



Seeds of Time: Archaeobotanical Insights into Late Bronze Age Agriculture from the Heart of Central Asia

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Abstract

Recent excavations at Tilla Bulak have produced the first systematically collected dataset of archaeobotanical remains from a Bronze Age site in the Surkhandarya Plain, southern Uzbekistan. The rich assemblage is dominated by economic crops, primarily hulled barley, wheat, and broomcorn millet, along with legumes, grape, and wild fruits, including pistachio, plum, and apple. The identification of a complex cultivation strategy illustrates the breadth and diversity of economies at this early date, distinguishing them from low-investment cultivation systems further north. We interpret the remains of fruits and nuts as evidence of early forest management rather than systematic orchard cultivation, though tree management represents a set of cultural practices not identified in earlier periods in Central Asia. Although most cultural traits of Surkhandarya's early farmers are similar to those of other southern Central Asian urban centers, their agricultural practices appear less intensive, relying more on grains than legumes and integrating foraged resources.

Keywords Late Bronze Age · Bactria-Margiana Archaeological Complex · Arboriculture · Complex agriculture · Uzbekistan · Arid Central Asia

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Introduction

The social and ecological landscapes of Central Asia have supported long-distance interactions since the introduction of agriculture in the sixth millennium BCE (Charles & Bogaard, 2010; Jones et al., 2011; Sherratt, 2006; Spengler, 2019; Spengler & Willcox, 2013; Stevens et al., 2016). From the Bronze Age onward, the regions at the heart of Inner Asia have functioned as a cultural contact zone between northern, small-scale pastoralist communities and practitioners of more intensive irrigation agriculture in southern Central Asia. The region's diverse landscapes, from fertile river valleys to arid steppes, have shaped both the systems and the scale of farming. In turn, the degree of agricultural investment, ranging from mobile pastoralism complemented by low-investment farming to intensive irrigated farming, has shaped the scale and dimensions of social complexity (Spengler et al., 2021). Archaeobotanists working in these ecologically diverse regions have consistently noted that ancient and historic communities adapted to local environmental conditions by utilizing irrigation systems, cultivating drought-tolerant crops, and relying on social networks that mitigated risk and promoted the exchange of ideas and technology (Li

et al., 2025; Motuzaitė Matuzevičiūtė et al., 2020; Spengler, 2015). While certain regions of Central Asia have received increased attention in archaeobotanical research over the past decade, the core area of Surkhandarya in southern Uzbekistan remains critically understudied. How complex social systems were maintained in this region during the second millennium BCE, when most of Inner Asia was characterized by smaller-scale social units, remains unanswered. Specifically, the region's agricultural base is understood only in broad terms, and the exact crops cultivated at this time are unknown. We show that a diversity of crops and managed wild resources were part of the diet, all integrated into a complex economy. We also show that during the second millennium BCE, agricultural systems diversified through the adoption of southwest Asian legumes and two East Asian millets (Mir-Makhamad, 2024; Spengler, 2015).

This agricultural diversification was part of broader cultural and demographic developments accompanying the rise of complex societies in southern Central Asia. As communities dispersed outward from this core region (through demic expansion) (Guarino-Vignon et al., 2022) they carried their farming practices with them. The second-millennium BCE communities of southern Central Asia are subsumed under the broad term Bactria-Margiana Archaeological Complex (BMAC) or Oxus Civilization. It is generally accepted that the BMAC originated in the valleys and oases of the Kopet Dag, where the first urban settlements developed in the third millennium BCE (Baumer & Novak, 2016; Kircho, 2021; Kohl, 1984; Lyonnet & Dubova, 2021).

Around 2000 BCE, BMAC-style material culture expanded suddenly into Bactria and a large swath of eastern Iran (Biscione & Vahdati, 2021). The diffusion of traits from the Eurasian steppe or the Andronovo Cultural Complex is also documented in the archaeological record for this period, first at the northern periphery of the BMAC range and by 1700 BCE in the BMAC core areas (Lyonnet & Dubova, 2021). The nature of the interaction between steppe peoples and those living in southern Central Asia has been a topic of interest for decades (Hiebert & Moore, 2004; Rouse & Cerasetti, 2014). Much archaeobotanical research in the BMAC core areas has focused on the degree of integration among these people and the structure of their economies (Rouse and Cerasetti 2018; Spengler et al. 2018b). Despite longstanding narratives describing culturally distinct people living adjacent to one another, archaeobotanical data demonstrate that a wide variety of crops were cultivated across the BMAC sphere (Billings et al. 2022; Spengler et al. 2014, 2018b).

Recognizing that the BMAC label obscures considerable regional diversity, archaeologists often describe its easternmost variant in the Surkhandarya valley of southern Uzbekistan as a distinct cultural group within the BMAC. The term Sapalli Culture refers to an ancient population that has been

studied since the early 1970s (Askarov, 1973). Major settlements organized around central, carefully planned compounds were identified at the key sites of Sapallitepa, Dzarkutan, and Molalitepa (Askarov, 1973, 1977, 1981). Large cemeteries with hundreds of burials have enabled the periodization of the Sapalli Culture and have provided insight into social structure and cultic practices (Abdullaev & Kaniuth, 2024; Askarov & Abdullaev, 1983). Archaeologists generally describe the people of the Sapalli Culture as integrated into wider interaction spheres thought to have included Mesopotamia, the Indo-Iranian borderlands, and possibly Anatolia (Kaniuth & Shaydullaev, 2022; Possehl, 2002, 2007; Wilkinson, 2020). Although it is often assumed that the inhabitants of the Surkhandarya region shared an agricultural economy similar to that of the broader BMAC-influenced populations, this assumption lacks evidence, particularly given the area's distinct ecological constraints and unique social landscapes (Kaniuth, 2020). Agriculture in the arid and semi-arid regions of southern Central Asia has been systematically studied only on the Murghab alluvial fan within the foothills of the Kopet-Dag (Billings et al. 2022; Miller 1999; Rouse et al. 2024; Spengler et al. 2018). Our study shows that it would be premature to assume that this cultivation system was also used on the northeastern periphery of the BMAC range. Prior to our study, knowledge of Surkhandarya agriculture was limited to small-scale archaeobotanical samples—one from the settlement at Dzarkutan (Chen et al., 2024; Miller, 1999), one from Toda Cave (Zhou et al., 2025), and another based on handpicked plant remains from Sapallitepa (Askarov, 1977). These datasets, while informative, provided only a partial view of agricultural practices in the region.

Study Area

Tilla Bulak (N 37.71067, E 66.80075) lies immediately west of the Surkhandarya Plain, in the piedmont zone of the Kugitangtau Mountains at an elevation of 850 m.a.s.l. (Fig. 1). The site was excavated from 2007 to 2010 and, among other scientific approaches, provided the first systematic archaeobotanical sampling in the region. Tilla Bulak covers approximately 0.4 ha, of which about half has been excavated. The settlement appears to have been short-lived. Radiocarbon dates from charred seeds indicate it lasted for little more than 150 years, from ca. 1950–1800 BCE (Fig. 2). The first occupation phase ended around 1900 BCE in a conflagration that engulfed the entire settlement. The houses were quickly rebuilt with only minor changes, and occupation continued in a second phase until ca. 1800 BCE (Kaniuth, 2020). It is important to note that the inhabitants of Tilla Bulak are currently the earliest known sedentary farmers in the Surkhandarya Plain, likely migrants from the south who introduced the first cultivated plants to northern Bactria.

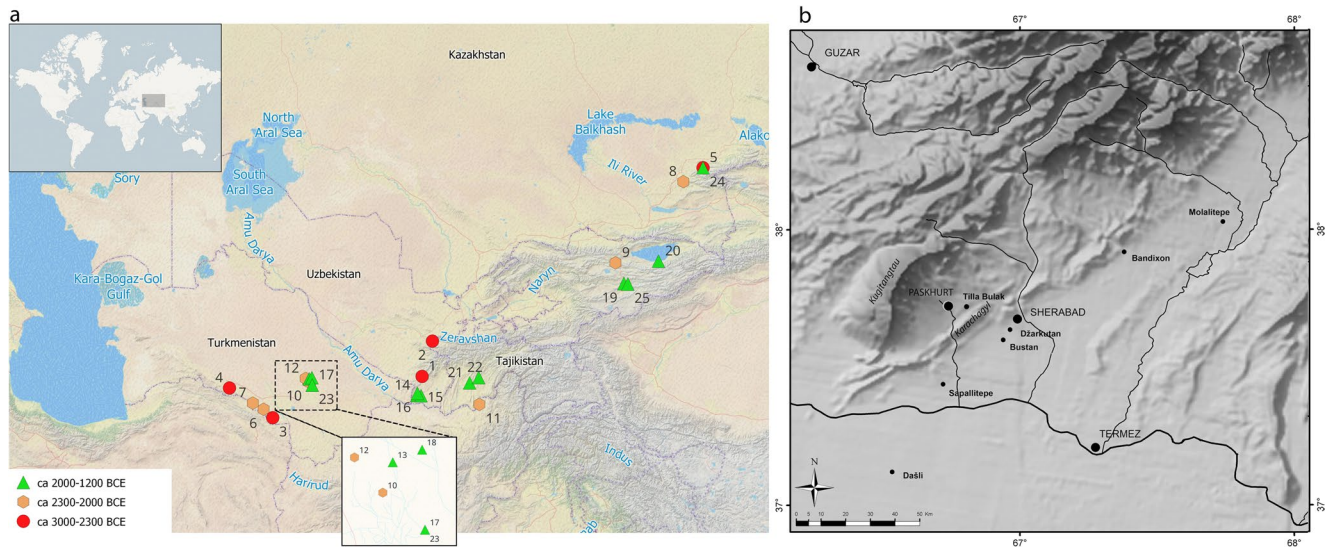


Fig. 1 a – Bronze Age sites in Central Asia with archaeobotanical remains. ca. 3000–2300 BCE: 1 – Kainar Kamar, 2 – Sarazm, 3 – Altyn-Depe, 4 – Anau South, 5 – Tasbas; ca. 2300–2000 BCE: 6 – Ulug-Depe, 7 – Namazga-Depe V, 8 – Begash-Phase 1a, 9 – Chap II, 10 – Togolok 1, 11 – Shortugai, 12 – Adjikui 1; ca. 2000–1200

BCE: 13 – Gonur, 14 – Sapallitepa, 15 – Dzarkutan, 16 – Tilla Bulak, 17 – Chopontam-1219, 18 – Ojakly, 19 – Aigyrzhal, 20 – Uch-Kurbu, 21 – Tashguzor, 22 – Kangurttut, 23 – Chopontam-1211, 24 – Tasbas, and 25 – Mol-Bulak; b – a map of Bronze Age sites on the Surkhandarya Plain

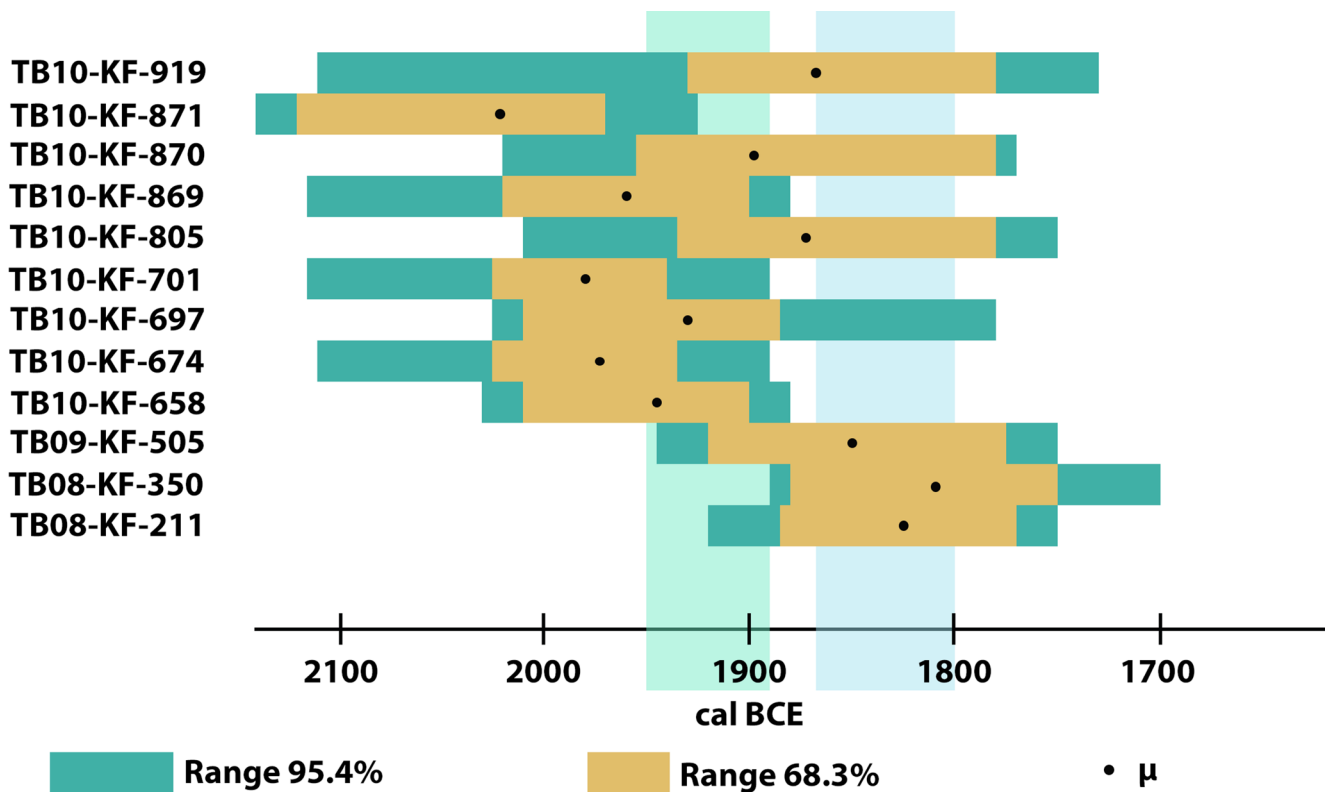


Fig. 2 Radiocarbon dates of seeds from Tilla Bulak. The figure shows previously published ¹⁴C results indicating two likely periods of occupation (the two vertical boxes) (Kaniuth, 2016). All dates have been

recalibrated using OxCal v4.4.2 software (Bronk Ramsey, 2009, 2020) and the IntCal 20 curve (Reimer et al., 2020)

In the deeply incised valley of the Surkhandarya River, all recorded prehistoric settlements are located on alluvial fans at elevations of 400–440 m.a.s.l., along the broader western part of the plain. The settlements in the valley are positioned to permit diversion of smaller tributaries for runoff irrigation (Kaniuth, 2020). Tilla Bulak sits on the central watercourse of the Pashkhurt Plains, the Ulanbulaksaj River, which is also deeply incised and poorly irrigated; therefore, sites associated with the river were positioned along its tributaries. Geomorphological studies have shown that Tilla Bulak was established in an equally advantageous but spatially restricted microenvironmental pocket on a drainage divide, with direct access to a perennial water source discharging into a small, fertile valley (Makki in Kaniuth, 2011, 2020).

The first archaeobotanical data from Tilla Bulak were published in 2009, based on 5 samples containing 880 macrobotanical remains from the previous year's campaign. (Peters in Kaniuth, 2009). In the 2009 and 2010 seasons, when the lower, burned stratum of the site was more widely exposed, the recovery rate for botanical remains improved considerably. Ultimately, we present more than 10,000 carbonized plant remains in this study. In presenting the full assemblage and discussing its constituent parts, we seek to better understand the details of an agricultural system that supported the rise of urban centers in the northeastern periphery of the BMAC.

Methods

Research at Tilla Bulak was conducted over four years as a joint venture between the Tokharistan Expedition of the Institute for Art Historical Research of the Uzbek Academy of Science and Munich University (Kaniuth, 2016, 2020).

Archaeobotanical samples were systematically collected during three excavation seasons using bucket flotation. Samples were obtained from various contexts, including fireplaces, room fills, and *tannurs* (Fig. 3). Fragmented grains of free-threshing wheat (*Triticum aestivum*), hulled barley (*Hordeum vulgare* var. *vulgare*), and naked barley (*Hordeum vulgare* var. *nudum*) were quantified using minimum number of individuals (MNI) estimates, with three fragments in a single sample counted as one grain, based on observations made during laboratory work. In contrast, a single grape pip (*Vitis vinifera*) was represented by four fragments in a sample. Pistachio (*Pistacia vera*) nutshell fragments were estimated by weight, with one pistachio nutshell corresponding to 136 mg in a sample, whereas all MNI estimates were rounded up to the nearest whole number. Many wild seeds could be identified only to the generic or familial level. Specimens in Poaceae and Brassicaceae were particularly difficult to identify to the genus level, as many species overlap morphologically. The category of 'Unidentifiable' was used where seed fragments were too fragmented to identify to genus or even family. The categories of unidentifiable seeds, nutshells, chaff, Cerealia, and Legumes were not included in the total counts. The "Unidentified" category included all seeds that were sufficiently whole but could not be identified due to insufficient knowledge of local species.

We calculated the ubiquity and relative abundance of each economic plant. In our study, ubiquity estimates the relative importance or commonness of plants across contexts, whereas relative abundance identifies dominant crops and corrects for preservation biases. During excavation, sample volume was inconsistently recorded; only 60% of samples are linked to volume information, with volumes ranging from 1 to 18 L (S11).

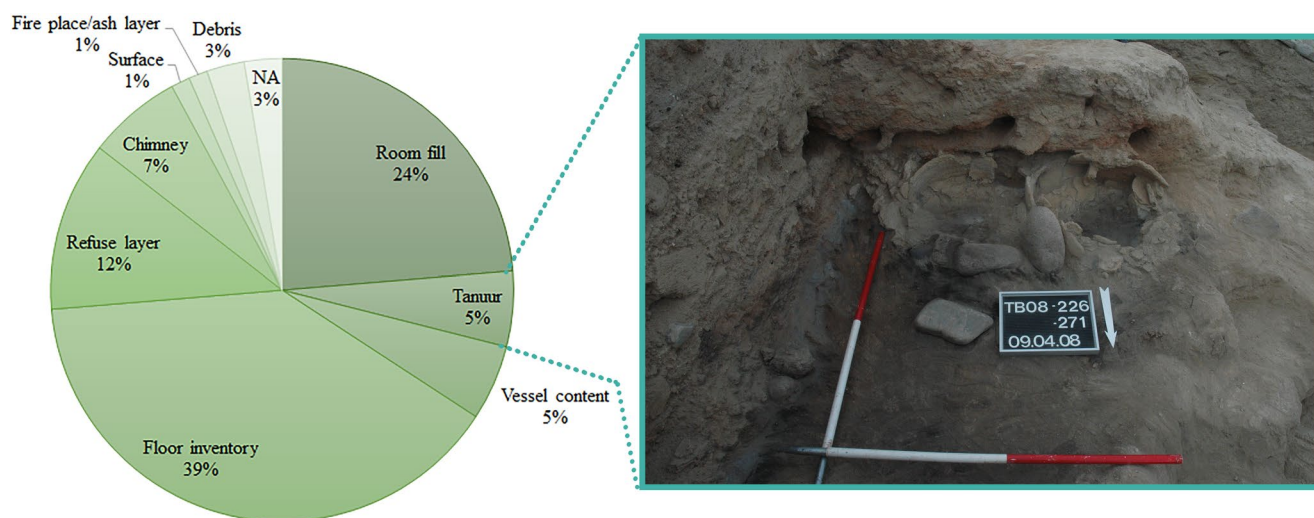


Fig. 3 Relative abundance of context representation and two *tannurs* (TB-271 and TB-226) in Room 22 (photo by the Tilla Bulak project, C. Fink)

Results

The archaeobotanical assemblage comprises 10,721 carbonized seed and fruit fragments, 1,630 unidentifiable seed fragments, and 474 unidentifiable nutshell fragments (> 2 mm). In addition to seeds and nutshells, 2,048 diagnostic plant remains, including cereal rachis internodes and culm nodes, 4,030 Cerealia, and 77 Legume fragments, were recovered (SI 1). Of the identified seeds and fruit parts, 73.5% are economic plant remains, and 26.5% are wild herbaceous plants. In addition to carpological remains, 1,652 wood fragments > 2 mm were retrieved.

Economic crops consist of 89.4% cereals, 4.8% legumes, and 5.8% fruit and nut remains. Domesticated cereals include hulled barley ($n=5,880$), naked barley ($n=15$), hexaploid free-threshing wheat ($n=176$), wheat (*Triticum* sp., $n=102$), broomcorn millet (*Panicum miliaceum*, $n=471$), and immature millet ($n=17$). Legumes include peas (*Pisum sativum*, $n=360$), a mixed group of peas and

grass peas (*Pisum/Latyris* sp., $n=12$) due to poor preservation, and lentils (*Lens culinaris*, $n=3$) (Fig. 4).

Besides annual crops, we also recovered long-generation perennial remains, including pistachio ($n=19$), plum (*Prunus* sp., $n=6$), an unspecified type with a thin shell (see Fig. 5b), cherry (*Prunus* cf. *avium*, $n=1$), apple (*Malus* sp., $n=3$), and grape ($n=425$). In addition to nutshell fragments with clear features, we recovered 474 small nutshell fragments in the fraction below 2 mm, which are likely all pistachio shell fragments; however, due to their fragmented nature, we present them separately as unidentifiable nutshell fragments.

Wild plants make up a large part of the assemblage and are dominated by several sedge types (Cyperaceae), notably *Carex* spp., followed by wild Fabaceae, particularly *Medicago/Melilotus*, *Trigonella* sp., *Cornilla* sp., and *Alhagi* sp., chenopods (*Chenopodium* sp.), and Brassicaceae, represented by *Euclidium syriacum* pods. Grasses (Poaceae) are also present, predominantly *Aegilops* sp., and *Galium* spp.

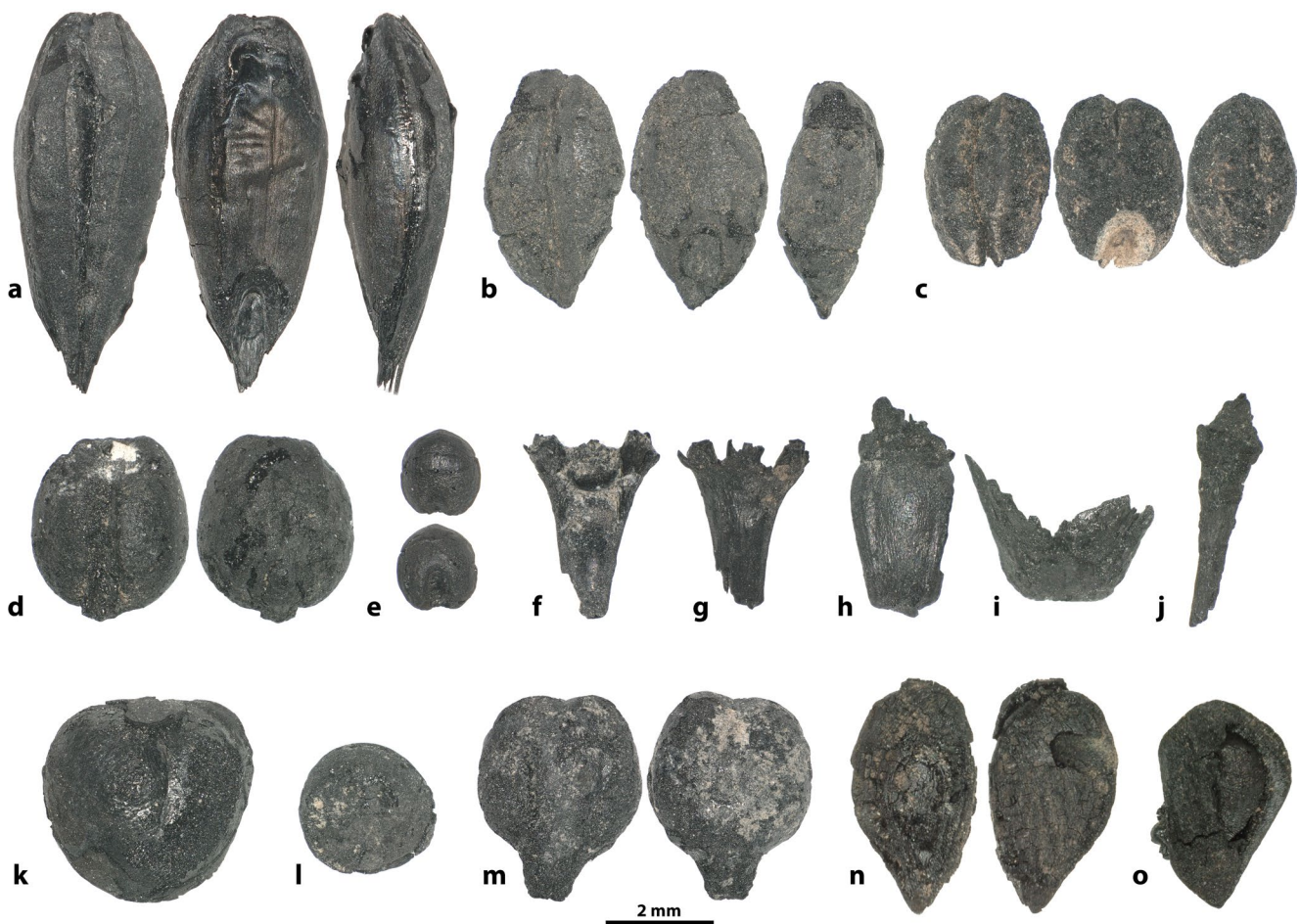


Fig. 4 a – *Hordeum vulgare* var. *vulgare* (hulled barley), b – *Hordeum vulgare* (6-row barley), c – *Hordeum vulgare* var. *nudum* (naked barley), d – *Triticum aestivum* (free-threshing wheat), e – *Panicum miliaceum* (broomcorn millet), f – rachis of six-row barley, g – rachis of

naked barley, h – free-threshing wheat rachis, i – *Aegilops* sp. (goat grass spikelet base), j – *Vitis vinifera* (grape peduncle), k – *Pisum sativum* (green pea), l – *Lens culinaris* (lentil), m – grape, n – *Malus* sp. (apple), o – *Rosa* sp.



Fig. 5 **a** – *Pistacia vera* (pistachio), **b** – thin-shelled *Prunus* sp., **c** – *Prunus* cf. *avium*

Although abundance varied, cereal remains were recovered from all samples except one, which came from the only fireplace context in this study. Barley was the dominant cereal and the most abundant plant remains in the *tannur* samples, with only four cereal chaff fragments recovered (Fig. 6). Small quantities of wild plants and charcoal were also present. The floor inventories, represented by 30 samples, contained a relatively high proportion of cereals (76%), compared with other plant remains, such as legumes, which still comprised a significant portion (~7%). Additionally, fragmented pistachio shells and grape pips were recovered in most samples. Notably, this group of samples contained nearly 50% of all chaff remains in the assemblage (Fig. 6). Pistachio was the most abundant species (likely wild-growing) in the nut/fruit category from the floor inventories, while grape pips were mainly recovered from samples taken from the room fills, where apple seeds and fragments of cherry stones were also present. Wild herbaceous plant remains were the main category in these contexts, primarily represented by *Carex* sp., Fabaceae (including *Trigonella* sp., *Medicago/Melilotus* spp., and *Cornilla* sp.), and *Euclidium syriacum* capsules.

Discussion

Farming Strategies Beyond the BMAC Heartland

The introduction of new crops such as millet and legumes into Central Asia during the second half of the third millennium BCE may be linked to either intensification or extensification of the agricultural system. In a Boserupian sense (1965), a rising population or the consolidation of people within the town was likely a key driver of changes in farming methods to maintain or enhance soil fertility. Boserup also suggested that the advent of irrigated farming led to corollary increases in labor demands, such as weeding and maintaining irrigation canals. These demographic and agricultural shifts may have coincided with and been further

shaped by broader patterns of mobility and cultural interaction. The currently available evidence for ancient human genetics from this time period and region suggests increased gene flow from the north (Narasimhan et al., 2019), which does not necessarily mean that people were moving over great distances, as many intermarriages over time can lead to population mixture and gene flow.

Despite the increased focus on agriculture, southern Central Asians continued to rely on local wild fruits and nuts (Fig. 7). Contemporaneous populations further north, where data are available, notably in the central Tian-Shan Mountains, Xinjiang, and Semirechie, show that people largely lacked legumes (see Fig. 7). By contrast, archaeobotanical assemblages from southern Central Asia, on the Murghab alluvial fan and in regions near the Amudarya River, contain pea, lentil, grass pea, vetch (*Vicia sativa*), chickpea (*Cicer arietinum*), and fava bean (*Vicia faba*) (Fig. 7). At Tilla Bulak, people appear to have grown only peas and lentils, with lentils present at low ubiquity. In these ways, the Tilla-Bulak assemblage is intermediate between contemporaneous sites to the north and south.

A diversified crop repertoire can serve as an adaptive strategy, mitigating losses from unpredictable weather and spreading labor demands over time. Mixing long- and short-season crops with water-demanding and drought-tolerant forms can buffer agricultural uncertainty, especially in ecotonal regions, such as the foothills of Central Asia. Greater interconnectivity during the second millennium BCE facilitated transcontinental crop diffusion, enabling farmers to adopt new crops as they spread through their social networks (Spengler, 2015). Each new crop has a distinct narrative of spread and adoption, reflecting complex interactions among cultures in the region, but large gaps in Central Asian data continue to obscure these stories.

Cereals

Several wheat specimens appear to belong to a compact morphotype, which is widely reported at coeval sites across

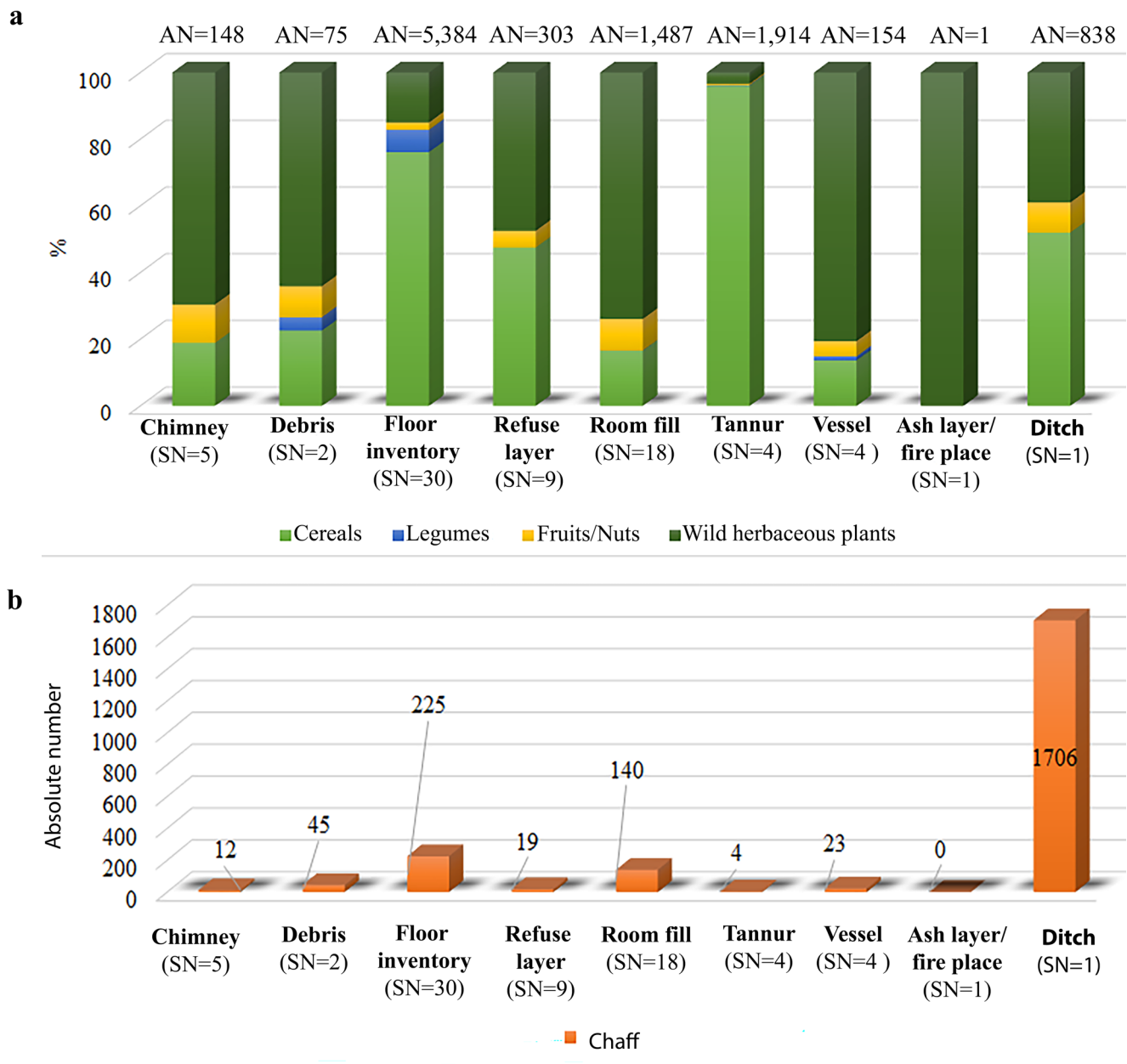


Fig. 6 a– relative abundance of economic and wild herbaceous plants across all contexts, where AN is the absolute number of seeds recovered in each context, which contains a different number of samples (SN) (for more detail, see Fig. 3), and b – absolute number of chaff remains per context

southern Central Asia (Miller, 1999; Spengler et al., 2014). Miller (1999) suggests that there may be genetic links to a specific semi-dwarfing wheat type historically documented in India and Pakistan, known for greater drought resistance than other wheat landraces. Spengler (2019) noted that semi-dwarfing landraces from Japan and India were also historically recognized for reduced lodging, which would have been advantageous in windy areas, such as deserts or mountain valleys.

Nearly all (99.7%) of the recovered barley is a hulled morph, in contrast to other sites from this time period, which

show a shift toward naked morphs (Billings et al., 2022; Lisitsina, 1981; Miller, 1999; Motuzaitė Matuzevičiūtė et al., 2020; Spengler et al., 2014). Additionally, the barley shows considerable variation in grain size, particularly in grains from *tannur* TB-271 (Fig. 8). Many factors can affect grain size within a site, likely reflecting developmental responses to external influences, including environmental changes, climatic conditions, irrigation practices, soil fertility, diseases, or seasonality (Motuzaitė Matuzevičiūtė et al., 2021). Assuming these crops represent a contiguous gene pool, are genetically compatible, and are wind-pollinated,

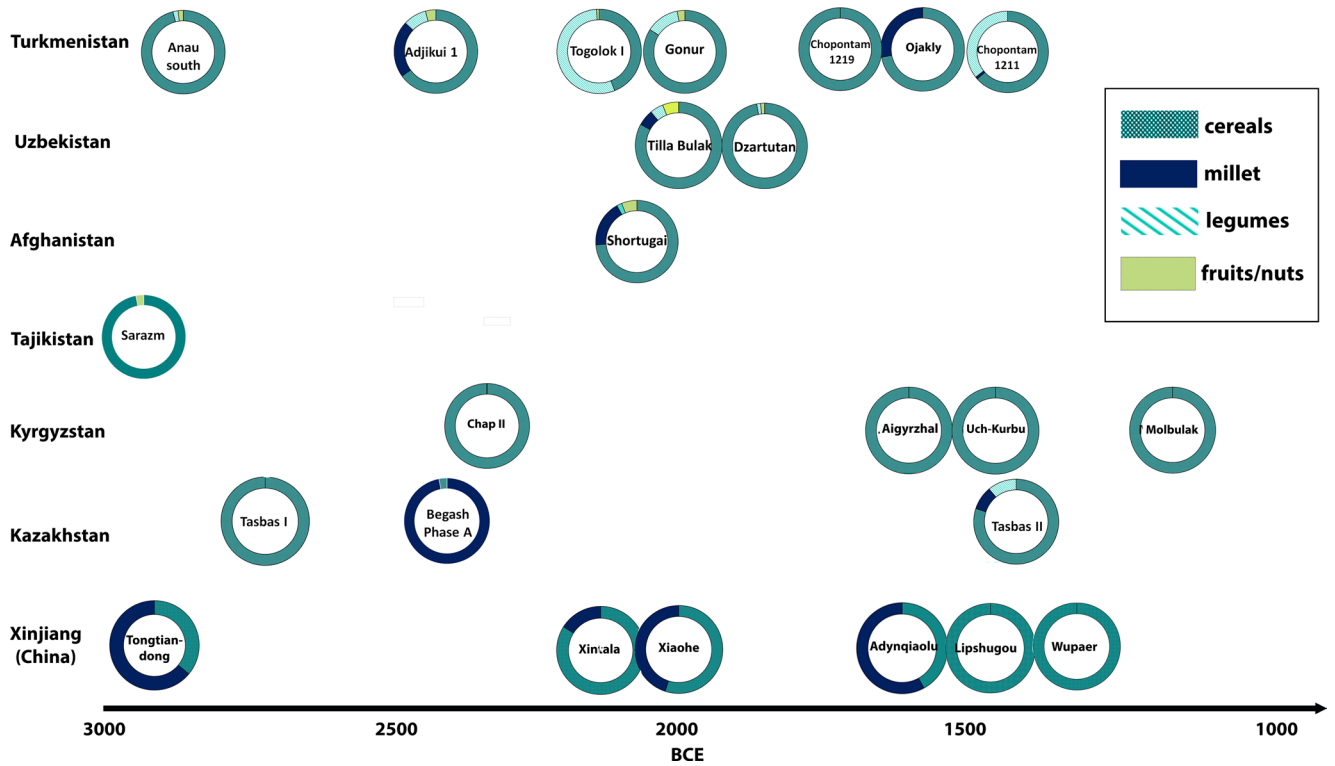


Fig. 7 Relative abundance of cereals, legumes, and fruit/nut groups recovered through archaeobotanical analysis from 3000–1000 BCE. Note: At Togolok I, millet is less than 0.2%. Cereals and millets were

also recovered at the Goukou site in Xinjiang, but the total number of seeds is unknown

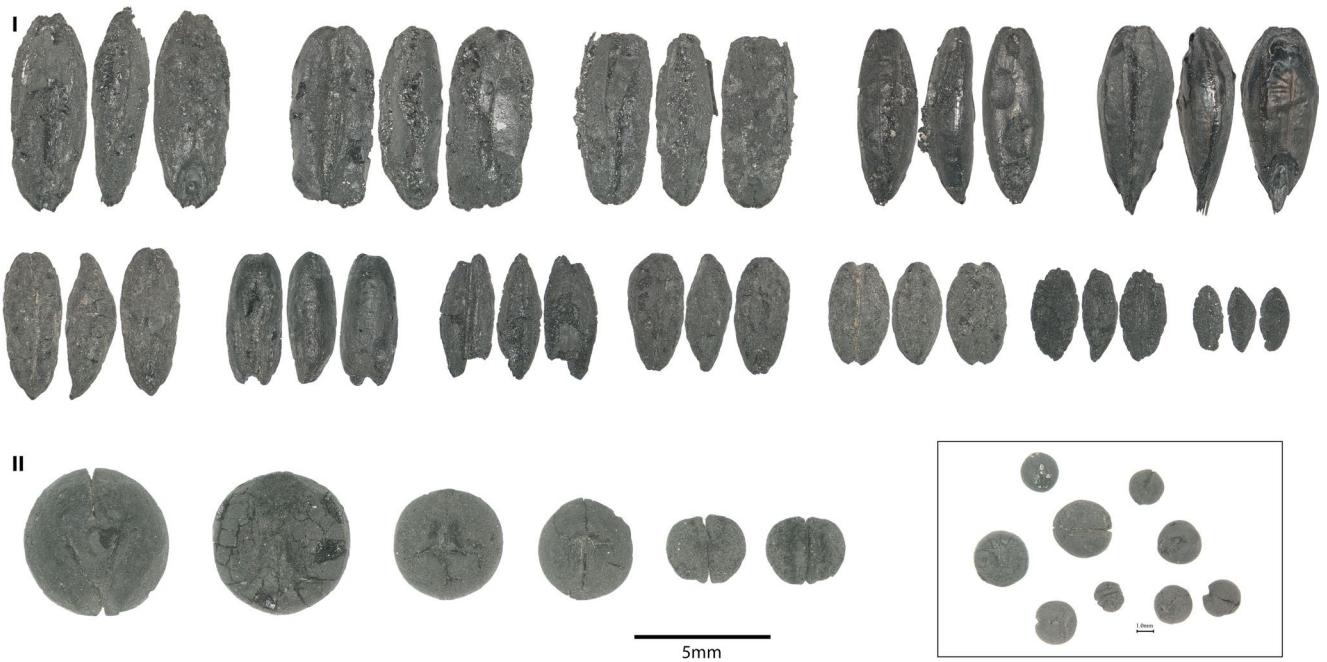


Fig. 8 An illustration of the range of variation in **I** – barley and **II** – peas

it seems unlikely that the variation is due to evolutionary adaptations that have produced landraces or ecotypes. The possibilities that: (1) not all specimens were fully developed at harvest; (2) different parts of the fields received varying levels of irrigation; or (3) the grains represent a palimpsest of different seasons, are all viable explanations.

Stable isotope analyses of human remains indicate that C_4 plant consumption appears along the Inner Asian Mountain Corridor of Central Asia, beginning in the third millennium BCE (Motuzaite Matuzeviciute et al., 2022). Archaeobotanical data confirm that broomcorn millet spread into the core areas of Central Asia by the second half of the third millennium BCE (Billings et al., 2022; Frachetti et al., 2010; Spengler 2013; Spengler et al. 2018b; Zhou et al. 2020). Tian et al. (2023) argue that millet dispersal into Xinjiang followed three primary pathways: the Hexi-Altai route, the Tianshan oasis corridor, and the Kunlun piedmont. From the second millennium BCE onward, broomcorn millet spread throughout the region and has been identified at many archaeological sites from this period (Askarov, 1977; Chen et al., 2024; Spengler et al., 2014). Meanwhile, foxtail millet appears to have emerged only in the late second millennium BCE; for this reason, it was not recovered at Tilla Bulak or at any other coeval sites in southern Central Asia. The earliest reported find comes from Kangurtut in Tajikistan (1594–1291 BCE); however, this claim is based on impressions on pottery (Lebedeva, 2004). Setting aside the difficulties of identification, assigning a precise date through radiometric methods is not possible. Although not directly dated, the foxtail millet grains from Kimirek-Kum are the most securely dated earliest remains in central Central Asia thus far recovered, dating to 1250–1050 BCE (Stark et al., 2024). However, foxtail millet is less commonly submitted for direct dating than broomcorn millet; thus, much remains unresolved about its dispersal through Central Asia.

Complementing the recovered cereals (Table 1), archaeologists have reported that grinders and pestles are the second-largest category of finds after pottery (Kaniuth, 2016). The high ubiquity of chaff likely indicates local processing of cereals, and *Aegilops* sp., a weedy crop mimic often harvested with cereals, may further indicate local grain processing. *Aegilops* plants often grow near wheat fields in Uzbekistan today, and their similar seeds and chaff often lead to their being harvested with cereals (personal observations). The high ubiquity of crop-harvesting remains has also been used to argue that grains were stored unprocessed, whereas they would have been threshed and ground in the domestic setting daily or as needed (Fuller et al., 2014; Stevens, 2003). Collectively, these data demonstrate that the occupants of Tilla Bulak maintained a bread-baking cuisine similar to that of later Central Asian peoples.

Table 1 AN (absolute number), RA (relative abundance), and U (ubiquity)

Taxa	AN (#)	RA (%)	U (%)
Hulled barley (<i>Hordeum vulgare</i>)	5,880	74.6	67
Naked barley (<i>Hordeum vulgare</i> var. <i>nudum</i>)	15	0.19	11
Free-threshing wheat (<i>Triticum aestivum</i>)	176	2.23	26
Wheat (<i>Triticum</i> sp.)	102	1.3	21
Broomcorn millet (<i>Panicum miliaceum</i>)	471	5.9	52
Immature millet	17	0.22	5
Pea (<i>Pisum sativum</i>)	360	4.6	16
Lentil (<i>Lens culinaris</i>)	3	0.04	3
Pistachio (<i>Pistacia vera</i>)	19	0.24	23
Cherry (<i>Prunus</i> cf. <i>avium</i>)	1	0.01	1
Plum (<i>Prunus</i> sp.)	6	0.08	5
Apple (<i>Malus</i> sp.)	3	0.04	3
Grape (<i>Vitis vinifera</i>)	425	5.4	71
Flax (<i>Linum</i> sp.)	2	0.03	1

Legumes

Compared with cereals, legumes constitute a minor component of the assemblage (4.6% of all economic plants). Given their absence from most sites further north, we theorize that they played a smaller role in the overall diet, complementing a grain, meat, and dairy economy, or that their biochemical composition can negatively impact their survival in archaeological deposits (Zong et al., 2017). Legumes (lentils and peas) and cereals spread beyond their natural range as part of the Southwest Asian agricultural package (Fuller, 2006; de Gregorio de Souza et al., 2022; Lev-Yadun et al., 2000) in the seventh millennium BCE. Similarly, in Pakistan's Kech Valley, legumes are first attested two millennia after the earliest record for wheat and barley (Tengberg, 1999). Spengler (2015) suggested that legumes arrived later in northern Central Asia because plant proteins were unnecessary in an economy dependent on dairy and meat. It is also plausible that less intensive farming systems extracted less nitrogen from the soil; hence, a lower presence of legumes in the cultivation system may have led to shifting cultivation and more frequent fallowing. Archaeobotanical evidence indicates that when Central Asian populations began cultivating legumes, they initially grew peas and only later, toward the end of the third millennium BCE, introduced multiple species (see Fig. 9). By the second millennium BCE, data from sites across far southern Central Asia, at Anau South (Miller, 1999), Togolok 1 (Billings et al., 2022), Adjikui 1 (Spengler et al. 2018), Shortugai (Willcox, 1991), Gonur (Castiglione & Cottini, 2002), and Dzarkutan (Miller, 1999), all show that a variety of legumes were widely cultivated.

Masson (1992) proposed that the limited wear on human teeth from Sapalli Culture burials indicates that their diet

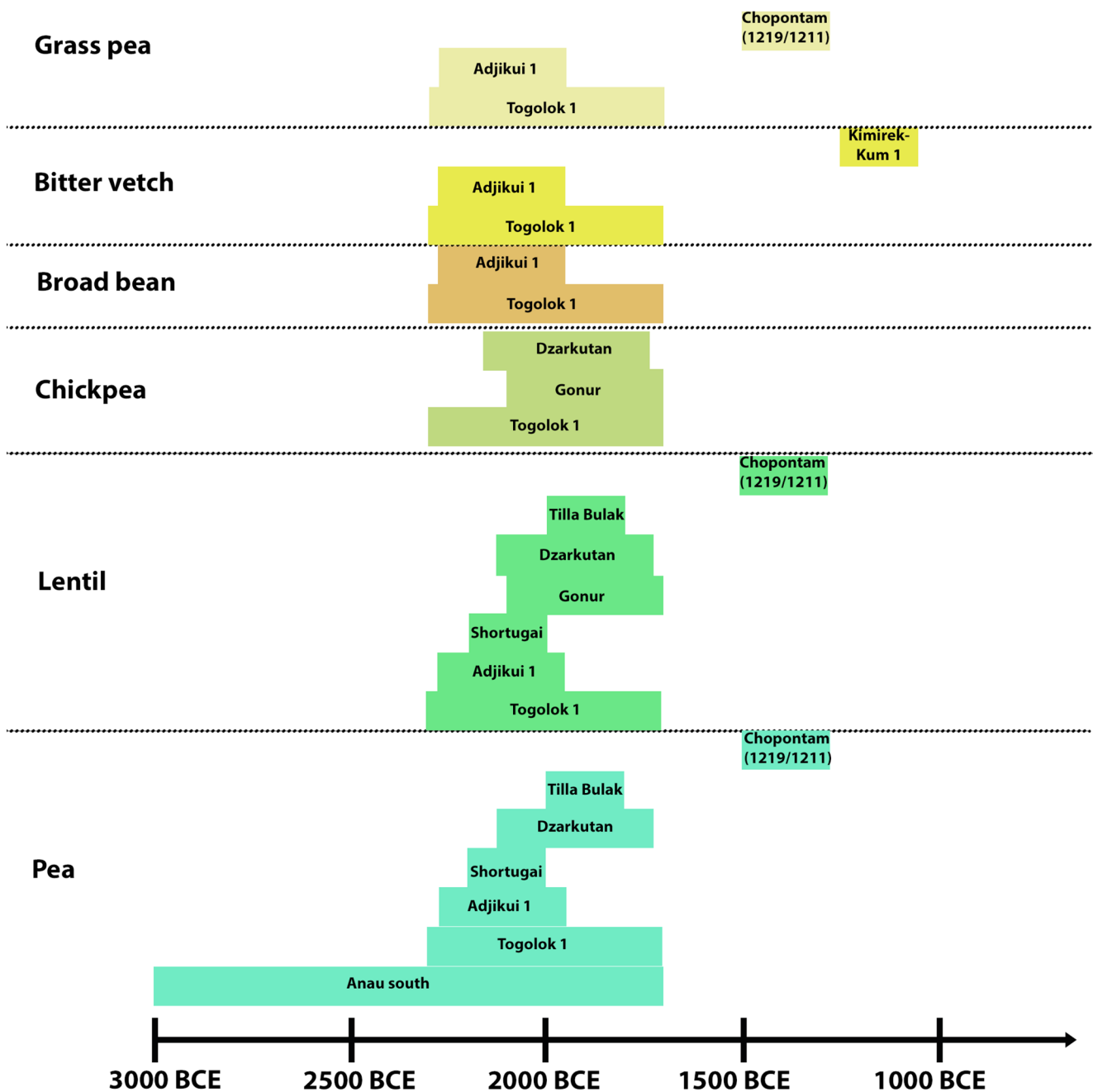


Fig. 9 Legume distribution at Bronze Age sites in southern Central Asia: Anau south and Gonur (Miller, 1999); Togolok 1 (Billings et al., 2022); Adjikui 1 (Spengler et al. 2018); Shortugai (Willcox, 1991);

Dzarkutan (Chen et al., 2024; Moore et al., 1994); Tilla Bulak (current study); and Chopontam, 1219, and 1211 (Spengler et al., 2014)

was largely based on legumes and dairy products. Scholars note sheep offerings in burials, typically the hind legs or shoulders, with some ribs, and claim to have identified porridge preserved in many vessels from the graves (Askarov, 1981; Masson, 1992; Abdullaev & Kaniuth, 2024). The legumes were primarily peas and several lentils, which largely came from the floor of Room 30 (TB-705: KF 625 and KF 633). Peas are less drought-resistant than grass pea

and common vetch; they require over 350 mm of annual precipitation or irrigation for their cultivation (Billings et al., 2022; Tulbek et al., 2017). Spengler et al. (2014) note that, while many of these legumes were historically cultivated as grain crops in large irrigated fields, they can also be grown as garden vegetables. In such cases, they may have been produced by manual watering in small, non-irrigated plots or in fields near the sources of irrigation canals.

Fruit and nuts

Over the past few years, interest in the earliest steps toward arboriculture in Central Asia has focused on the transition to full orchard cultivation. It has been particularly difficult to distinguish between maintaining wild trees and cultivating them for seed and wood. The Tilla Bulak assemblage provides an unclear picture of trees in the economy. For example, wood remains identified as pistachio account for 8% of all analyzed wood samples (Herzig in Kaniuth, 2009); the progenitor of the modern commercial pistachio is the only wild pistachio species native to the region. Given current knowledge of arboriculture in Central Asia, it seems unlikely that this species was under cultivation during the period of occupation (Mir-Makhamad et al., 2022), and the shell fragments likely represent a wild foraged resource. Recently published finds of pistachio shells at Toda Cave in the same region show that people have been collecting these nuts for at least 9,200 years (Zhou et al., 2025), and they are also attested at Dzarkutan (Miller, 1999) and Shortughai (Willcox, 1991). Pistachio remains were recovered from several rooms at Tilla Bulak (1, 27, 30, 47, and 51), with 97% of the pistachio remains concentrated in Room 30, particularly within the floor inventories and tannur.

Miller (1999) identified fruit and nut remains at Bronze Age sites in southern Central Asia and considered them a sign of a significant innovation, suggesting cultivation. The earliest evidence of grapes in Central Asia comes from Monjukli Depe in Turkmenistan, dating to the fifth millennium BCE. (Miller, 2011). Miller (1999) concluded that grape cultivation dates back to the beginning of the second millennium BCE, arguing that their presence at these sites indicates anthropogenic range expansion. In a more recent study at Dzarkutan, scholars have argued that grape pips primarily represent a cultivated form (Chen et al., 2024). It is therefore relevant that at Tilla Bulak, the ubiquity of grapes is (0.71), even higher than that of barley (0.67) (see Table 1). Most of the seeds were retrieved from room fills, floor inventories, and chimneys. Almost 18% of all grape seeds found at Tilla Bulak come from the infill of ditch TB-634.

The earliest known apple seeds in southern Central Asia have been identified at the sites of Togolok 1 (ca. 2100–1900 BCE) (Billings et al., 2022) and Gonur (ca. 2100–1700 BCE) (Miller, 1999) in present-day Turkmenistan. Current evidence suggests that the earliest steps toward apple management occurred in southern Central Asia, as ancient apple seeds are absent from sites in the more northern regions. The Tilla Bulak data further raises the question of when and how early forest and perennial crop management practices first emerged in southern Central Asia.

An increased archaeobotanical signal of fruit-tree crops often indicates cultivation (Stevens et al., 2016). However,

current archaeobotanical evidence does not clearly indicate the systematic cultivation of perennial crops (other than grapes) in Central Asia before the second millennium BCE, and such cultivation likely dates even later. The cultivation of perennial plants would have required a markedly different system of traditional ecological knowledge than that for annual crops. The recovered remains of perennial plants in Central Asia, such as pistachio, Russian olive (*Elaeagnus angustifolia*), almond (*Prunus dulcis*), and apple, are found exclusively within their native ranges prior to the first millennium BCE (Billings et al., 2022; Miller, 1999, 2011; Nishiaki et al., 2022; Spengler & Willcox, 2013; Willcox, 1991). For instance, pistachio likely began expanding westward at least 2,000 years ago, possibly reaching the mountains of modern-day Syria a few centuries earlier, and only began moving eastward at the end of the first millennium CE (Mir-Makhamad et al., 2022). As a dioecious species reliant on wind pollination, pistachio cultivation could not have been achieved simply by planting a handful of seeds. Instead, successful propagation would have required relocating an entire population, comprising both male and female plants, to a suitable ecological setting. Moreover, effective cultivation would have depended on advanced horticultural knowledge, particularly grafting techniques and artificial pollination methods (Mir-Makhamad et al., 2022). A recent geometric morphometric analysis of Russian olive stones from Sapallitepa provided no evidence of domestication during the second millennium BCE (Chen et al., 2025). Similarly, no significant increase in apple seed size was observed at the Tilla Bulak site, suggesting that selection for larger fruit was absent. In the context of the Bronze Age, the presence of pistachio, apple, and *Prunus* species is therefore more plausibly interpreted as indicative of wild resource management or proto-agroforestry practices rather than true orchard-based cultivation (Table 2).

Table 2 Economic plants recovered at the sites in the Surkhandarya region

Site/Species	Tilla Bulak (this study)	Dzarkutan (Chen et al., 2024; Miller, 1999)	Sapal- litepa (Askarov, 1977)
Wheat	+	+	+
Barley	+	+	+
Broomcorn millet	+	+	+
Foxtail millet			
Lentil	+	+	
Pea	+	+	
Chickpea		+	
Pistachio	+	+	
<i>Prunus</i> sp.	+		
Grape	+	+	+
Russian olive		+	+

Household Activities

Waste disposal

Sample variation provides valuable insights into agricultural practices and domestic behaviors. Ditch TB-634 marks the settlement boundary on its northwestern side (see Fig. 10). The ashy infill in the ditch is a secondary deposit that may have accumulated over an extended period. From an archaeobotanical perspective, the fill is dominated by crop-processing debris and economically important plant remains. Notably, this context yielded the highest quantity of grape seeds, along with substantial amounts of barley grains and rachises ($n=1,665$). In addition to evidence of crop processing, the fill also reflects aspects of fuel use and waste management. The presence of carbonized dung pellets from sheep or goats ($n=338$), alongside charcoal, indicates that both animal dung and wood served as fuel sources. Elsewhere, the use of such ditches for the disposal of human excrement has been documented (Prost et al., 2017), which is a possible interpretation in this case, given the absence of artifacts in the ditch. The discard of ashes from household hearths and *tannurs* during cleaning activities would have been beneficial in such a case, using the ash for its disinfectant properties

(Murphy, 2014; Smith, 2013). If the ditch did not serve as a latrine and was instead primarily used for ash disposal, the ash might have been redistributed onto agricultural fields as a natural fertilizer (Hejman et al., 2011).

Beyond Cooking: Rethinking the Role of *Tannurs*

In Room 22, two *tannurs* (TB-271 and TB-226) with diameters of 40 and 55 cm were found adjacent to each other. Both ventilated into the same air duct built into the room's mud-brick wall (see Fig. 10). *Tannur* TB-271 yielded more than 1,600 barley grains and only a single central barley spikelet. Notably, residues typically associated with oven use, such as chaff, charcoal, and wild herbaceous plants, were absent. In contrast, *tannur* TB-226 contained charcoal fragments, a small quantity of cereal grains, several peas, and wild herbaceous plants, all of which are commonly encountered in oven-related contexts. The differences in their contents can be explained by either differential cleaning stages or functional uses. This raises the possibility that TB-271 was repurposed over time, potentially transformed from an oven into a storage space. One intriguing interpretation is that TB-271 may have served to dry or roast cereals (using the heat from the neighboring *tannur*) to reduce moisture

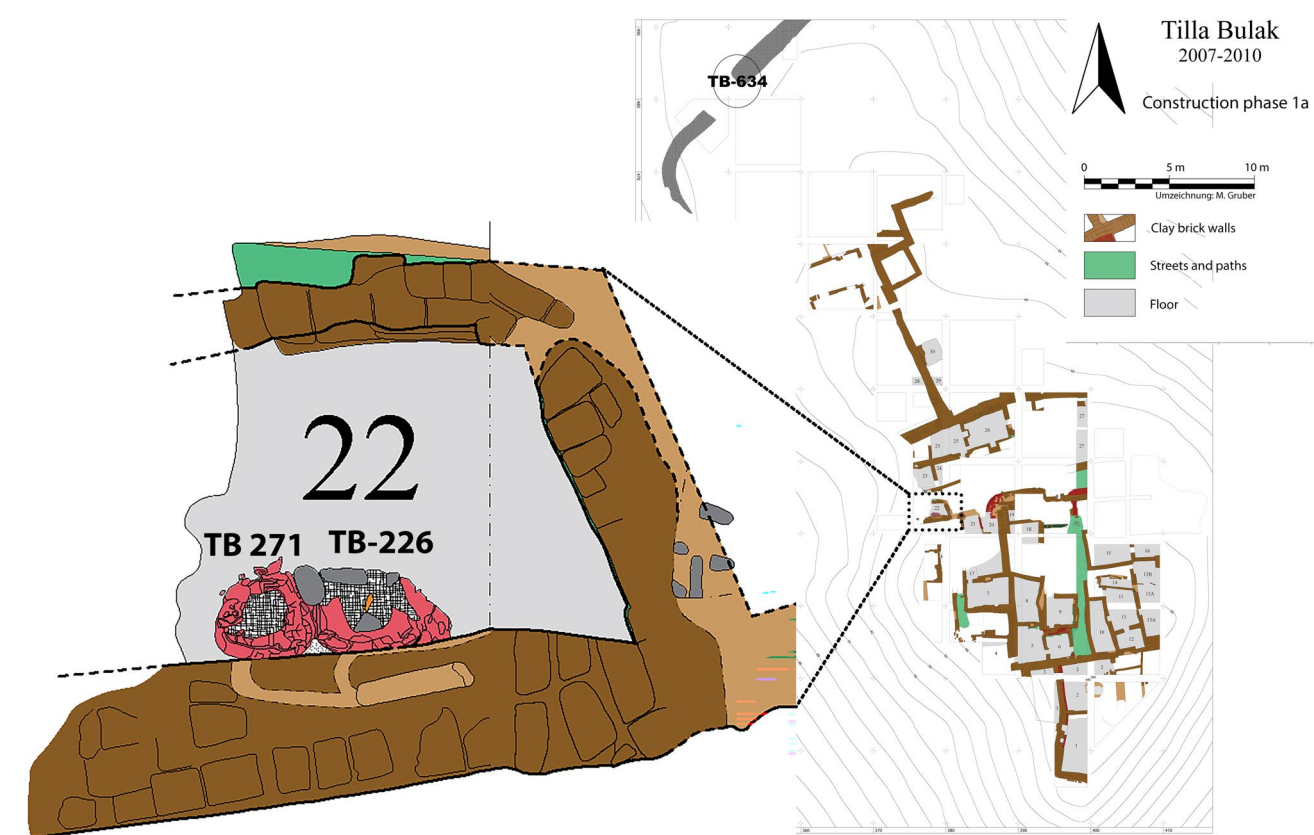


Fig. 10 Plan of room 22 with two *tannurs*. Ditch TB-634 in the northwest of the settlement, shown in dark gray (the map was prepared by M. Gruber)

in harvested grain prior to storage, or perhaps as part of the production of fermented beverages, such as beer or bozo, in which roasting is one of the possible steps for flavor, color development, enzyme deactivation, and sterilization, reducing unwanted microorganisms that could spoil a good drink.

Conclusion

Archaeobotanical evidence from an increasing number of second-millennium BCE sites in Central Asia indicates the prominence of barley and wheat in culinary and cultivation traditions, whereas broomcorn millet and several legumes appear to have been gradually integrated into these systems. Synthesizing data from across the region, our study shows that southern communities (the BMAC core region) cultivated a broader range of crops than northern groups during the early second millennium BCE. While northern communities tended to inhabit small villages or dispersed homesteads, populations in the southern regions, particularly in the Murghab and surrounding areas, resided in more complex proto-urban centers, often interpreted as early polities or city-states. Despite sharing cultural characteristics with southern BMAC urban centers, the Surkhandarya Valley and parts of southwestern Central Asia appear to have had agricultural systems that were less intensive than those of people further south but more complex than those maintained further north. We base this conclusion on (1) a greater presence of wild foraged fruits and nuts in the archaeobotanical repertoire; (2) barley dominance over wheat, whereas wheat is historically preferred as a bread-baking crop when irrigation is sufficient; (3) greater cultivation of the drought-tolerant broomcorn millet; and (4) lower legume diversity and abundance, which are far more water-demanding than grains. The available archaeobotanical data from the region suggest that fruits, such as pistachios, apples, plums, and almonds, were primarily gathered from wild trees, reflecting early forest management or proto-agroforestry rather than systematic orchard cultivation. While grapes may have been under early cultivation, most perennial crops remained within their native ranges and show no clear signs of domestication. Nonetheless, evidence for grape cultivation, grain-processing tools, and animal husbandry points to a complex, integrated agropastoral economy that supported settled communities participating in broader regional exchange networks during the second millennium BCE.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Clinical trial number Not applicable.

Competing interests The authors declare no competing interests.

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