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The transition to a barley-dominant cultivation system in Tibet: First millennium BC archaeobotanical evidence from Bangga

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Abstract: Historically, agricultural and culinary traditions on the Tibetan Plateau have centered on a specific variety of naked frost-tolerant barley. Single-crop-dominant cultivation systems were rare in the ancient world, and we know little about how, why, and exactly when and where this unique barley-dominant economy developed. Previous research has shown that early cultivation systems in Tibet relied on a mix of barley, wheat, and millets, and that barley-dominant economy first formed around two millennia ago. However, systematically collected data from the transition period between a mixed-cropping and a barley-dominant system have been lacking. We present new archaeobotanical data from the Bangga site (ca. 1055-211BC) in central Tibet, and compare it with a growing corpus of data from other archaeological sites at high elevations across the plateau. We argue that a specialized barley-dominant farming system started to develop, due to a combination of ecological and social factors, at least a millennia earlier than previously recognized in central Tibet and this was eventually adopted across a large geographic area in high-altitude regions (3500 masl) of Tibet.

Keywords: Tibet, barley, high elevation, prehistory, archaeobotany, monocropping

Introduction

The Tibetan Plateau, known as the "rooftop of the world", with a hypoxic environment, cold ambient temperatures, high exposure to solar radiation, hyper aridity, unpredictable weather, and limited resources, presents one of the most challenging landscapes that humans have ever permanently settled. Remarkably, in spite of these challenges, people developed a productive agropastoral system on the plateau several millennia ago (d'Alpoim Guedes and Aldenderfer, 2019). By the mid-seventh century, these high-elevation populations were so well adapted that demographic expansion and imperial conquest led the Tibetan Empire to rule over a vast territory. In AD 763, Tibet even conquered the capital of the Tang Empire, Chang'an (Beckwith, 1993). By this time, a barley-dominant cultivation system fed the populations of many high-elevation areas of Tibet. Despite its clear importance, we know little about how this sustainable agricultural system developed and eventually formed the dietary foundation of a substantial state. Compared with single-crop-dominant systems, crop diversification is often more productive and less risky, especially in ecologically unpredictable settings. Therefore, many cultures around the world have relied, since prehistory, on dynamic multi-cropping systems, helping to mitigate risk (Thrupp, 2000, Jones et al., 2011, Marston, 2011, Spengler et al., 2016, Petrie and Bates, 2017, Liu et al., 2019). Despite the unpredictable ecology and inherent risks of specialization, a highly specialized cultivation practice has

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remained stable in Tibet for thousands of years. There is thus significant impetus to understand the development of a mono-crop-dominant system in one of the least hospitable environments on the planet three thousand years ago.

Naked barley (*Hordeum vulgare* var. *nudum*) has historically been the major staple food of Tibetans, used as a frying-roasted flour called *tsampa*, as well as animal fodder, or for fermentation. Currently, naked barley accounts for over 65 percent of the total food production in Tibet, and more than 69.7 percent of farmland is used to cultivate barley, despite the heavy influx of New World crops over the past century (Al-Menaie et al., 2013). Previous research on the northeastern and southeastern Tibetan Plateau indicates that barley and wheat spread to high elevations during the second millennium BC (Chen et al., 2015, d'Alpoim Guedes et al., 2016, Liu et al., 2017). Nonetheless, Tibet's early agricultural developments have been obscured by a lack of systematic archaeobotanical sampling from different periods and regions on the plateau (Lu, 2016). In recent years, new archaeobotanical and genetic data have begun to shed more light on the questions of when, how, and why different crops, including broomcorn (*Panicum miliaceum*) and foxtail millet (*Setaria italica*), bread wheat (*Triticum aestivum*), and barley, spread onto the plateau and, in the case of barley evolved to withstand the extreme environmental stressors there (d'Alpoim Guedes et al. 2014, 2016a, Chen et al., 2015, Lu, 2016, Liu et al., 2017, Song et al., 2017, Lister et al., 2018, Zeng et al., 2018). By comparing new systematically collected archaeobotanical data from the Bangga site in central Tibet with data from surrounding areas (Figure 1), we can explore the timing and patterns of adoption for this barley-dominant economy and hypothesize driving factors behind this critical economic change.

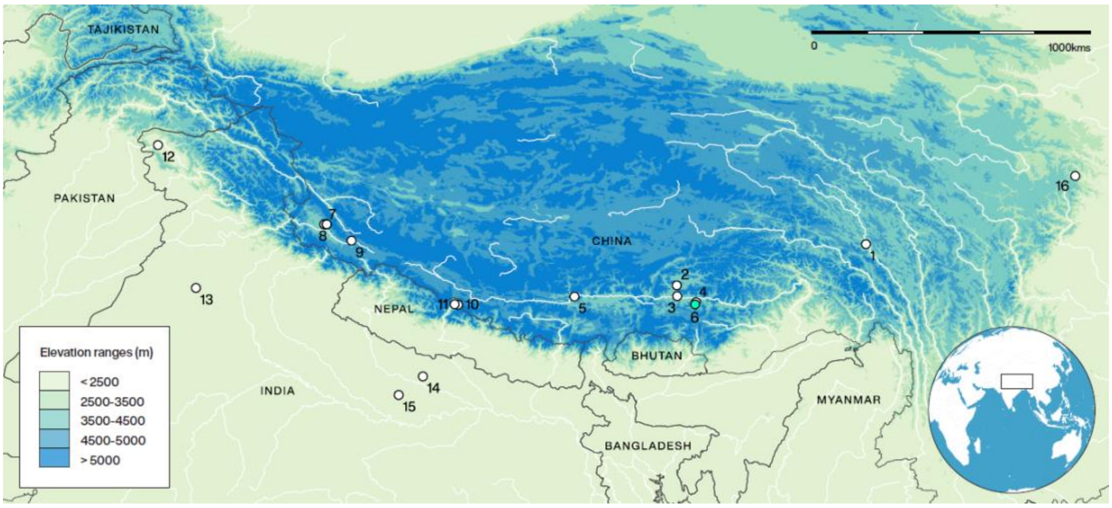

Figure 1: The Tibetan Plateau is situated within the Eurasian landmass. The main sites discussed in the text are indicated. Shades of blue reflect elevation above sea level (see scale on left). 1. Karuo (3100 masl); 2. Qugong (3680 masl); 3. Changguogou (3570 masl); 4. Bangtangbu (3620 masl); 5. Kuoxiong (3950 masl); 6. Bangga (3715 masl); 7. Dingdong (4100 masl); 8. Piyangdongga (4085 masl); 9. Kaerdong (4300 masl); 10. Mebrek (3500 masl); 11. Puldezing (3000 masl); 12. Kanispur (1680 masl); 13. Masudspur (219 masl); 14. Lahuredewa (85 masl); 15. Damdama (99 masl); and 16. Ashaonao (2500 masl).

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Dispersal of Barley Eastward

Some scholars have suggested a second barley domestication east of the well-recognized center or region of domestication in southwest Asia (Morrell and Clegg, 2007, Harris, 2010). However, scholarship has hardly reached a consent on this topic, and the Tibetan *spontaneum* is considered to be a feral derivative (Lister et al. 2018). Archaeobotanical and genetic data attest to a complex domestication process involving several parallel evolutionary trajectories at different sites within the Fertile Crescent (Riehl et al., 2013, Weiss and Zohary, 2011, Willcox, 2013). Domesticated barley evolved from a wild, brittle-rachised, two-rowed, hulled type (*H. vulgare* ssp. *spontaneum*). Non-brittle-rachises evolved to dominate the cultivated population by 8000 BC, controlled by the genes *Bt1* and *Bt2* (Azhaguvel et al., 2007). By 6500 BC, the six-rowed morphotype of barley, which is programed by the *VrS1* allele, replaced the two-rowed form, likely driven by ideal cultivation conditions in farmers' fields and evolutionary selection for higher production rates (Komatsuda et al., 2007, Leon, 2010). The Neolithic dispersal carried this cereal crop across much of the ancient world. This process of dispersal caused further evolutionary change in the plant. By 6000 BC, a thin-glumed morphotype started to disperse across Eurasia, after the *nud* mutation introgressed into cultivated populations in many regions (Taketa et al., 2008). As the crop moved into more northern regions or higher elevations, it was confronted with novel stressors (Liu et al. 2017, Lister et al., 2018). In Asia in particular, the naked variety replaced hulled forms during the second millennium BC (Spengler, 2015).

The removal of the plant from the gene-flow range of its progenitor population likely caused stochastic pressures, including a genetic bottleneck (occurring long after the initial domestication process), and would have further driven diversification and rapid adaptation. To adapt to different day lengths in northern regions, the photoperiod sensitivity mutation, *Ppd-H1* switched off, presumably in the fourth or third millennium BC (Jones et al., 2008, 2012, Lister et al., 2009). Some scholars suggest the possibility that this allele later switched back on in East Asian populations, because the same photoperiod sensitive responses are present in landraces from southern China and southwest Asia. Alternatively, it is also possible that a secondary southern route of dispersal brought a different population of barley to China (Liu et al., 2017). Debates over the timing and routes of cereal crop spread into East Asia, and the question of whether a secondary dispersal, south of the Himalayas, facilitated further crop diversification continue to dominate the literature (Betts et al., 2014, Barton and An, 2014, Spengler et al., 2014a, Liu et al., 2017).

Dispersal of Barley into Tibet

While largely discredited through recent scholarship, there has been a long-standing debate over a possible separate center of barley domestication in Tibet (Xu, 1982, Ma et al.,1988, Dai et al. 2012, Ren et al., 2013). While this debate was undoubtedly fueled by the well-known cultural significance of barley in Tibet, recent discussions have focused on misinterpretations of genetic data and the unclear status of wild or feral barley forms. Whole-genome sequencing has indicated that local varieties of wild barley, which were native to high-elevations on the plateau, hybridized with cultivated varieties once they were carried up to these elevations. This

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hybridization contributed genes to the modern naked barley varieties in Tibet, which made them better suited to local ecological constraints (Dai et al., 2012, Zeng et al., 2015, 2018). Parsing out how this process unfolded is difficult genetically, due to continual and long-term gene flow between cultivated and wild populations on the plateau. Wild or feral types of six-rowed barley were identified on the plateau decades ago and were once thought to be a separate crop progenitor (Xu, 1982, Ma et al., 1988), but they likely originated from hybridization between wild barley and six-rowed domesticated barley (Zeng et al., 2018).

As noted, questions about how, when, and from where domesticated barley spread into Tibet remain unresolved. Considerable evidence supports the idea that barley, as well as wheat, spread along the Inner Asian Mountain Corridor into the Tianshan Mountains, then to northwest China, during the late third millennium BC (Spengler et al., 2014a). Others suggested the initial eastern expansion of wheat and barley into China might be distinct in time and space (Liu et al. 2017). Some scholars argue that famers across Eurasia intensified cultivation practices, notably of barley, and facilitated its dispersal further east into Tibet, possibly through the Pamirs or along the Qinghai highlands (Lister et al., 2018). Others have suggested that a second and likely later route of crop dispersal may have crossed the southern foothills of the Himalayan range into Tibet, possibly also passing through some of the high-elevation passes in the Pamirs or further south, such as through the Swat and Kashmir Valleys (Spengler et al., 2014a, b, Lister et al., 2018). Recent radiocarbon dating of barley grains from northwestern India place domesticated barley at the site of Masudspur by ca. 2800-2500 BC, and as far east as the Ganges, like the Lahuredewa site and the Damdama site in northern India by ca. 2800-2300 BC (Liu et al., 2017). This hypothesis is also supported by archaeobotanical studies in the Kashmir Valley, specifically based on finds indicating the presence of barley at the site of Kanispur by ca. 2467-2236 BC (Liu et al., 2017, Pokharia et al., 2018). New genetic data also suggest that naked barley may have been introduced to southern Tibet through north Pakistan, India, and Nepal between 2500 and 1500 BC (Zeng et al., 2018).

A millet-based cultivation system was already presented in the rich river valleys of the northeastern Tibetan Plateau when barley and wheat spread into this area (d'Alpoim Guedes et al., 2014, Chen et al., 2015). Chen et al. (2015) argued that millet agriculture spread from the middle and lower Yellow River into the northeastern Tibetan Plateau before 3200 BC. The earliest evidence for domesticated millet in Tibet dates to between ca. 2800 and 2100 BC at the site of Karuo, located in eastern Tibet (Xizang zizhiqu wenwu guanli weiyuanhui, 1985, d'Alpoim Guedes et al., 2014, Song et al., forthcoming). Compared to millet, barley's tolerance of high-elevation stressors, notably frosts at night, short durations of suitable growing days, and drought, make it well adapted to high elevations (Jamieson et al., 2010, d'Alpoim Guedes et al., 2016a, b, Spengler, 2019). Abundant naked barley alongside foxtail millet and few wheat remains were recovered from the Changguogou site (ca. 1595-1236 BC) in central Tibet, representing the earliest barley-millet mixed cultivation system in Tibet (Fu, 2001, d'Alpoim Guedes et al., 2014, Lu, 2016, Liu et al., 2016, 2017). Archaeobotanical assemblages from western Tibet indicate that a barley-centric economy had developed by the mid-first millennium AD (Fu, 2008, d'Alpoim Guedes et al., 2014, Song et al., 2017). However, a 1000-year time gap and huge landscape differences between the recorded sites in central and western Tibet

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make it impossible to pinpoint when and why the transition from a millet-dominant to a barley-dominant economy occurred. The systemic archaeobotanical data from Bangga that we report in this article shed light on this vital agricultural transition.

The Bangga Site

The prehistoric settlement of Bangga (29°05'13.66''N, 91°43'15.36''E), located midstream along the Yalu Tsangpo River (Brahmaputra River), was excavated over four field seasons from 2015-2018. In this paper, we only report samples recovered from the first three seasons of fieldwork. Located at an elevation of approximately 3715 masl, the site is situated on a colluvial slope. It is about 2 km to the west of a seasonal stream that flows from south to north, and a modern agropastoral village is currently situated next to the site (Figure 2). Bangga is, to our knowledge, the first excavated site in central Tibet that has yielded unequivocal evidence of settlement. Due to the limited availability of arable land and flatter topography, prime occupation sites in the mountain valleys have often been returned to repeatedly over millennia, with archaeological sequences indicating punctuated phases of occupation. It is currently unclear if the site was continually occupied long term or if it was revisited annually or periodically. Abundant ceramic sherds, animal bones, and lithics including grinding stones and napped tools, were recovered during excavations. Ten AMS dates indicate that the site was occupied for a long period, from ca. 1055 BC to ca. AD 1204 (Table 1).

The archaeological data from Bangga suggest that occupation of the site occurred in roughly two phases. The early phase, representing the major occupation period, includes eight stone enclosures (F1-F8) and occupation layers 13-14, with several activity surfaces, hearths and an impressive array of artifacts, dated from ca. 1055-211 BC. The late phase consists of layers 1-12 (L1-12), with sporadic artifacts and pits, suggesting less intensive human activity. The stratigraphic sequence with feature-by-feature descriptions will be published separately (Lu et al. in press)

Figure 2: The Bangga site and its surrounding ecological context, the arrow shows the location of the site (Photography by Zhengwei Zhang)

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Table 1: Calibrated AMS chronology of charred seeds from Bangga

Sample No.	Feature No. (Original)	Feature No. (New)	Conventional age	Calibration (95.4% credible interval)	Plant types
Beta-439868	2015QBT1(5)	L7	910 +/- 30 BP	ca. AD 1033-1204	Barley
Beta-471994	2015QBL7	L10	1790 +/- 30 BP	ca. AD 133-330	Barley
Beta-425894	2015QBT1(11)	L13	2280 +/- 30 BP	ca. 403-211 BC	Cerealia
Beta-471995	2017QBL16	F7L2	2420 +/- 30 BP	ca. 748-402 BC	Wheat
Beta-471997	2017QBF1Z1	F1Z1	2450 +/- 30 BP	ca. 754-411 BC	Wheat
Beta-471996	2016QBF6	F6	2460 +/- 30 BP	ca. 758-429 BC	Barley
Beta-425895	2015QBT1(12)	H14	2450 +/- 30 BP	ca. 754-411 BC	Cerealia
Beta-471998	2017QBF4Z1	F4Z1	2480 +/- 30 BP	ca. 774-434 BC	Barley
Beta-448782	QBT0201L15:1	F2L1	2590 +/- 30 BP	ca. 820-595 BC	Wheat
Beta-425896	2015QBF2(2)	F5L5	2820 +/- 30 BP	ca. 1055-899 BC	Barley

Material and Methods

A total of 306 flotation subsamples were collected from the Bangga site during three excavation periods in the summers of 2015, 2016, and 2017. Eighty (totaling 1144.9 L) of these subsamples were analyzed and reported in this paper, including 47 subsamples (593.7L) from the early phase and 33 subsamples (551.2L) from the late phase. Given the remote location of the site and the cost of transporting sediments to the water source, we chose a labor-conserving sampling strategy, which targets the identified cultural features, such as pit fills and fills in house structures. However, we sampled all contexts wherever feasible throughout the stratigraphic complex. The sampling approach used is in line with the MOLAS (1994) environmental sampling procedure. However, by targeting key features to maximize the output, we do recognize that this sampling strategy may introduce biases, such as recently discussed by Banning (2020). No more than two subsamples were taken from each context in order to limit redundancy. Within each context, sediments were collected randomly, and we used 20 liters as the target volume, although some samples were smaller. Given the discrepancies between subsample volumes we used both ubiquity and density in hopes of accounting for biases introduced by differences in volumes. We floated these subsamples in the field using both the bucket method and machine flotation in 2015, and an additional overflow kit was added in 2016 and 2017 (Zhao, 2004). The flotation machine was built locally, modified from the SMAP type, initially designed by Patty Jo Watson in the 1960s. Sediment samples were suspended in a 2,000-micron mesh to catch the heavy fraction, with the overflow feeding into 0.25mm mesh to catch the light fraction.

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In the lab, sample sorting was only conducted down to 0.5mm. The fraction between 0.25 and 0.5mm contained too many seeds from small herbaceous plants to systematically sort; therefore, for several of the larger subsamples, we sorted a measured portion of the subsample and then estimated the number of seeds in the remainder of the sample using weights. While this method only provides an estimate, we believe it is relatively accurate because the vast majority of the small seeds were from the same clade, specifically *Chenopodium* Type; these seeds were all roughly the same size and weight, making estimates of quantities more reliable. While weight estimates are not as accurate as actual systematic counts and very few Central Asian archaeobotanical assemblages have been sorted down to 0.25mm, we deemed it important to get an idea of what we were missing by sorting only part of this fraction. The archaeobotanical assemblage was sorted under a low-power binocular microscope. The macrobotanical remains were identified using a comparative collection of modern seeds held at the archaeobotany laboratory at Sichuan University and with several identification keys (Guo, 1995, Zhang, et al., 1995, Li, 1998, Guan, 2000).

Results

The archaeobotanical assemblage from the early phase at Bangga (ca. 1055-211 BC) consists of 77,374 identified carbonized seeds (counts not estimates). The total sum of seeds from the late phase (ca. 211 BC to modern times) was 1156. In addition to these identified seeds, we recovered 86 unidentified fruits/nuts, as well as 571 unidentified seeds and 2604 unidentifiable fragments (Table 2). In addition to these identified seeds, we estimated the seed counts for the portion of the 0.25-0.5mm archaeobotanical fraction that was not systematically sorted, yielding a total estimated seed count of 97,317 seeds for all the samples combined (45,525 small fraction seeds from 0.25 to 0.5mm were counted, plus the total weight estimation small seed was 97,317). This suggests that at least approximately 140,000 small seeds would have been lost using current archaeobotanical methods in Eurasia. Among the identifiable grain crops, barley is the most abundant, accounting for 88.89% of the domesticated crop portion of the assemblage from the early phase and 78.95% of the crop portion from the late phase. Other crops are rare (Table 2); wheat and buckwheat (*Fagopyrum* sp.) only account for a very small portion of the total crop assemblage, at 9.62 % and 5.44% respectively across the two phases. In total, 128 barley and 16 wheat seeds were identified from the early phase deposits, and no buckwheat grains were recovered (Figure 3). Seventy-five barley and seven wheat grains were recovered from the late phase deposits. In addition, 13 buckwheat grains were identified from the same period, the earliest buckwheat were recovered from L10 (ca. AD 133) (Table 2). No millet grains were recovered from Bangga.

(a) (b) (c)

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Figure 3: Carbonized barley, and barley rachis from Bangga: (a) three views of a lax-eared specimen of barley; (b) three views of a compact barley grains; (c) a barley rachis.

Wild herbaceous seeds dominate the archaeobotanical assemblage from Bangga, accounting for 98.24% of the total seeds, with Amaranthaceae relatives (all *Chenopodioideae*), Cyperaceae, Rosaceae, and Asteraceae being most abundant. More details about the wild resources at Bangga will be published in a forthcoming paper. Among the wild plant remains, the *Chenopodium* Type was dominant, accounting for 98.31% of the wild seeds recovered. The Amaranthaceae collected in the assemblage represent multiple species and presumably more than one genera, but a large portion of them appear to be *Chenopodium*, with small and large types present. Many of small specimens may be the same species as the large ones, but without the testa we were unable to differentiate them. Many scholars use that category cheno-ams when only the perisperm is present; however, due to the range of arid-adapted Chenopodioideae in high elevations in Tibet and a general lack of *Amaranthus*, such a category loses utility. Carbonized seeds with perisperm but no testa were more abundant than complete seeds. Seed fragments and specimens of unclear generic-level identification dominate the Amaranthaceae category below 0.5 mm. Four types of Cyperaceae were recovered, but due to a lack of reference specimens, we could not identify them to species or even genus. Considering a large amount of carbonized sheep/goat dung was recovered at Bangga, we assume that the high number of wild seeds were carbonized and introduced into the assemblage through the burning of dung as fuel. Dung from yak, cattle, sheep, and goats is still the most popular fuel in Tibetan villages.

Table 2: Total, density, ubiquity, and ratios for domesticated seeds at Bangga

	Late phase ca. 211 BC- AD 1204				**Early phase** ca. 1055- 211 BC			
	Total	Density (551.2L)	Ubiquity (n=33)	Specific grain/ domesticated	Total	Density (593.7L)	Ubiquity (n=47)	Specific grain/ domesticated
Barley	75	0.136	45.45%	78.95%	128	0.216	40.43%	88.89%
Wheat	7	0.013	6.06%	7.37%	16	0.027	14.89%	11.11%
Cerealia	88	0.16	60.61%	_	134	0.226	27.66%	_
Buckwheat	13	0.024	24.24%	13.68%	0	_	_	_
Chenopodioideae	653	1.185	81.82%	_	75,189	126.645	95.74%	_
Asteraceae	275	0.499	27.27%	_	141	0.237	42.55%	_
Cyperaceae	8	0.015	18.18%	_	532	0.896	76.60%	_
Fabaceae	20	0.036	30.30%	_	122	0.205	55.32%	_
Malva sp.	10	0.018	21.21%	_	197	0.332	68.09%	_
Poaceae	22	0.04	21.21%	_	16	0.027	17.02%	_

Polygonaceae	3	0.005	6.06%	_	17	0.029	23.40%	_
Potentilla/Fragaria	3	0.005	9.09%	_	359	0.605	74.47%	_
Other wild plants	5	0.009	9.09%	_	62	0.104	27.66%	_
Unidentified	61	0.111	45.45%	_	510	0.859	80.85%	_
Unidentifiable	2	0.004	3.03%	_	2602	4.383	78.72%	_

*Counts presented are actual counts down to 0.25mm, without estimates.

Discussion

Transition to a barley-dominant economy

Previous research on the northeastern and southeastern Tibetan Plateau indicates that a crop transition from a millet-based and a mixed millet-cereal economy to a barley-dominant (or cereal-dominate) economy appeared in high-elevation regions (＞2500 masl) during the mid-second millennium BC (Chen et al., 2015, d'Alpoim Guedes et al., 2016a). However, all sites with archaeobotanical data are located at an altitude under 3400 masl on the margins of the Plateau. In this paper, we focus on sites in Tibet, with an elevation above 3500 masl. From this region, only the sites of Karuo, Changuogou, Dingdong, and Kaerdong (also referred to as Kyung Lung Silver Castle) have reported flotation work (Fu, 2001, d'Alpoim Guedes et al., 2014, Song et al., 2017). Except Karuo, all of them are from small-scale test excavations (Song et al. forthcoming). In order to mitigate biases relating to the limited subsample size and distribution of data points, we consider archaeological contexts to re-explain the published archaeobotanical data.

Karuo is the oldest known Neolithic settlement located in eastern Tibet. Charred botanical remains, including foxtail millet, were first reported in the 1970s during the first excavation (Xizang zizhiqu wenwu guanli weiyuanhui 1985). In 2002, six flotation subsamples (approximately 12L, 63 grains, 210 seeds) were collected from test trenches and subsequently analyzed archaeobotanically (d'Alpoim Guedes et al., 2014). While the sample size in 2002 is constrained by the scope of test excavation, a domesticated grain density of 5.25/L is significantly higher than many agricultural sites. A more comprehensive flotation program was carried out during the excavation season in 2012 and, subsequently 2018 (1490 liters, 96 subsamples), and this is the first time that the flotation machine is used in Tibet (Song et al. forthcoming). An insightful discussion among scholars is whether millet at high-altitude locations such as Karuo could be cultivated locally, or they were obtained through networks of seed exchange and/or trade (d'Alpoim Guedes et al. 2018b, Lu 2016, Song et al. forthcoming). One can never rule out the possibility that some millet grains, particularly broomcorn, at Karuo were derived from the exchange (d'Alpoim Guedes 2015). Nonetheless, Song and colleagues (forthcoming) considered the potential local foxtail millet cultivation at Karuo, and hypothesized the high-altitude adapting landraces might be initially developed with the

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contribution of unusual (C_4 photosynthetic) cold tolerant weedy *Setaria*. In addition to millets, wheat was introduced to Karuo ca.1500 BC (Liu et al. 2016), resonating with the mixed-grain cultivation system across the broader Eurasian mountain zone by the mid-second millennium BC (Chen et al., 2015, Spengler, 2015, Ventresca Miller and Makarewicz, 2019). Other plant food was potentially utilized at Karuo including *Chenopodium*, contributing to the multi-resource economy characterized by localized hunting strategy (Zhang et al. 2019).

The Qugong and Changguogou sites in central Tibet belong to the Qugong culture (ca. 1742-1236 BC), with archaeological assemblages featuring elaborate smooth pottery, grinding stones, and microlithics (Wang, 1990, Zhongguo Shehui Kexueyuan, 1999). Scholars excavated twenty-two pits from the early phase of Qugong, the function of these pits is unclear, and they might have been used for habitation, storage, or ritual (Huo and Wang, 2014). Du (1999) analyzed nine pollen samples, which contained abundant Amaranthaceae, Poaceae, and Fabaceae pollen, depicting an open meadow landscape. Additionally, Zhou (1999) identified a large quantity of domesticated yak and sheep bones from these pits, and the excavators theorized that an agropastoral economy was present at Qugong. However, a quantitative analysis of macrobotanical and zooarchaeological data is still lacking. At Changuogou, several surface surveys and small test excavations were conducted roughly 20 years ago. Hundreds of lithics, grinding stones, and ceramic sherds from these investigations were reported (Zhao et al., 1999). More than 3000 naked barley, four wheat, and possible pea and oat seeds were recovered by means of hand-collection at Changguogou. Fu (2001) also noted the presence of some small preserved seeds (possibly millet) in the ash, but they did not identify these seeds. In a follow-up study targeting these small seeds, flotation was conducted using a large-mesh sieve borrowed from local farmers, and 78 foxtail millet and 94 naked barley grains were recovered. Recognizing that barley grains are bigger than millet seeds, to understand the explicit proportion of millets and cereal, a 0.6 mm sieve was used for flotation in yet another follow-up study, leading to the recovery of 201 foxtail millet and 31 naked barley grains (Fu, 2001). Fu's study illustrates that millet and naked barley were both part of the economy at Changuogou.

While being piecemeal, these sporadic data indicate that a high-altitude-adapted agropastoral economy was established in rich river valleys of central Tibet during mid-second millennium BC, featuring foxtail millet, wheat, and naked barley, as well as sheep and yak. Some scholars have suggested, on the basis of material culture industries and shifts in ceramic and burial styles, that there was a significant cultural transition during the late second and early first millennia BC (Chen, 2017). Informatively, this purported transition seems to correlate with a shift in crop preferences, as we lay out through this paper.

The increased preference towards barley in the economy is evident by 3000 years ago at the long-term-occupation site of Bangga, but the transition likely began earlier than ca.1055 BC, more early archaeobotanical research in this region will shed light on this issue. The overall abundance of grains at Bangga is low and the density of grains per liter of sediment parallels levels at low-investment and potentially seasonal sites in other areas of Inner Asia. However, with high colluvial accumulation rates on these hill slopes, high winds, and periods of site

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abandonment, the abundance and density levels are not surprising. Additionally, the ubiquity of barley was relatively high, suggesting a regular and steady use of barley at the site. The material culture accumulation suggests an intensive occupation phase, especially when considering early stone occupation enclosures. Most of the barley grains were collected from activity surfaces near fireplaces, indicating processing for daily food. Wheat grains have also been recovered, but the quantity (16), density (0.027), and ubiquity (14.89%) are much lower than that of barley (128, 0.216, and 40.43%) (Table 2). We did not identify any millets or other crops from the early period. We did collect buckwheat from several layers that date to after AD 133. However, compared with barley, the lower abundance, density, and ubiquity of buckwheat and wheat grains, suggest less prominence in the economy (Table 2 and Figure 4); although, the implication of these results should also be considered in the context of assemblage formation process, which may or may not bias towards human food. For example, millet can be used in foddering context exclusively in a range of environments, leaving little trait archaeobotanically (Hermes et al. 2019, Vaiglova et al. 2020). Future research using isotopic and gas chromatographic approach will be timely and plausible, and shall clarify the situation.

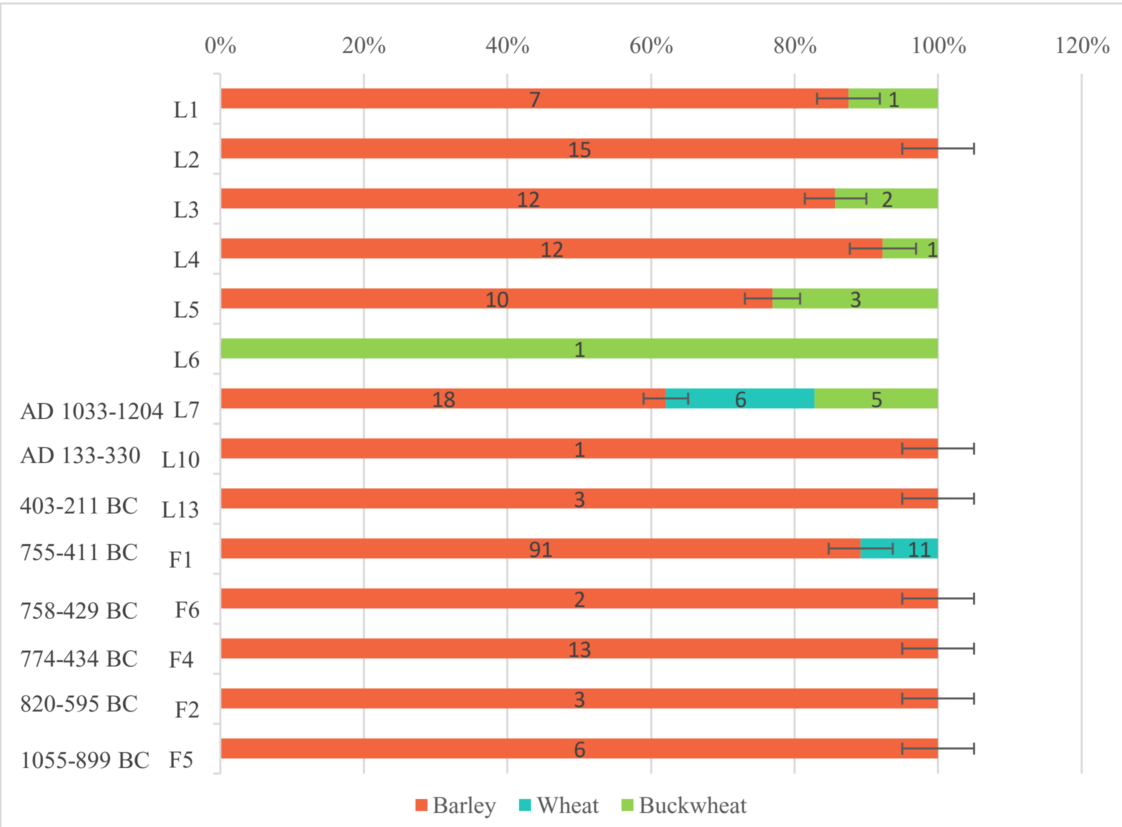

Figure 4: Percentage of different crops in grains (late to early period; the quantity of each crops is shown in the bar chart; add error bars only base on barley)

While all of the assemblages that we compiled in this paper are limited in richness of data, including our own in some fashion, when pulled together into one narrative, we can begin to discuss transitions in crop repertories (Figure 5). Ten km from Bangga, the site of Bangtangbu, contained extensive carbonized wood, animal bones, lithics, and ceramic sherds, which possibly indicate an intensive occupation. One flotation sample was collected from Bangtangbu (ca. 1263–1056 BC) in the summer of 2016 (following a similar flotation method to Bangga). Nine naked barley, 4 wheat grains, and 2 broomcorn millet, as well as 46 Cyperaceae, 131 *Chenopodium*, and other wild seeds were collected. In addition, one soil sample was recovered from the Kuoxiong site (ca. 1393-1052 BC), with an altitude of about 4000 masl, only naked barley grains have been published for dating; although, no quantitative data were reported, the whole crop assemblage is still ambiguous (Wangdue, 2014, Liu et al., 2017). These available evidences in central Tibet indicate that a cereal-millet mixed economy was still practiced before 3000 BP, and a barley-based economy probably had been developed at this time, although we don't know the rates of this crop transition because of current limited data.

Archaeobotanical data from western Tibet illustrate that the barley-dominant economy was stable after the crop transition occurred in central Tibet. Although, two wheat grains were recovered from 2004 excavations at the site of Kaerdong (ca. AD 220-334 and 694-880), at an altitude of about 4300 masl, most of the cereal grains (15 whole and 15 fragments) and all of the rachises (n=46) were from barley (d'Alpoim Guedes et al., 2014). A follow-up test excavation and sampling at Kaerdong (ca. AD 455-700) were conducted in 2013, and 129 barley grains and 15 barley rachises were identified at the site, while only five wheat, two buckwheat, and one rice (*Oryza sativa*) grains were recovered. Which support the idea that a barley-dominant economy was practiced there (Song et al., 2017). Additionally, roughly 100 barley grains were recovered by hand-collection inside a stone structure at the Dingdong site, with an altitude of about 4100 masl, and dated to ca. 348 BC-AD 71 (Lu, 2008). The rachises, in particular, recovered from these sites, illustrate that the crops were locally grown. The role of each crop in the diet is not yet clear, and further follow-up research is needed, to illustrate how important wheat, buckwheat, and rice were in this apparently barley-dominant system. Except for five foxtail millet palea-lemma from Kaerdong (d'Alpoim Guedes et al., 2014), no millets seeds have been published from any site in Tibet after the late second millennium BC Collectively, current data suggest that the transition to a specialized barley-based economy possibly began during the late second millennium BC, developed completely during the early first millennium BC, and remained sustainable for more than 3000 years in Tibet above 3500 masl.

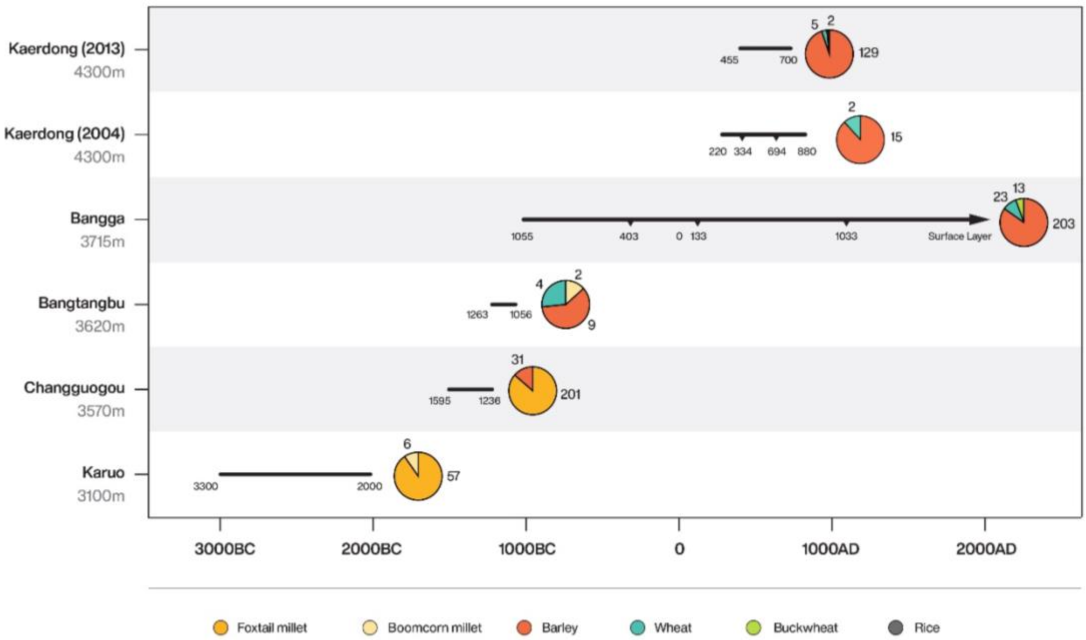

Figure 5: Percentage of different grains at different sites/excavation seasons in Tibet (only quantitative studies that used flotation methods are reported here; the pie chart shows the quantity of each crops)

Archaeobotanical evidence for this crop transition is also present in the surrounding mountains. This same crop transformation also occurred at high-altitude sites (>2500masl) in Qinghai after ca. 1600 BC. However, people at low-altitude sites in this region continued to cultivate both millets and cereals (Chen et al., 2015). On the southeastern margin of the Tibetan Plateau a millet-based economy developed into a millet-rice-cropping pattern in Sichuan during the third millennium BC (Zhao et al., 2011, Chen et al., 2015). A wheat-based economy, with barley and flax (*Linum usitatissimum*) was reported at Ashaonao in the late first millennium BC (d'Alpoim Guedes et al., 2016a). A transition from a millet-rice mixed economy to a wheat-dominant system, accompanied by millet, is present in Yunnan (Xue, 2010, Dal Martello et al., 2018). Archaeobotanical data from Mebrak (3500 masl) and Phudzeling (3000 masl) in Nepal revealed a specialized high-elevation economy, with barley and buckwheat, accompanied by wheat and millet from the first millennium BC to modern times (Knörzer, 2000). On the western Tibetan Plateau, the farming system was even more diverse, with wheat, barley, millets, and pulses cultivated in Kashmir (Pokharia et al., 2018, Spate et al., 2017). Additionally, a mixed package of crops was introduced to Central Eurasia and Xinjiang during the second millennium BC (Spengler et al., 2014a, b, 2015, 2016, 2017, Yang et al., 2014, Chen et al., 2016, Zhang et al., 2017, Tian et al., 2018).

Driving factors of this specialized crops transition

Ecological factors

While all the neighboring regions to Tibet experienced a gradual process of crop diversification through time (Spengler, 2019), in Tibet proper, the farming strategies became

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more specialized. Exploring why the transition to a barley-dominant economy occurred in these specific areas is critical for us to understand high-elevation adaptation. Crop transitions are usually tied into complex sets of ecological and social factors, which are not easy to parse out archaeologically. Some scholars have suggested that climatic cooling during the mid-second millennium BC stimulated the transition from a millet to a cereal economy in these highland areas. Barley and wheat share some key traits, including greater frost-tolerance, making them more adaptable to cold high-elevation areas than millets (Chen et al., 2015, d'Alpoim Guedes et al., 2016a). Although, the complex ecology of the highlands makes purely environmentally deterministic arguments hard to support, especially in relation to the diverse microenvironments and biologically rich river valleys. Scholars working in the mountains of Central Eurasia has noted the importance of microenvironmental pockets or ecotope in the adaptive strategies (Spengler et al., 2013), and a similar adaptive system has been proposed for prehistoric Tibet (d'Alpoim Guedes et al., 2016b). However, we feel that this is only part of the story, and culture or demographic changes among Tibetan populations need to be further explored. Additionally, we know little about the habits of ancient millet or cereal landraces; it is unclear when high-elevation traits introgressed into barley or what the growing constraints of ancient millet varieties were. Approaching all of Tibet with a broad brushstroke belies the diversity of this landscape; all archaeological sites thus far explored in western Tibet are located on xerophytic landscapes above 4100 masl. Central Tibet, on the other hand, especially in the middle of Yalu Tsangpo River, is referred to as the Tibetan granary, with optimal hydrothermal conditions and flat fertile land. The Changguogou and Bangga sites are all locate in this region, and they share a similar ecological environment. The reasons why ancient Tibetans also switched to a mono-crop-dominant setting in these richer regions is less clear (d'Alpoim Guedes et al., 2016b).

The fact that wheat was effectively abandoned as an essential staple food on the high-altitude Tibetan Plateau, despite many similarities in habit as barley, is also difficult to reconcile. Although, as noted above, the hybridization of domesticated barley with native wild barley relatives on the plateau may have played a role in transferring traits into Tibetan barley that made it particularly well adapted. These traits may have evolved in wild high-elevation populations over millions of years; whereas, the hexaploid wheats that spread onto the plateau with humans were not biologically compatible with any wild diploid relatives. The long process of hybridization with the local wild type makes naked barley more adapted to the frost-prone high-altitude environment (Dai et al., 2012). In addition, compared with wheat, barley provides better yields when presented with drought conditions, especially in regions characterized by an annual rainfall of ≤400 mm (Jamieson et al., 1995, Albrizio et al., 2010). Low soil moisture during the growth period causes yield losses due to reductions in potential grain number per unit land area in free-threshing wheats (Cossani et al., 2009). The middle Tsangpo River region receives between 300-450 mm of precipitation a year, which is concentrated in the summer (90-95%) (Tang et al., 1996). The low organic content of soils also means higher evaporation rates. While high-resolution precipitation rates for the first and second millennia BC in these regions are far from clear, it seems likely that barley contained traits that were preferential over wheat in a non-irrigated farming context. In general plant physiological terms, response to water stress is often corelated with response to cold stress, as they trigger similar protective biomolecules

(Hussain et al. 2018), and barley adapts both conditions better than wheat. It is also important to note that the millets, notably broomcorn millet are significantly more drought tolerant than barley, so rainfall constraints would not have been a factor in the gradual rejection of millet crops. Accordingly, from the ecological perspective, more tolerance to frost and dehydration than wheat and millets, probably played a role in making barley an important crop.

Social factors

Social factors should also be considered when discussing this crop transition, and scholars have demonstrated that ecological factors are rarely the sole drivers of agricultural development or choice (Jamieson et al., 2010, Boivin et al., 2012). Culinary practices can direct cultivation decision making. Previous studies of pottery, grindstones, ancient and historical texts, and ritual traditions all indicate that eastern Eurasia had a food preparation tradition based on boiling, and whole-grain eating, as opposed to the roasting and bread-baking cuisines of western Eurasia (Fuller and Rowlands, 2011). Such a divided East-and-West cooking preference could have consequences for the selection of grain type and quality. In the case of wheat, it has been illustrated the introduction to China may have exerted selection for phenotypic traits adapted to the eastern boiling-and-steaming tradition (Liu et al. 2016). However, Tibet's low-oxygen and low-pressure environment alters fuel combustion characteristics. At the site of Bangga, with an altitude of 3715 masl, the boiling point is 87.44 ℃ (from Omni calculator), which makes boiling more fuel and time demanding. With the exception of eastern Tibet, most regions have limited wood resources, and many Tibetan villages use animal dung as fuel. Therefore, fuel-saving during food preparation would have been critical in food selection, and this is consistent with the absence of pottery vessels for boiling-and/or-steaming function at Bangga (Lu et al. in press). The most popular staple food in modern Tibet is *tsampa*, a rapidly fried barley flour. Barley grains are fried (usually using dung as fuel), then milling stones are used to grind the grains to flour. After the flour-*tsampa* is prepared, it can be consumed directly with hot water or butter tea. Additionally, *tsampa* can be stored for an extended period. This specialized cuisine uses less fuel than it would take to boil porridge or steam buns, and is better suited for mobile pastoralists. It is still unclear when the *tsampa* tradition appeared in Tibet and where it came from. However, early milling stones possibly support the theory that a flour-eating tradition was present in the region for millennia. Most grinding stones in central China in the Neolithic are small and have a flat profile, suggesting a lack of prolonged use (Fuller and Rowlands, 2011). The grinding stones at Bangga are large and flat, indicating they were used intensively. Although, milling stones could have multiple functions, like de-shelling, breaking nuts, removing husks, and for craft activities, these functions are not archaeologically supported at Bangga. Combined with macrobotanic evidence that Bangga was dominated by naked barley, and the archaeological contexts that grindstones were collected from activity floors, we suggest these milling stones from Bangga played vital roles in ancient people's daily life.

Taking a broad geological perspective to understand the origins of these culinary traditions, long-distant cultural diffusion has been in place across Inner Asia for at least five millennia based on the typology of artifacts, burial features, and genetic data (Wagner et al., 2011, Frachetti, 2012, Frachetti and Maksudov, 2014, Doumani et al., 2015). Although the cultural dynamics between Tibet and surrounding areas has not been studied systematically, current

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spatial evidence seems to support an interaction between Tibet and Central Asia during the mid-second and first millennia BC. For example, a Eurasian stylish bronze mirror was collected from Qugong, and sheep/goat, barley, and wheat, were recovered from the sites of Qugong, Changuogou, and Bangga. The flour-eating culinary tradition perhaps was accompanied by the spread of artifacts, goods, and technologies from central Eurasia. A form of pastoralism with characteristics from Central Asia also became prominent in the dietary economy in Tibet after the mid-second millennium BC (Zhang, 2016). The transition toward more mobile economies might have stimulated the heavy requirement of durable and portable food resources. Under this socioeconomic context, the increased reliance on barley in Tibet likely was driven by the adaptation of new culinary practices and more pastoral economies. Therefore, ancient Tibetans in high-elevation regions (3500 masl) practiced a barley-based economy and were likely tied into a web of ecological and social factors.

Conclusion

The archaeobotanical remains from Bangga indicate that the transition to a barley-dominant farming economy started in Tibet by about 3000 years ago, 1000 years earlier than suggested by previous data. Combining new archaeobotanical data from Bangga with a critical analysis of published records, we argue that barley-millet mixed agriculture and pastoralism started to develop in central Tibet during the mid-second millennium BC. Later, as evidenced at the long-term occupation site of Bangga, millets were displaced, barley became the major focus of cultivation. Compared with surrounding areas, this specific crop transition only occurred in Tibet and high-elevation areas in Qinghai where mobile pastoralism is an important component of the economy. We, therefore, speculate that a combination of factors drove this crop transition, including specific growth traits in barley, including frost tolerance, low irrigation requirements, fuel-saving qualities, and convenience in a mobile economy. More systemically collected faunal and floral evidence, as well as paleoclimate data, from different regions across different time periods on the Tibetan Plateau can help to further clarify the timing and motivational factors of this unique high-altitude adaptation.

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