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Farming and multi-resource subsistence in the third/second Millennium BC: archaeobotanical evidence from Karuo

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Abstract
Over the past few years, archaeobotanical studies have clarified much of the process of dispersal and adaptation of crops across Asia. However, the development of farming systems that could function in the high-altitude environments of Tibet requires more in-depth consideration. In this article, we present the results of systematic archaeobotanical investigation at Karuo, a third millennium BC site in eastern Tibet. We argue that millet cultivation was possibly practiced at the site, and that it was likely an important aspect of the economy from 2700 to 2100 cal. BC. The role of millet in the cultivation system might have declined after the mid-second millennium BC, during which time wheat—a grain originating in southwest Asia—appeared at the site. In addition to farming, evidence of foraging, hunting, and fishing are present suggesting a diverse subsistence strategy. The diversification of human diets may have contributed to the long-term occupation of the site. Taking a broad regional perspective into account, the diverse spectrum of subsistence strategy engaged by Karuo people provides new insights into the understanding of early lifeways on Tibetan Plateau.

Keywords millet, wheat, Tibet, dietary diversity, adaptation

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Introduction

Archaeological research on the Tibetan Plateau has drawn considerable scholarly attention in recent years (e.g., Aldenderfer 2011; Brantingham et al. 2013; d'Alpoim Guedes and Aldenderfer 2019; Hein 2018; Hung et al. 2014; Lu 2016; Madsen et al. 2017; Meyer et al. 2017; Zhang et al. 2018). Some of the most lively debated topics include the advent and development of agriculture, as well as the contribution of multi-resource subsistence activities to the residence of the Tibetan Plateau (Chen et al. 2015; d'Alpoim Guedes et al. 2013; d'Alpoim Guedes 2015, 2016a, b; d'Alpoim Guedes and Butler 2015; Dong et al. 2015; Lu 2016; Meyer et al. 2017; Zhang et al. 2019). Some recent research focuses on the adaptation of southwest Asian originating crops, notably barley and wheat, to high-altitude environments (above 2500 m.a.s.l.) as old as 1665-1518 cal. BC (a direct wheat date from Karuo: Liu et al. 2016). Representative sites for such adaptation of barley/wheat cultivation are found in the northeastern area, the eastern area, e.g. Ashaonao, the southern area, e.g. Changguogou and Bangga, and the western area, e.g. Dingdong and Kaerdong, of the plateau (Fu 2001; d'Alpoim Guedes et al. 2013, 2015; Chen et al. 2015; Dong et al. 2015; Liu et al. 2016; Song et al. 2017; Tang 2018).

The Karuo site is the earliest known Neolithic settlement in high-altitude eastern Tibet and is pivotal for our understanding of early farming and subsistence on the plateau. Charred foxtail millet (*Setaria italica*) grains were first recovered at the site during early excavations in the 1970s (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985). A total of 77 foxtail and broomcorn millet (*Panicum miliaceum*) grains/fragments were later identified during a small-scale test excavation in 2002 (d'Alpoim Guedes et al. 2013). These discoveries highlighted the importance of millet in the diets of the Karuo population. The question remains, however, whether these grains were cultivated locally or derived via trade or plant/seed exchange networks, and scholars have suggested both scenarios (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985, P154; Wu et al. 1985; Li 2007; Lu 2016; d'Alpoim Guedes et al. 2013; d'Alpoim Guedes and Butler 2015; d'Alpoim Guedes 2015, 2016a, b). The subsistence of people at Karuo is of interest given the growing knowledge of the multi-resource economic spectrum implemented across Tibet, particularly in the eastern Plateau, as drawn from recent investigations (e.g., Zhang et al. 2019; d'Alpoim Guedes et al. 2013; Zhao and Chen 2011). In the context of these, further investigation into the materials systematically collected from recent excavations and additional profile sampling (2012 and 2018) at Karuo is timely.

In this paper, we present the flotation results of systematically collected sediments from excavations in 2012 and additional archaeobotanical sampling in 2018. The results demonstrate that intensive on-site archaeobotanical research is essential for understanding the nature of farming and subsistence, in association with stratigraphic sequences, displaying diachronic changes. These results, together with other recent findings from this region, help us to understand the unique dietary economy in eastern Tibet, and contribute to the understanding of early lifeways on the Plateau as a whole.

Karuo site

Karuo (97°2′E，31°1′N) is a prehistoric occupation site in Changdu City, eastern Tibet, with an elevation of 3,100 masl (Fig1a). It is situated on a terrace at the southern foothills of the Zilongla Mountains, in conjunction between the Karuo River (a small tribute of the Lancang River) to the south of the site, the Lancang River to the east of the site. The eponymous modern Karuo village is approximately 1 km to the west. The landscape of this region is characterized by alternating mountains and valleys (Fig1b). The terraces on both sides of the Lancang valley are ideal places for human residence and many modern settlements are indeed situated at those locations. Evaporation rates on the southern slopes of the mountains and in open river valleys are high, resulting in arid microenvironment . Plants grow more readily on shady slopes and in narrow river valleys (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985). The vegetation in this region is cataloged as the Changdu-Chaya sub-region of evergreen broad-leaved forests in the middle and lower reaches of the Yarlung Zangbo River. At locations below 3,400 masl, dry valley thickets grow, dominated by *Artemisia veslita*, *A. roxburghii*, *Buddleja crispa* var. *glandulifera*, *Ceratostigma minus*, *Ephedra intermedia* var. *tibetica*, *Rhamnus tangulicus*, *Sophora davidii*, among other plants. In addition, *Elsholtzia stauntoni* is prominent along roadsides and highly disturbed areas (Comprehensive Scientific Expedition of Tibetan Plateau Chinese Academy of Sciences 1988).

The climate at Karuo is suitable for cultivation, and as elsewhere on the Tibetan Plateau, barley is the major crop in the present day. Minor crops include wheat, turnips, and rape seeds. The site is in a plateau temperate semi-arid climatic zone, under the influence of summer monsoons, with an annual average temperature of 6-8 °C, and annual precipitation of 500-700 mm. Precipitation is unevenly distributed throughout the year, with 78% of it concentrated in the summer from May to September. As a result it is wet in the summer, but very dry in spring and winter. Sunlight in this region is abundant. The average annual daytime duration is 2,276.5 hours. The cumulative duration with a temperature above 5°C and 10°C is 2,715.3 and 2,108.0, respectively (Comprehensive Scientific Expedition of Tibetan Plateau Chinese Academy of Sciences 1984; Song and Wang 2013). According to pollen data from the Karuo site, and nearby lakes, the climate of the study region in the mid-Holocene was warmer and wetter than that of today. Annual average temperature and precipitation were 2 to 3°C and 150-250 mm higher than those of today, during a period between 7450 and 450 cal. BC (Wu et al. 1985; Tang et al. 2004).

Karuo was excavated during the field seasons of 1978-1979, 2002, and 2012 (Fig 2). Large-scale excavations (1800 m^2) were carried out in 1978 and 1979. Twenty-eight house structures were excavated, including semi-subterranean stone structures. A large quantity of artefacts, including ceramic, lithic, and bone objects, were unearthed. Dense deposits of carbonized millet grains were reported in house structures F8 and F22.29 and within one stratigraphic layer (T4L3) (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985; P10, 27, 41). They were later identified as foxtail millet (Wu et al. 1985). Animal remains were mostly identified as wild species, except for thirty-two pig bones (*Sus* sp.) (Huang and Leng 1985). The excavators believed that the ancient occupants at Karuo practiced millet farming, hunting, and raised pigs (Cultural Relics Management Committee of Tibet Autonomous Region and Department of history of Sichuan university 1985). The chronology of the site was suggested to span 3050-2050 cal. BC , based on radiocarbon dating results from wood charcoal, which were collected from house structures typical of the early and late phases of the site (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985; Tong et al. 1987).

In 2002, five test trenches (230 m^2) were excavated by a joint team of archaeologists from Sichuan University and the Cultural Relics Bureau of the Tibet Autonomous Region to investigate Karuo's subsistence economy. In total, three houses, sixteen ash pits, one road, and one ditch were excavated. Thousands of animal bones and six flotation samples (> 6 L) were collected from stratigraphic layers, ash pits, and other contexts. Both foxtail and broomcorn millet grains were identified; foxtail millet was more abundant than broomcorn millet (d'Alpoim Guedes et al. 2013). Direct dating of selected millet grains produced a range of dates between 2750 and 2350 cal. BC (d'Alpoim Guedes et al. 2013). All animal remains from the 2002 excavation were identified as wild species, which would have natural habitats at different altitudes, indicating the importance of local hunting (Li 2007; Zhang et al. 2019).

In 2012, a five by ten m^2 unit (referred to as 2012XCKT1) was excavated to investigate the Karuo subsistence further. In total, nine stratigraphic layers, including layers that represent post-occupational periods (L1-L2), cultural deposits (L3-L6), nature sediments (L7-L9), and few ash pits, and house structures were excavated (Fig. 3, Fig. 4, Fig. 5). Animal remains, lithics, and ceramics were collected. During this field season systematic flotation sampling was carried out at Karuo, led by one of the co-authors (X. Liu), and this is the first time that flotation machine is used in archaeology in Tibet. It is worth noting, however, that the features and associated artefacts recovered in 2012 were considerably less dense than what were recovered in the 1970s, which is likely located at the core area of the settlement (i.e., the 1978-1979 excavation area). To explore the core area further in 2018, we cleared three profiles in the 1978-1979 excavation area, including T25/T15, T31, and T35 (please refer to Fig. 2 for the location of these profiles). Three stratigraphic layers, a two-room house structure (F22.29) were observed on these profiles (Fig. 6), including the post-occupational layer (L1), and occupation layers of the Karuo culture (L2, L3, F22.29). Thousands of millet grains were visually observable in contexts related to house structure F22. 29 (Fig. 7). Flotation samples were collected from these contexts.

Materials and methods

Archaeobotanical assemblages from the 2012 and 2018 field seasons are reported in this article. Sampling and flotation methods differed slightly between the two seasons. In 2012, we designed and built a flotation machine locally, modified from that initially developed by Patty Jo Watson in the 1960s (the SMAP type; Fig.8). The machine is fed by clean pumped groundwater in a nearby factory. Sediment samples were suspended in a 2,000-micron mesh to catch the heavy fraction, with the overflow feeding into a 500-micron mesh to catch the light fraction. In this manner, a total of 89 flotation samples (1,402 Liters of sediment) were floated during the 2012 excavation season. Sample sizes vary, with 10L as the target volume. We sampled a range of identified features, primarily compromising pit fills (H2-H6) and fills in the house structures (F2K3, F2K5, F2k8, F3), as well as contexts through the stratigraphic sequence (L3-L9). Only one sample was collected from layers L7-L9, respectively. Plant remains recovered in these three samples were very rare and no crop remains were recovered; therefore, these samples are not included in the discussion section. Sampling was conducted using MOLAS (1994) procedure with modified MOLAS environmental sampling sheets. In 2018, six flotation samples (88.882 L) were collected from the reopened profiles in the 1978-79 excavation area. We sampled features within the house structure F22.29 and stratigraphic units L2 and L3. We floated the 2018 samples in the field, using a bucket method described by Crawford (1983) and Zhao (2004). The light fraction was collected using a sieve with 0.25mm mesh.

Samples were sorted under a low power binocular microscope at Sichuan University. Carbonized seeds and seed fragments were separated from vascular tissues. In some cases, uncharred seeds were also encountered, but these are regarded as modern intrusions and are not considered in the seed counts. For the samples from the 2012 season, systematic sorting and counting were conducted down to 0.25 mm. For the samples from the 2018 season, systematic counting was conducted down to 0.25 mm, except for the sample from house structure F22.29. Considering the extremely high density of millet grains, we used a weight estimation method to calculate this sample (original data is attached in Supplement Table 1). Identifications were made on the basis of morphological characteristics, and compared against modern comparative reference materials curated at the archaeobotanical laboratory at Sichuan University and various illustrated identification keys (Li 1998; Guo 1995; Guan 2000; Zhang and Guo 1995).

Results

Plant remains

The plant remains recovered from the Karuo site are listed in Tables 1 and 2 (Fig. 9; sample by sample plant assemblages from 2012 field season are provided in Supplement Table 2). A large quantity of seeds, including seed fragments, were identified. The majority of the seeds in the assemblage were millets or agricultural weeds, e.g., grasses. Wheat was also present, but in very low abundance and only occurred in the later period, after 1665 cal. BC. There are also some seeds that may belong to edible fruits, such as *Rubus* sp.

Table 1 Plant remains recovered from 2012 excavation of the Karuo site. L represents cultural layer.

Context	L3	L4	L5	L6	H2	H3	H4	H5	H6	F2K3	F2K5	F2K8	F3	L7	L8	L9	Totals

Cereals																	
Setaria italica	1	16	1			8		2	4	51	34	13	1				**131**
Panicum miliaceum	1	6				1				9	19	1					**37**
Triticum aestivum	1	1															**2**
Grasses																	
Setaria		6	1			2			2	9	11	1					**32**
Panicoideae		2							3	2	3						**10**
Poaceae		1							1	11	3						**16**
Pooideae		3						1			52	2		1			**59**
Other weeds																	
Chenopodium	9	67	13	1		31	5	1	6	98	176	139	3	3		3	**555**
Artemisia		7	3			6			8	10	17	12		1			**64**
Galium	1																**1**
Plantago		10	1			2				3	3			1			**20**
Euphorbiaceae											2						**2**
Rumex						1					2	1					**4**
Polygonaceae		1								1							**2**
Amethystea		1								1	3	1					**6**
Fruits																	
Fragmented fruit pericarp		10	1							4	10						**25**
Potentilla/Fragaria/ Duchesnea	3	33	5			9	1		7	49	78	48	3	4			**240**
Rubus		2															**2**
cf.*Malus*											1						**1**
Cotoneaster											2						**2**
Other																	
Seed fragments	4	21	1		1	4	1	1		37	45	4					**119**
Indeterminate	2	5				1		1	3	3	28	1					**44**
Totals	**22**	**192**	**26**	**1**	**1**	**65**	**7**	**6**	**34**	**288**	**489**	**223**	**7**	**10**	**0**	**3**	**1374**

Table 2 Plant remains recovered from 2018 survey of Karuo, presented sample by sample. L represents cultural layer.

Context	**2018XCK T35F22.29**	**2018XCK T31L3**	**2018XCK T25/T15L2**	**2018XCK T35L2**	**2018XCK T25/T15L3**	**2018XCK T31L2**	**Totals**
Cereals							
Setaria italica	366381	60	29	37	30	103	**366640**
Panicum miliaceum	27	50	5	38	2	40	**162**
Hordeum cf. *vulgare* frag			1				
Grasses							
Setaria viridis	1009	2	3	1	2		**1017**
Panicum sp. wild					1		**1**
Pooideae	2000						**2000**
Poaceae	9	7	2	2	8	55	**83**
Other weeds							

Chenopodium	20	89	11	9	46	644	**819**
Salsola						1	**1**
Artemisia	1	2	7		9	114	**133**
Galium		1					**1**
Plantago		2					**2**
Solanaceae						1	**1**
Polygonaceae	94	8		1		5	**108**
Amethystea		4				2	**6**
Fruits							
Potentilla/Fragaria/ Duchesnea	1	14	5	2	25	333	**380**
Rubus	33	74		2		7	**116**
Other							
Seed fragments	13	12	8	9	3	6	**52**
Indeterminate	7	17	2	6	14	45	**91**
Totals	**369595**	**342**	**73**	**107**	**140**	**1356**	**371613**

Chronology of the site

The excavators of the 1978-1979 field seasons suggested a date range of 3050-2050 cal. BC, based on conventional radiocarbon measurements of wood charcoal from house structures typical of different phases (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985; Tong et al. 1987). Mu (1987), however, questioned this chronological range and pointed that only three radiocarbon dates were referenced in the 1985 report, while 41 radiocarbon measurements were available by the time. Subsequently, after analysis of the 41 radiocarbon results, derived from wood charcoal specimens, Wang (1994) proposed a modified time span of 3350-2350 cal. BC . Shi (1994), on the other hand, argued that the start point of the occupation might be earlier than 3350 cal. BC and the site might be used until around 2250 cal. BC, taking the stratigraphic relations into account. In addition to these differing opinions, some dates from supposedly different occupational phases are contemporaneous, indicating potential intrusions of recent-age charcoals into earlier layers. Finally, all of the 41 dates were derived from wood charcoal, which has inherent problems, notably in the context of the old-wood effect (d'Alpoim Guedes et al. 2013).

To better understand the chronology of the site and subsistence activities, we submitted five single grain crop specimens (three millet grains and two wheat grains) and four bone specimens selected from the 2012 collection, together with five millet samples (multiple grains for each specimen) from the 2018 collection for AMS dating (Table 3; Fig.10). Radiocarbon (^{14}C) analyses were conducted at Oxford Radiocarbon Accelerator Unit (ORAU) and through Beta-Analytic. The sample preparations undertaken at these labs were similar, with a standard acid-base-acid (ABA) chemical pre-treatment method. It is worth noting, two single millet grains were analyzed at Oxford (OxA – 28025 and OxA - 28026) utilizing the methodological refinements for very small sample sizes (small graphite), as described in Motuzaite Matuzeviciute et al. (2013). These were necessary since the weights of single charred millet were such that they fell below the standard graphite yields. Another single millet grain

(Beta-560376) from the 2012 collection was analyzed using similar pretreatment procedure via the service of Beta-Analytic.

The dates of specimens from 2018 ranged roughly between 2500-2100 cal. BC, while the dates of specimens from 2012 show a broad range of 2800-700 cal. BC. The 2018 sampling was conducted in the core area (1978-79 excavation area)of the site, which is now under conservation restrictions. This prevents us from sampling contexts other than 1978-79 excavation profiles, including layers beneath the initial excavation. We suspect the oldest anthropogenic activities at this ‘core area’ predate 2500 cal. BC. As for the 2012 excavation, 2855-2810 cal. BC is the oldest date available thus far. The 2012 excavation was conducted in the southwestern sector of the site, which may not represent the earliest occupation of the site. It is believed northern part of the site is older according to the initial report. (Cultural Relics Management Committee of Tibet Autonomous Region and Department of History of Sichuan University 1985). Nevertheless, our results suggest that the terminus date is much younger than what we previously considered and the site was in use for a more extended period until the first millennium BC. It is also interesting to note that there is a chronological gap—between 2100-1600 cal. BC—in the radiocarbon results. To sum, the new radiocarbon measurements obtained from floral and faunal remains are better indications of subsistence related activities comparing to wood charcoal, illustrating a much longer duration of the site—lasting more than two millennia—with a potential chronological gap for five centuries between 2100 and 1600 cal. BC.

Table 3 Dating results of the Karuo site. Dates of the two wheat grains were previously published in Liu et al. (2016) and Lu (2016). Other results are published first time.

Dated materials	**Context**	**Lab No.**	**Conventional 14C age BP (±1σ)**	**Calibrated age (cal.BC)**
Broomcorn millet	2012 XCK T1:(3)	Beta-560376	2630±30	838-777
Wheat	2012 XCK T1:(3)	OxA - 28029	2913 ± 27	1207 - 1017
Wheat	2012 XCK T1:(4)	OxA - 28850	3317 ± 27	1665 - 1518
Foxtail millet	2012 XCK T1:(4)	OxA - 28026	3853 ± 32	2460 - 2207
Animal bone	2012 XCK T1(4)	Beta - 483708	3840 ± 30	2409 - 2202
Animal bone	2012XCKT1(5)	Beta - 483709	3830 ± 30	2351 - 2198
Broomcorn millet	2012 XCK T1:F2	OxA - 28025	3984 ± 33	2581 - 2356
Animal bone	2012XCK T1(6)	Beta - 483710	3940 ± 30	2496 - 2338
Animal bone	2012XCK T1(6)	Beta - 392720	4090 ± 30	2855 - 2810
Broomcorn millet	2018XCKT35(2)	Beta - 515585	3870 ± 30	2465 - 2278
Foxtail millet	2018XCKT35F22.29	Beta - 515586	3780 ± 30	2296 - 2132
Foxtail millet	2018XCKT35F22.29	Beta - 515587	3780 ± 30	2296 - 2132
Foxtail millet	2018XCKT31(3)	Beta - 515588	3920 ± 30	2480 - 2299
Foxtail millet	2018XCKT25/T15(3)	Beta - 515589	3860 ± 30	2461 - 2276

Discussion

Millet

Broomcorn and foxtail millet were first cultivated along a series of foothill locations broadly running northeast-and-southwest, adjacent to the eastern edge of the Loess Plateau and the Mongolian Plateau, around 6000 BC (Liu et al. 2009; Liu et al. 2015). Between 5000 and 2500 BC, millet cultivation became visible in the archaeological record of regions far beyond its center of origin (Liu et al. 2019). For example, broomcorn millet is reported in Primorye of the Russian Far East by 3000 BC (Sergusheva 2006), and foxtail millet reached Taiwan in the late third millennium BC (Tsang 2012). Before and during the third millennium BC, both millets are reported in abundance in Gansu and eastern Qinghai (e.g., Chen et al. 2015; Zhou et al. 2016; Dong et al. 2018). From there, the cultivation of these crops likely moved southward and reached the mountainous region of western Sichuan and the eastern Tibetan Plateau between 3350 and 2650 cal. BC (Zhao and Chen 2011). At Karuo, the macrofossil evidence of both millet species and the direct radiocarbon measurements associated with them is consistent with previously known evidence for the dispersal of millet. By 1500 BC, the geographic expansion of millet cultivation stretched across the Eurasian continent and northeast Africa (e.g. Fuller et al. 2011; Frachetti 2012; Spengler et al. 2014; Stevens et al. 2016; Liu et al. 2018). In Tibet, both species are recorded at Changguogou by the Yarlung Tsangpo in central Tibet, dated to c. 1500 BC (Fu 2001; d'Alpoim Guedes et al. 2013).

An insightful question is whether these millet grains at Karuo were cultivated locally, or they were obtained through a network of exchange and trade (e.g., d'Alpoim Guedes et al. 2016). Both broomcorn and foxtail millet utilize the C_4 (Hatch-Slack) photosynthetic pathway. In high altitude environments, C4 photosynthesis is generally considered to be maladapted. The contribution of C_4 species to local floras and vegetation stands shows a sharp decline with increasing altitude (see Sage and Monson 1999 for a review). High elevation locations, like Karuo (c. 3,100 masl), create considerable challenges for millet cultivation, due to the difficulties in meeting physiological and practical requirements for low-temperature tolerance. Between the two millets, *Setaria italica* is better at adapting to high altitude environments than *Panicum miliaceum* (e.g., d'Alpoim Guedes et al. 2013; Sage et al. 2015). This is consistent with our results, showing that there are more foxtail millet grains than broomcorn millet in the Karuo assemblage. Previous studies highlighted the ecological challenge to millet cultivation, and hypothesized that populations of Karuo might have potentially become involved in small-scale cultivation of foxtail millet, but broomcorn millet cultivation was less likely, and some of these grains were possibly moved through trade or networks of exchange (d'Alpoim Guedes and Butler 2015; d'Alpoim Guedes 2015, 2016a, b; d'Alpoim Guedes et al. 2016).

It is not uncommon for communities—regardless of subsistence strategy—to trade grain (among other commodities) or exchange seeds for a variety of social and economic reasons, including to maintain the genetic diversity of landraces in high altitude environments (e.g., Frachetti 2014; Asfaw 1999). We consent with the previous suggestions that some millet grains at Karuo were derived from trade or exchange networks (d'Alpoim Guedes and Butler 2015; d'Alpoim Guedes 2015, 2016a, b; d'Alpoim Guedes et al. 2016). It is, nevertheless, helpful to consider the potential of local millet cultivation near Karuo. Here the presence of *Setaria viridis* and other Panicoidieae taxa at the site is noteworthy. These taxa are commonly known as arable weeds in agricultural fields in northern China today. Archaeobotanists often encounter them in assemblages where millet is dominating, spanning from the Neolithic to the Bronze Age in the Yellow River region. The presence of *Setaria viridis* and other Panicoidieae taxa hints at the possible existence of agricultural fields near Karuo. These weedy species were likely incorporated into the archaeobotanical assemblage through harvesting or weeding. On-going morphometric analysis of foxtail millet caryopses from Karuo shows distinct morphological characteristics, indicating that these grains may belong to a unique landrace that is morphologically distinct from lowland varieties. This finding is consistent with the modern observations of the morphological differences between Tibetan foxtail millet landraces and those from lowland China (Hu ed. 1995: P161-164), and adds to the considerable literature on the variation of C_4 landraces (such as maize and finger millet) concerning altitudinal adaption (Goodman and Brown 1988; Tsehaye et al. 2005). *Setaria viridis*, in particular, is a weedy relative of the domesticated foxtail millet (*Setaria italica*) and a notable cold tolerant C_4 annual grass, adapting to a range of extreme environments in Asia and America (Sage et al. 2015). It is not impossible, that early developments of high-altitude adapted millet landraces was achieved through the crossing between *S. italica* and *S. viridis,* that both are present at Karuo. Additionally, many stone sickles have been recovered at the site, indicating grain harvesting (Cultural Relics Management Committee of Tibet Autonomous Region and Department of history of Sichuan university 1985).

In terms of cultivation practices, it is well documented that various cultivation strategies were commonly used in Tibet, including flexibility in sowing time and management of cultivation depth, soil preparation and weeding— to control and modify the thermal, hydrological, and nutrient environments to optimize the growing condition during germination and plant development (Hu ed. 1999: p. 252-255). Should these cultivation strategies be employed with the development of high-altitude-adapted landraces, it would have been possible to cultivate millet near Karuo. However, archaeobotanical reconstructions of these practices are conceptually challenging without additional evidence, and future investigations into the crop processing practice would be profitable (e.g., Song et al. 2013; Liu et al. 2017a). Today, foxtail millet is cultivated in the Changdu region, the Rikaze region, and near Lasha City at altitudes as high as 3000 masl (Hu ed. 1999: P161-164). Paleoenvironmental studies demonstrate that the environment was potentially wetter and warmer in the Changdu region during the period of the Karuo occupation further supporting the argument of local cultivation (Liu et al 1997; Tang et al. 2004).

Millet was present throughout the occupation period of the site from 2800 to 700 cal. BC, inferring a long engagement with millet. Diachronic changes, however, can be observed in the 2012 samples (Fig. 11). The relative frequency and ubiquity both show that there is a decrease in the proportion of millet remains from earlier phase L5 to later L3, which might indicate the decline of millet economy or changing functions of the area in the context of assemblage formation. Our results show millet dates concentrate in a period between 2600 and 2100 cal. BC, which is consistent with the millet dates from the 2002 sampling previously published (d'Alpoim Guedes et al. 2013). It is likely that millet contributed most significantly to local diets during the second half of the third millennium BC.

Wheat and Barley

Turning our attention to the cereal crops, which originated in Southwest Asia, two charred free-threshing wheat and one possible barley grain fragment were recovered at Karuo. The two wheat grains were directedly dated to the first half of the second millennium BC (Liu et al. 2016; Lu 2016). It is worthy to note that the two wheat dating results—1665-1518 cal. BC and 1207-1017 cal. BC from Layer 4 and 3, respectively—are significantly younger than the dated millet grains from the same layers, indicating the potential movements between stratigraphic units. Such movement of macrofossil remain resonates with the 'early' dates of broomcorn millet in Europe, indicating intrusions of recent-age grains from the post-Neolithic layers (Motuzaite Matuzeviciute et al. 2013). Nevertheless, wheat did exist at Karuo in the second millennium, and suggests that during the late phase of occupation, people at Karuo incorporated novel crops into their diet. There has been considerable discussion on the routes and chronology for the eastern expansion of these Fertile Crescent crops (e.g., Spengler et al. 2014; Liu et al 2016, 2017b; Stevens et al. 2016; Zhou et al. 2020). We consider wheat and barley to have been introduced to China via multiple pathways—each distinct in time and space—and underlined by different social and culinary drivers (Liu et al. 2016, 2017b; Lister et al. 2018). The dates of the Karuo wheat are consistent with other recent evidence from locations in central and western Tibet, such as Changguogou, Bangga, the new sites in Ngari, and even in Kashmir and Kyrgyzstan. Between 1500 and 1000 cal. BC, naked barley and potentially free-threshing wheat had become common cereals across the west, south, and eastern Tibetan Plateau. Wheat and barley from eastern Qinghai, however, predates this trend by a few centuries (Chen et al. 2015).

Other potential food resources

In addition to millet and cereal grains, a large amount of small wild herbaceous plant seeds were recovered. The list includes *Rubus*, *Artemisia, Potentilla/Fragaria/Duchesnea*, species in the Poaceae family, as well as *Chenopodium*. Many of these plants may be used by humans as food resources, and a previous study suggested foraging activities at Karuo (d'Alpoim Guedes et al. 2013). *Chenopodium* is especially notable for constituting the highest proportion of seeds in the floated samples of almost every occupational period at the site (Fig. 12). This evidence should be considered in the context of the assemblage formation process. In Central and West Asia for example, Spengler (2019) highlights that endozoochoric seeds (seed dispersed through animal ingestion) are often overrepresented, and could have been preserved through dung burning. In Central and West Asia, the most prominent of such seeds in dung assemblages are from the Amaranthaceae family, notably *Chenopodium* (Spengler 2019). At Karuo, however, the lack of dung-producing domesticated ruminants, such as sheep/goat and cattle/yak, argues against the usage of dung as fuel. In a nearby Karuo cultural site, Xiaoenda, where zooarchaeological research has been carried out systematically, domesticated ruminants are also absent (Zhang et al. 2019). Wild ungulates do exist at Xiaoenda, so dung could be collected across the landscape. However, neither the surrounding environment of Karuo nor Xiaoenda is the typical landscape for dung collection. Alternative pathways for the formation of a *Chenopodium*-rich assemblage at Karuo should be considered.

Some archaeological evidence in north China suggests possible human uses of *Chenopodium*. For example, at Han Yangling Mausoleum, a large quantity of potentially cultivated *Chenopodium giganteum* were recovered (Yang et al. 2009). At Erlitou, an urban site in the Xia period, tens of thousands of *Chenopodium* seeds were recovered from what are suggested to be storage pits. Both contexts hint at human uses, rather than endozoochoric dispersal, and deserves further investigation (Zhao 2014). Large quantities of *Chenopodium* are also frequently encountered in sites in southwest China, such as at Baiyangcun and Haimenkou in Yunnan, as well as at Shawudu and Yingpanshan in Sichuan (Xue 2010; Martelloa et al 2018; Zhao and Chen 2011; Yan personal communication). These sites are situated in landscapes with dynamic ecological zones along altitude gradients, similar to the ecological settings of ethnographically documented *Chenopodium* (and rice and soybean) cultivation in the Himalayan region in India (Pratap and Kapoor 1985). It is highly possible that *Chenopodium* was utilized by people in the mountainous regions of southwest China as well. Future research into morphological traits resulting from cultivation or selection is necessary.

Subsistence strategy

The presence of millet and cereal grains, and evidence for potential local cultivation, in addition to exchange and gathering activities at Karuo suggests a broad spectrum of subsistence strategy. Fish bones were also retrieved at the site during the 2002 and 2012 excavations, providing evidence for fishing (Li 2007; Zhang 2013). Combining all currently available data on the flora and fauna at Karuo, its prehistoric inhabitants likely practiced a multi-resource subsistence strategy, which may have included farming, hunting, gathering, and fishing, to fully utilize available resources that enabled long-term occupation of the site. This is similar to the subsistence strategy (millet farming and localized hunting) proposed at Xiaoenda, a recently revealed Karuo cultural site that is 14 km away (Zhang et al. 2019).

In discussing the animal-based subsistence strategies at these sites, Zhang et al. (2019) highlights the dependence on diverse wild animal resources in the local environment around at Xiaoenda and Karuo. Zooarchaeological data indicate that the inhabitants took advantage of the local resources situated between highland and multiple lower elevation catchment zones, which allowed access to a range of wild prey species, including musk deer, roe deer, and likely goral and blue sheep. These practices with diverse localized hunting strategy focus on wild rather than domesticated animals are key subsistence strategies at Karuo and Xiaoenda. Together with the archaeobotanical results presented in this paper, Karuo provides a strong example (among many others in the world) to challenge the traditional "modes" of subsistence stages – hunting, foraging, pastoralism, and farming – in a linear evolutionary framework. It is evident that peoples move fairly fluidly between distinctive modes of subsistence, particularly in challenging environments, such as at high altitudes (Scott 2017). In China and elsewhere, it has become clear that early peoples combined subsistence modes in a variety of innovative hybrids (Liu and Reid, forthcoming), and Karuo is contributing to this growing literature.

Conclusion

Systematic archaeobotanical investigation at Karuo has improved our understanding of the diverse subsistence strategies at the site, where millet agriculture may have been established as early as 2800 cal. BC. From 2700 to2100 cal. BC, millet agriculture likely prospered at an elevation of 3100 masl. Wheat was introduced into the site starting around 1665 cal. BC, indicating the beginning of a multi-cropping system. In addition to crop remains, there are other potential food resources that could have been utilized, such as *Chenopodium*. Combining the results of archaeobotanical and zooarchaeological research at Karuo, we demonstrate the presence of a multi-resource economy at the site, including agriculture, hunting, fishing, and gathering. Our findings at the site, along with evidence from other sites in the region, suggests a diverse subsistence strategy, adding to the literature calling for rethinking of the conventional perception of subsistence modes.

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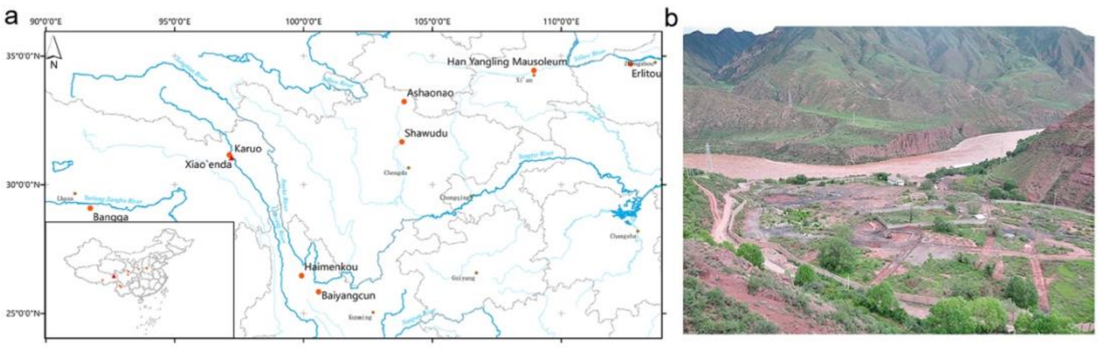

Fig. 1 Karuo site: a. Regional map showing the locations of Karuo and other sites mentioned in the text; b. Landscape view of the Karuo site

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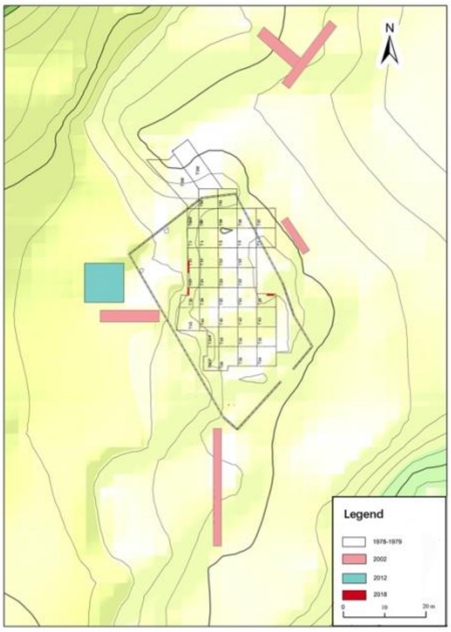

Fig. 2 Plan drawing of Karuo, showing locations of the 1978-79 and 2012 excavation areas in, the 2002 test trenches, and the 2018 sampling profiles.

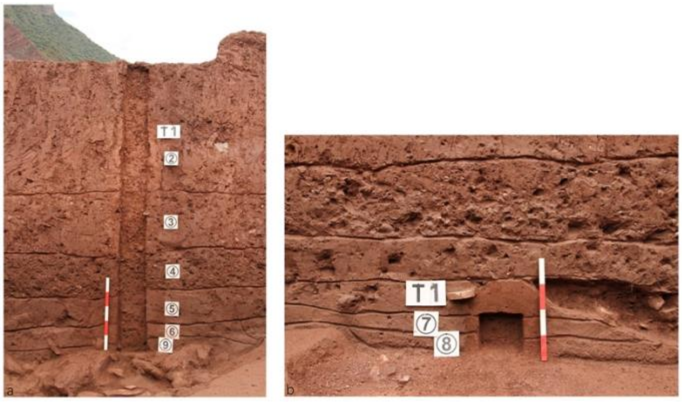

Fig. 3 Stratigraphic units of 2012XCKT1: a. Layer 1-6, 9; b. layer 7, 8

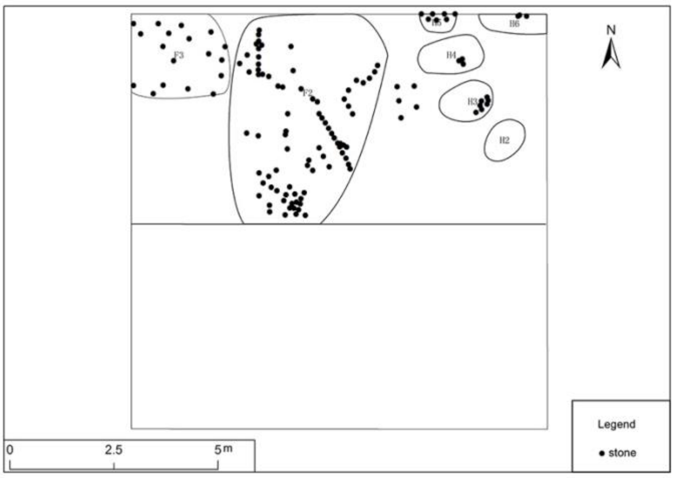

Fig. 4 Plan view of the excavated area in the 2012 field season

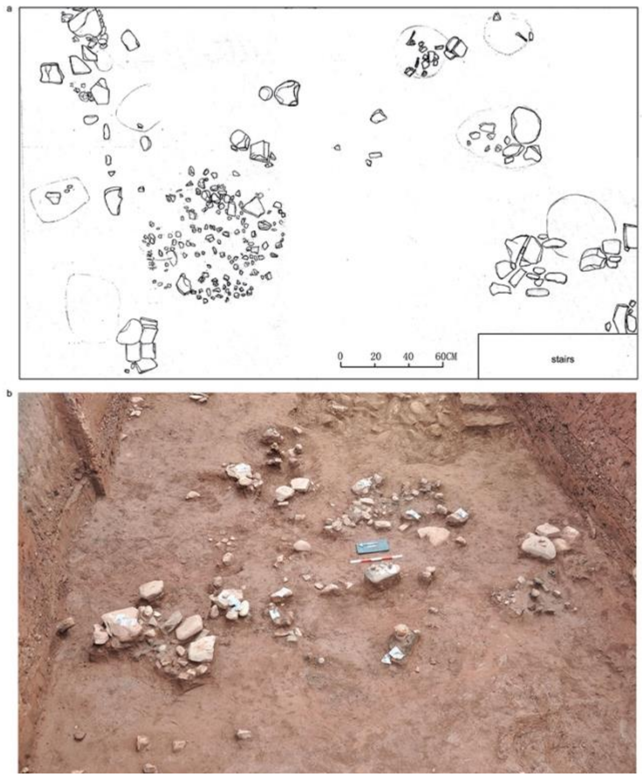

Fig .5 a. Plan view of the house structure F2, excavated in 2012; b. Post-excavation image of F2

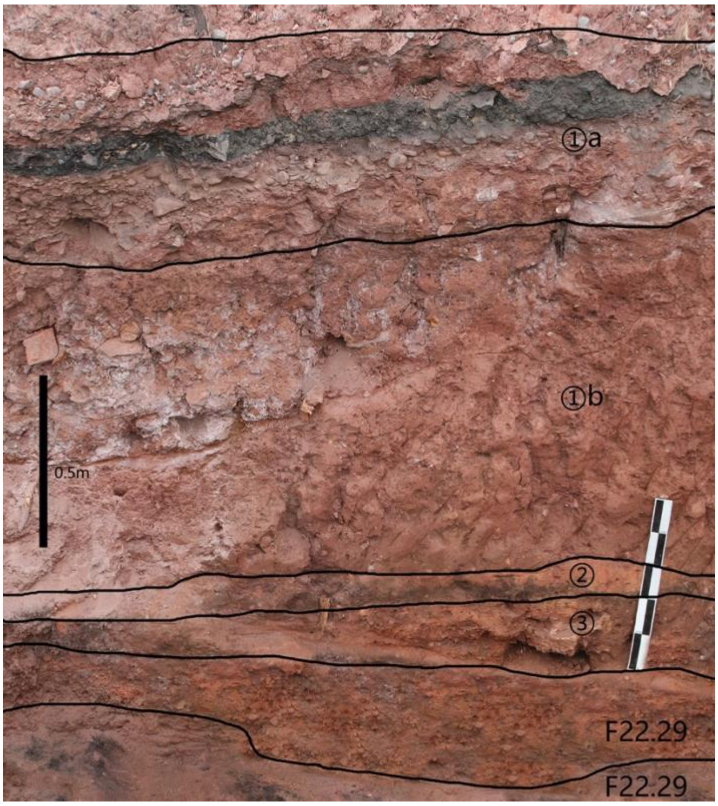

Fig. 6 Stratigraphic units of T35 in the 2018 survey

https://doi.org/10.1007/s12520-021-01281-9

Fig. 7 Millet remains recovered at 2018XCKT35F22.29

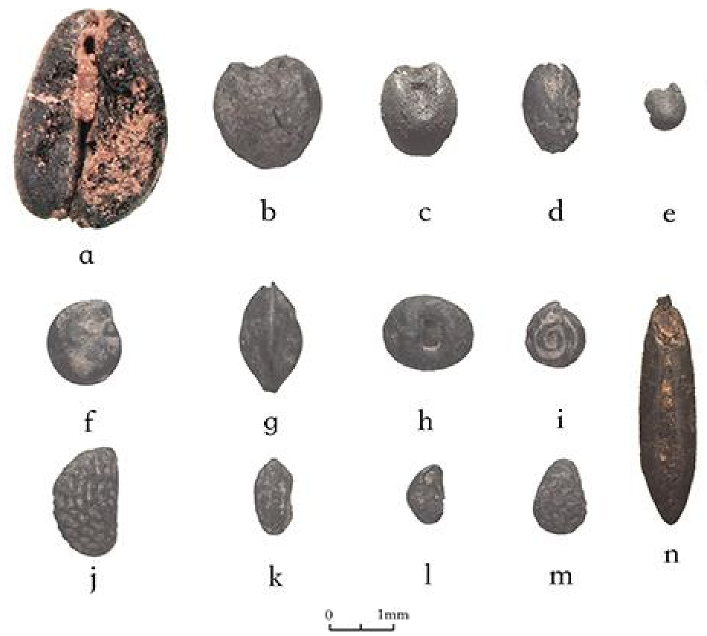

Fig. 8 Flotation machine in 2012, designed and modified from that initially developed by Patty Jo Watson in the 1960s. This is the first time flotation machine is used in archaeology in Tibet.

https://doi.org/10.1007/s12520-021-01281-9

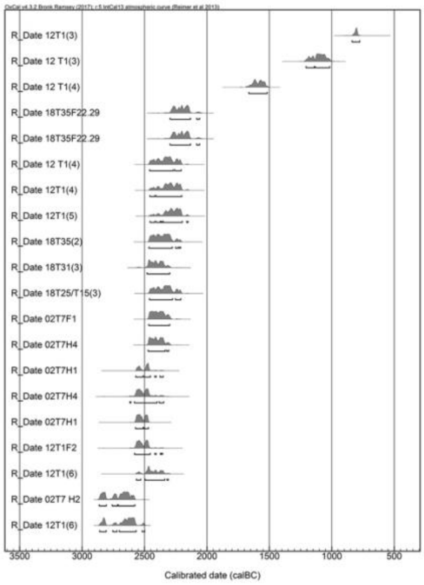

Fig. 9 Photomicrographs of representative seed taxa identified at Karuo: a) wheat b) broomcorn millet c) foxtail millet d) *Setaria* cf. *viridis* e) immature foxtail millet f) *Chenopodium* g Polygonaceae h) *Galium* i) Salsola j) *Rubus* k) *Plantago* l) *Potentiall/Fragaria/Duchesnea* m) *Amethystea* n) Poaceae.

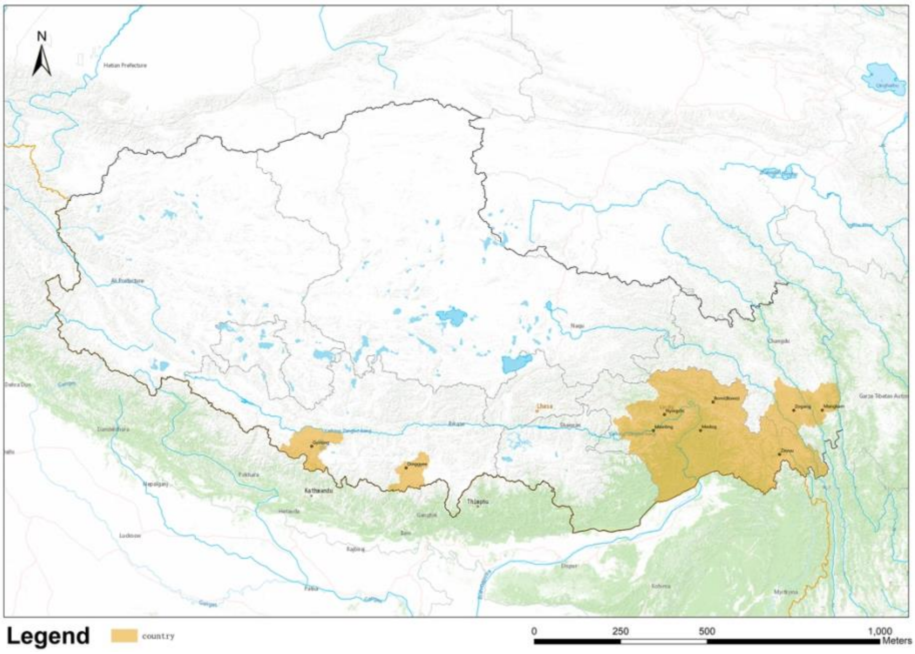

Fig. 10 OxCal calibrated curves of radiocarbon measurements, including results generated by this study and published previously in d'Alpoim Guedes et al. 2013

https://doi.org/10.1007/s12520-021-01281-9

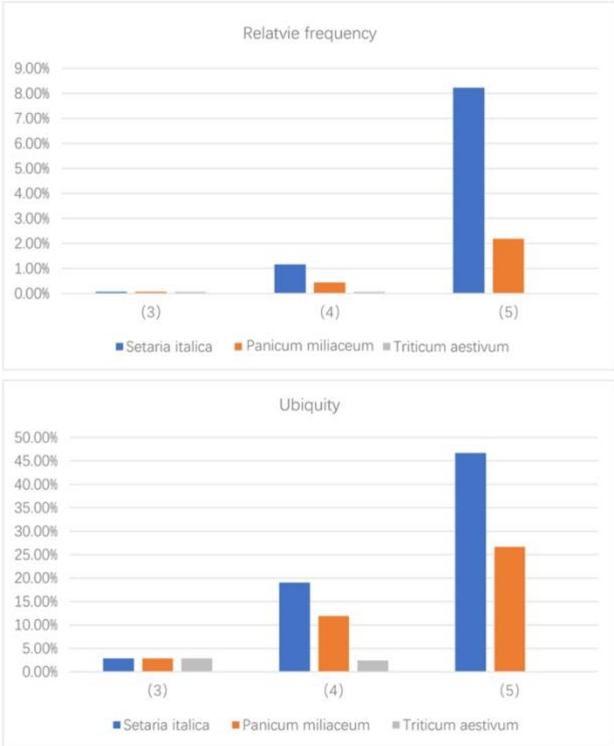

Fig. 11 Relative frequency and ubiquity of plant remains collected in 2012 excavation.

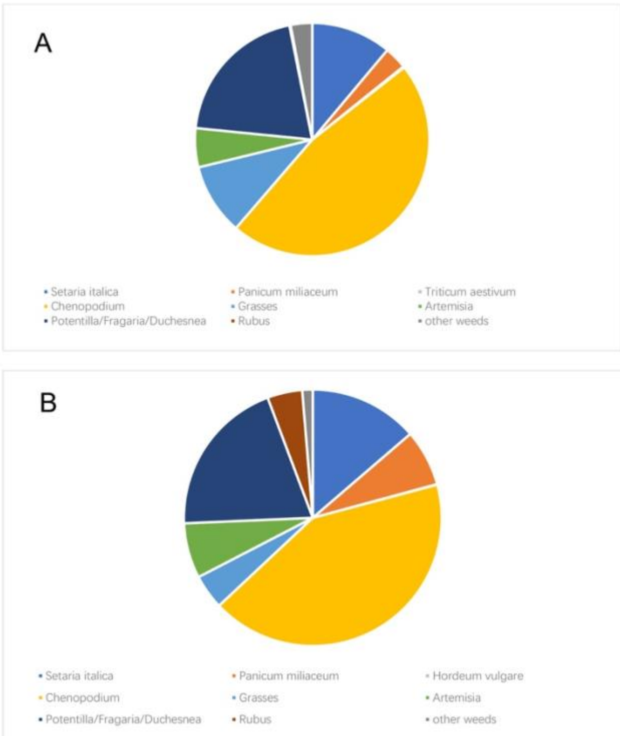

Fig. 12 Relative proportion of plant remains recovered at Karuo: A samples from 2012 excavation; B samples from 2018 survey.