on some Dian Culture period sites, as well as peripheral sites in Yunnan, where rice and millet appear to become of diminishing importance with the diet.

At Haimenkou while millet diminishes in the systematically taken samples, it still dominates in two of the arbitrary samples, demonstrating a continued importance. These cold and draught resistant crops, wheat and to a lesser extent millet, seem to become more prevalent during the later phases of occupation of the site, which could be ascribable to the continued drying of the monsoon which would have affected the ability to successfully grow rice. However, a high presence of wetland weedy taxa from the later phases of the site suggest that although the monsoon was drying, the agriculture was not, and people compensated for the drier climate through a higher human-driven input of water for the production of rice.

Chenopodium is also found in very high numbers and shows a comparable presence to other crop species, and is strongly associated with other crop remains (rice and millets), indicating that people were exploiting this species, possibly as part of a risk reducing strategy in times of high climatic instability such as that attested for the region between the late second and early first millennium B.C. Archaeobotanical evidence from Haimenkou and sites from the Dian basin also show that people in Yunnan incorporated wheat cultivation into the agricultural regime soon after its introduction, similarly to populations from northwestern and western China, and in contrast to people in the Yellow River where wheat was first a minor component of the economy.

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