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Dietary reconstruction of domestic mammals in the Keriya Valley (Xinjiang, China) during the Bronze and Iron Ages using stable isotope analysis of animal hair

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ABSTRACT

Textiles can provide a wealth of information about the practices of ancient cultures. Here we present the carbon and nitrogen stable isotope analyses of a large corpus of well-preserved animal fibres from two Bronze and Iron Age sites in the Keriya Valley (Xinjiang, NW China), an area which lies at the crossroads of exchange and circulation of goods, practices and culture in Eurasia. Our aim is to reconstruct the diets of domesticated herbivores (goat, sheep, cattle, camel) found at these sites in order to shed light on pastoral practices. Caprines and cattle relied heavily on C_3 plants with a $\delta^{13}C$ mean ratio of -19.8 ± 1.5 ‰ and -20.3 ± 1.8 ‰ respectively, in accordance with other studies in Xinjiang. Occasional consumption of C_4 plants is also observed in caprines. These variations may be due to herd mobility and/or seasonal availability of local vegetation or textile trade. Two Iron Age individuals (a camel and a bovid) show a high C_4 plants intake. This diet is highly unusual in this context and specific herding practices with millet feeding could be considered.

1. Introduction

Located in the heart of Eurasia, Xinjiang serves as a bridge between Central Asia, Upper Asia, China, and India (Fig. 1). This strategic location, considered the centre of the prehistoric Silk Road, has been a hub of trade, exchange, and cultural development (Hu, 2018; The Cultures of Ancient Xinjiang, Western China: Crossroads of the Silk Roads, 2019; Binhua and Liu, 2022). The Xinjiang region is bisected by the Tianshan Mountains, with the Junggar Basin in the north currently exhibiting a temperate arid climate, and the Tarim and Turfan Basins in the east and south displaying a warm temperate arid climate with a precipitation level five times lower than the global average. Most of the Tarim Basin is covered by the Taklamakan Desert, the driest region in the world. The eastern part of Xinjiang is connected to the rest of China by the Hexi Corridor, while the northern (Altai) and southern (Kunlun) sides are surrounded by mountains (Fig. 1) (Li, 2024). Crop cultivation appeared in Xinjiang around 3000 BCE, perhaps under the influence of western Central Asia with the introduction of barley and wheat, as a number of researchers have hypothesised (Betts et al., 2014; Li, 2020). Millet would have been introduced later from the Hexi corridor, before being spread through Xinjiang by different routes, probably around 2000 BCE for *Panicum* and 1500 BCE for *Setaria,* but a probable bias in the evidence must be taken into account in this regard (The Cultures of Ancient Xinjiang, Western China: Crossroads of the Silk Roads, 2019; Betts et al., 2014; Tian et al., 2023). This cereal is drought resistant and has a short growing season, making it perfect for the harsh environment of Xinjiang. Along with crop cultivation, herding developed in the region in prehistoric times. The domesticated animals commonly found in Xinjiang during this long period are mostly caprines, cattle and horses, although they may not have been homogeneous across time and area. They were

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bred for transport, food (meat, milk), textiles or work. The agropastoral economy adapted to the environment, with the development of the agricultural system from the middle of the 2nd millennium BC and the increase in the consumption of millet from 1300 BCE, leading to a mixed diet of the population according to Li Yuqi, but most probably at an even earlier date (Li, 2020). During the Bronze and Iron Ages, many settlements were found, distributed in different cultural clusters throughout the territory (Betts et al., 2019; Tan et al., 2022). The agropastoral economy of these populations has been studied in some of the archaeological sites, through the analysis of bones (Debaine-Francfort and Idriss, 2001; Pechenkina et al., 2005; Atahan et al., 2011; Hou et al., 2013; Qu et al., 2018; Wang et al., 2018) and food remains (Xie et al., 2016; Yang et al., 2014; Yang et al., 2014). Although different cultural groups developed in Xinjiang depending on the geographical location, many links between these groups can be found through the study of the pottery patterns (Li, 2024).

Many prehistoric sites have been discovered in Xinjiang, including settlements and numerous cemeteries. In the southern part of Xinjiang, oasis cultures are observed within the Lop Nur and Taklamakan deserts. Despite the arid climate, the oases support arable agriculture and a mixed vegetation of grasses and shrubs (*Typha, Chenopodiaceae, Artemisia, Ephedra, Eragrostis, Phragmites* and Gramineae) and trees (*Tamarix, Populus, Morus*) (Li, 2020; Debaine-Francfort et al., 2010; Li et al., 2013; Qiu et al., 2014). In particular, the Xiaohe sites (several cemeteries and a watchtower; 1980–1450 BCE) provide the oldest direct evidence in Xinjiang for the cultivation of wheat, millet, and barley. The Xiaohe people herded caprines and cattle. In addition to the functional use of cattle, they also played a strong symbolic role in this culture (Mai et al., 2016). The large number of excavated tombs (167 in total) allowed the characterisation of a specific culture that developed strongly during the Bronze Age before hypothetically declining due to climate change (Li, 2024). The Xiaohe (or Kongquehe) culture spanned a vast region in southern Xinjiang, situated between the Tianshan and Kunlun mountains. It encompassed the Xiaohe site along the Tarim River, the entirety of the Tarim Basin, and the Keriya Valley (Fig. 1). Two sites were discovered in the ancient delta of the Keriya Valley, 600 km southwest of Xiaohe: the Northern Cemetery and Djoumboulak Koum (Figs. 1 and 2). The Northern Cemetery has about 50 preserved graves (20 undisturbed) associated with remains of contemporary occupation dating to the Bronze Age (c. 1950 – c. 1400 BCE). On the other hand, the Djoumboulak Koum site, also called Yuansha Gucheng, is an Iron Age (mid-1st millennium BC) fortified site with cemeteries and settlements

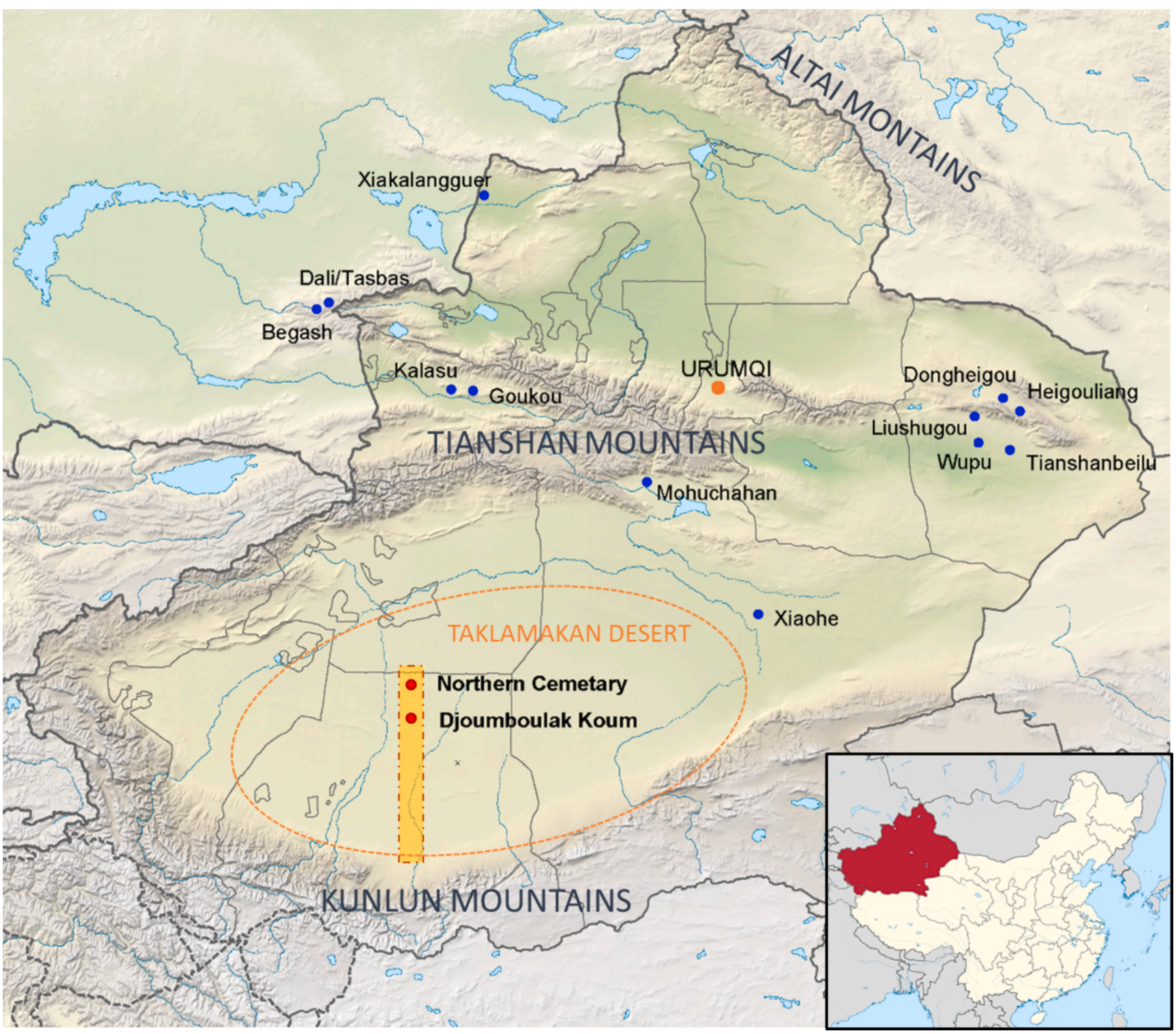

Fig. 1. Map of Xinjiang, China, and locations of the various Bronze and Iron Age archaeological sites where isotopic analyses (C, N) of animal remains were performed (Table S2). Yellow zone: Ancient Keriya Valley.

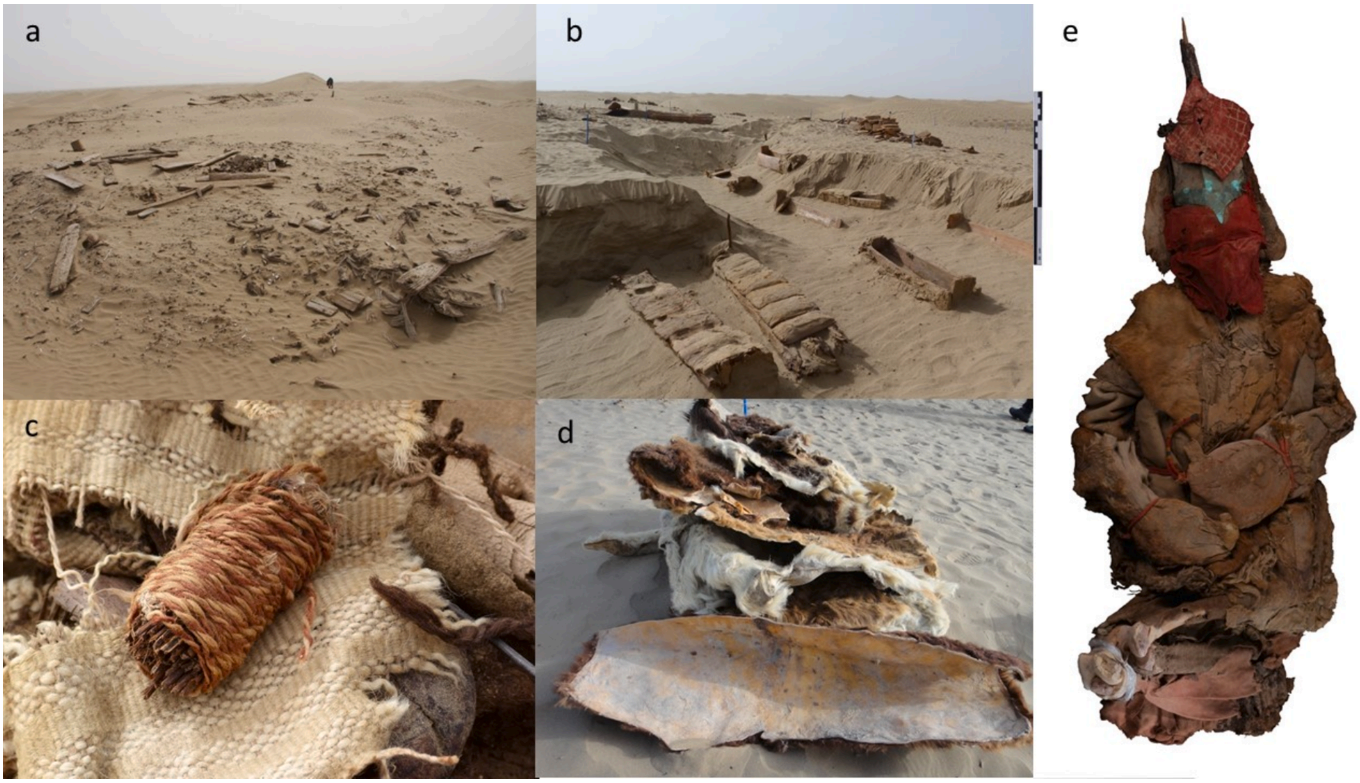

Fig. 2. The Northern Cemetery site before (a) and after excavation (b), textiles and threads from the Northern Cemetery (c), hides that covered the coffins in the Northern Cemetery (d), mummy from the burial MD17 in Djoumboulak Koum (e).

that relied on a network of irrigation canals to ensure the cultivation of millet, wheat, and barley (Debaine-Francfort and Idriss, 2001; Debaine-Francfort et al., 2010). The association of the Northern Cemetery with the Xiaohe culture is based on the numerous similarities in the burial practices: wooden coffins covered with freshly cut hides, sometimes with wooden poles placed near the graves (oblong and red, interpreted as phallic symbols for female's graves, and paddle-shaped and black, interpreted as female symbols for male's graves), small bags containing twigs or seeds, specific objects depending on the sex, wool necklaces and bracelets, large rectangular cloaks/blankets, similar skirts, etc (Debaine-Francfort, 2013; Cardon et al., 2013). However, the presence of beads (etched carnelian), textiles (cotton, flax) and dyes from India, China and even the eastern Mediterranean also attest to links with the rest of the world; inspiration from steppe culture can also be seen in textiles and woodwork (Debaine-Francfort and Idriss, 2001). The arid environment allows for excellent preservation of archaeological remains, including fibres: clothing, ropes, fleeces, bags and other animal fibre products were found during excavations in the Keriya Valley (Debaine-Francfort and Idriss, 2001; Debaine-Francfort, 2013; Cardon et al., 2013; Good, 1998; Zhang et al., 2008; Desrosiers and Debaine-Francfort, 2016) (Fig. 2).

The large corpus of textiles and skins recovered from these sites, together with spinning and weaving materials, highlighted the presence of an important local textile industry. Textiles of similar craftsmanship were found in both funerary and domestic contexts. In burial MD17 (an old female mummy – Fig. 2e), scraps of fabric and a spindle with its whorl and thread were recovered in a small bucket. In the domestic context, scraps of fabric and felt, balls of wool and parts of wooden tools used for spinning and weaving were also found. The weaving and dyeing techniques were complex and the raw materials varied, demonstrating a high level of craftsmanship (Debaine-Francfort and Idriss, 2001; Cardon et al., 2013). This type of industry has also been observed at many Bronze Age sites in Xinjiang, such as Yanghai, Gumogou, Chärchän, Hami or Zaghunlug (Li, 2024; Good, 1998; Beck et al., 2014). A preceding proteomic study identified the animal origin of the fibres and demonstrated that the selection of fibres is predominantly associated with the function of the textile (Azémard et al., 2019). Archaeological analysis revealed a high degree of homogeneity in the fibres used in the different burials, with the observed differences between men and women appearing mostly in the patterns or layout. The rearing of livestock and the associated diet are typically investigated through the analysis of bone and dental remains recovered from archaeological sites. In some cases, the presence of certain fibres can also assist in inferring the intended production purpose, which may pertain to meat, milk, wool, or a combination thereof. The Northern Cemetery yielded no evidence in the form of animal bones or teeth. The lack of available material precludes the possibility of deducing information about the diet or breeding practices of the deceased based on this particular source. In contrast, the DK settlement has yielded a considerable quantity of bones (Azémard et al., 2019; Lepetz, 2001). However, the majority of these finds were recovered from contexts that lacked sufficient definition or precision in their dating. For this reason, fibres and textiles provide invaluable information for these two sites, as they were found in abundance and in chronologically well-set contexts. However, it should be noted that only species providing hair for handicrafts are represented here, which represents a significant limitation. Nevertheless, these materials offer a primary source of knowledge about the raw materials used, textile know-how and cult practices, as some of the fibres studied come from garments found in funerary contexts (Azémard et al., 2019; Good, 2001; Hardy, 2007).

Stable isotope analysis of carbon in the bones, hooves or hair of herbivores is linked to their dietary intake of plants and thus can give insight into their husbandry practices. The incorporation of ^{13}C varies according to the photosynthetic mechanism of the plant. Most plants can be divided into two groups: C_3 plants, which follow the Calvin-Benson cycle, such as rice, wheat, barley and most temperate plants, grasses and shrubs; and C_4 plants, which follow the Hatch-Slack cycle, such as sugar cane, maize, millet and some tropical plants. A carbon isotope value between −36 ‰ and −20 ‰ is representative of a C_3 plant diet, while a $\delta^{13}C$ between −16 ‰ and −9‰ is found for a C_4 plant diet (Lee-Thorp, 2008; Zazzo et al., 2015; Makarewicz and Sealy, 2015; Schwertl et al., 2005). The $\delta^{15}N$ gives information about the trophic level. The nitrogen isotope ratio of the animal ($^{15}N/^{14}N$) is linked to that of the plant, which is derived from the soil composition. The enrichment between each step in the food chain is estimated to be between 2 and 4 ‰ (Schwertl et al., 2005; McCullagh et al., 2005; Knudson et al., 2015; White et al., 2009; Sponheimer et al., 2003), but can be more than 5 ‰ according to recent studies (Wittmer et al., 2010). Its high variability is due to the influence of various parameters: season, type of plant, age of the animal, protein intake, and so on (Schwertl et al., 2005; Sponheimer et al., 2003). In addition, $\delta^{15}N$ can vary with the use of fertilisers, temperature, leaching or salinity (Lee-Thorp, 2008). Other stable isotopes such as strontium, hydrogen or oxygen are sometimes used to provide more information (Lee-Thorp, 2008; von Holstein et al., 2013; Frei et al., 2009; Dufour et al., 2014; Balasse et al., 2002). There is a slight difference between collagen and keratin enrichment due to different amino acid compositions and the fact that bones can record a longer period of time, whereas hair usually records the last few months (as it grows about 1 cm/month). Collagen has a $\delta^{13}C$ enrichment of 2.0–2.7 ‰ over keratin, while $\delta^{15}N$ is similar (von Holstein et al., 2013) and this must be taken into account when comparing different studies. In China, faunal samples of caprines, cattle, and horses generally show a C_3 plant diet with sometimes low C_4 plant intakes (Pechenkina et al., 2005; Hou et al., 2013; Qu et al., 2018; Wang et al., 2018; Wang et al., 2019; Eng et al., 2009; Wang et al., 2016; Zhao et al., 2020; Dong et al., 2022; Wang et al., 2020). However, high C_4 plant intakes have also been found at a few sites, suggesting that millet was fed to pigs and dogs (Pechenkina et al., 2005; Lanehart et al., 2011; Ma et al., 2015) or sometimes to cattle (Hou et al., 2013; Chen et al., 2016; Hu et al., 2008). In Xinjiang, isotopic analyses of livestock from ten archaeological sites show a C_3-based diet with $\delta^{13}C$ below −17 ‰ and $\delta^{15}N$ usually above 7 ‰, due to aridity of the region (Qu et al., 2018; Wang et al., 2018; Wang et al., 2019; Eng et al., 2009; Wang et al., 2016; Zhao et al., 2020; Dong et al., 2022; Wang et al., 2020; Dong et al., 2021). Although it has been shown that millet has been widely cultivated since the Bronze Age, it seems that herbivores were not provided with this type of fodder. The C_4 intake could have come from wild plants growing on the site (Qu et al., 2018). A study carried out at the Xiaohe site showed that there is no strong evidence that millet was used as a staple food; instead, it may have been used for ritual practices (von Holstein et al., 2013). However, these studies are not representative of the whole of Xinjiang. In fact, no isotopic data have ever been published on the fauna of the south-western part of Xinjiang, which is covered by the Taklamakan Desert.

In this paper, we carried out stable isotope analysis on a large corpus of animal fibres (textiles and skins) from the Northern Cemetery and Djoumboulak Koum in Xinjiang in order to reconstruct dietary behaviours of domestic animals in the Keriya Valley during the Bronze and Iron Ages. A comparison of the diets of domesticated herbivores (goats, sheep, cattle, camels) found at these sites should help to reflect on herding practices and environmental adaptation. During this time period, arable agriculture and human diet underwent significant changes, with the inclusion of more millet, between Bronze and Iron Age sites. This study also addresses the question of the use of millet foddering along with these cultural developments. Finally, comparison of our data with published isotopic data from other sites in Xinjiang will help us to understand the differences in feeding strategies associated with different cultural groups, such as the Xiaohe culture, and more generally in Xinjiang, in order to integrate our results into the diachronic study of this region.

2. Material & methods

2.1. Samples

The Northern Cemetery and Djoumboulak Koum archaeological sites were discovered by the Sino-French archaeological mission in Xinjiang, in the protohistoric delta of the Keriya River in the Taklamakan Desert (see topographical maps of the two sites in Figures S1, S2 and S3). The Northern Cemetery dates from approximately 1950 to 1400 BCE. It is very similar to the cemetery of Xiaohe but was looted and is not as well preserved (Qu et al., 2018; Debaine-Francfort, 2013; Cardon et al., 2013; Mair, 2014; Debaine-Francfort, 2021). Djoumboulak Koum is a large Iron Age settlement (mid-1st millennium BCE) enclosed by walls. Both sites were more comprehensively described in our previous publication (Azémard et al., 2019). A corpus of 113 samples (5 from plants and 108 from fibres) from these two sites was studied (Table S1), including ninety-two fibre samples from the Northern Cemetery and sixteen from Djoumboulak Koum. Samples (Table S1) are from objects selected at the Xinjiang Institute of Archaeology and Heritage in 2014. Selection was based on the availability of the objects and permission to sample them. The most complete bodies were generally not accessible. In the Northern Cemetery, the graves were largely destroyed (Figures S4 and S5) and only three of the best preserved could be sampled for this study (6 samples for graves M2, M3 and M12, Figures S6 and S7). The majority of the finds were surface collections, scattered objects, most of which could not be attributed to specific individuals. Samples from the Djoumboulak koum site include three poorly preserved tombs (MB1, MB3 and MB5, Figure S8) from one of the cemeteries (MB) and a settlement in which textile fragments were found (dwelling F4, Figure S9).

Species identification was carried out by proteomics, as described previously (Azémard et al., 2019). It was not always possible to distinguish between goat and sheep; therefore, they are sometimes grouped together under the "caprine indeterminate" category. Some hides provided long hairs (between 7 and 13 cm) which were cut every 1 cm for sequential analysis; five come from the Northern Cemetery (P216, P225, P230, P257, and P261) and one from Djoumboulak Koum (P419). In such cases, mean values are given in Table S1 for comparison with the other samples. The domestication of camels in this context is not well understood (Olsen, 1988); hence, there is a possibility that the sample of camel fibre comes from a wild or tamed but not domesticated animal. Additionally, five plant remains from the Northern Cemetery were collected to be used as reference material for the isotope study.

2.2. Sample preparation

First, the samples are washed with Milli-Q water and 2 % DECON® under stirring until clear. Then, washing is carried out 2 times for 15 min in a $MeOH/CHCl_3$ solution (1:2) under stirring and for 15 min in Milli-Q water under sonication. During this protocol, textiles tend to disintegrate, unlike hides, which are unprocessed hairs.

2.3. Isotope analysis

Between 280 and 370 μg of sample were encapsulated in a tin capsule. The plant samples were previously ground with a mixer mill. Analyses were carried out with a Thermo Scientific EA Flash 2000 coupled to a Delta V Advantage mass spectrometer, enabling the measurement of $\delta^{13}C$ and $\delta^{15}N$. Alanine was used as a standard, with seven samples run before the analyses, plus two every twelve fibre samples. The isotope values are reported relative to the VPDB for $\delta^{13}C$ values and AIR for $\delta^{15}N$ values. The standard deviation (1σ) is ± 0.10 ‰ for $\delta^{15}N$ and 0.16 ‰ for $\delta^{13}C$. We considered that the carbon enrichment is about 3 ‰; therefore, $\delta^{13}C$ values between −17.0 and –32.0 ‰ are considered indicative of a C_3 plant diet, and $\delta^{13}C$ values between −6.0 and −13.0 ‰ are indicative of a C_4 plant diet. The C:N ratio was checked for all samples and is reported in Table S1. Carbon and nitrogen isotopic analyses of bone or enamel samples from various archaeological sites in Xinjiang dating from the Bronze and Iron Ages are found in the literature. To compare with our results on keratin, we added 2.35 ‰ to the fibre samples' $\delta^{13}C$ based on Holstein *et al.* (2013) study (von Holstein et al., 2013). These corrected values are found in Table S2 and Fig. 7.

2.4. Data treatment

ANOVA and Wilcoxon test were carried out by R 3.4.4. software, the statistical significance level was set to $p < 0.05$.

3. Results

3.1. Plants

We measured the $\delta^{13}C$ values of seeds and twigs found in the Northern Cemetery for comparison with herbivore results (Table 1). The $\delta^{13}C$ value of Tamaris is the lowest (−25.8 ‰) and close to barley (–23.2 and −24.2 ‰) and reed (–22.8 ‰). These three species are C_3 plants, and the observed values are within the usual ranges. The $\delta^{13}C$ value of millet seeds is the highest (−12.1 ‰), as expected for a C_4 plant. Unfortunately, the nitrogen concentration was too low to obtain usable results from the seeds and twigs.

3.2. Fibres

Stable isotope analysis results are summarized in Table 1 (full description in Table S1). Taxonomic attributions are based on proteomics results published by Azémard *et al.* (Azémard et al., 2019). We observed a C:N ratio between 3.4 and 4.5. A total of 197 samples were within the 3.4–3.8 limits described in the literature (von Holstein and Makarewicz, 2016; Boudin et al., 2016) and 11 were above. Boudin et al. suggested that values above 3.8 can indicate dye, mordant, or contamination (Boudin et al., 2016). Some of these samples are clearly dyed (photos previously published (Azémard et al., 2019), though it is not clear for others. To avoid contaminated samples, those with a C:N ratio > 3.8 were excluded from further data analysis.

Most of the $\delta^{13}C$ values range between −18.0 ‰ and –22.0 ‰ (Table S1, Fig. 4a) with a mean value of −19.8 ± 1.5 ‰ for caprine (n = 84) and −20.4 ± 1.8 ‰ for cattle (n = 9). Only a few samples show higher ratios, up to −13.3 ‰. Nitrogen isotope ratios range from 5.0 to 12.5 ‰, with a mean value of 8.0 ± 1.2 ‰ for caprine and 10.1 ± 1.4 ‰ for cattle. When comparing Djoumboulak Koum and the Northern Cemetery (Table 1, Fig. 4d), it appears that the sheep and goats have similar $\delta^{13}C$, with mean values of −19.6 ± 0.9 ‰ (n = 11) and −19.7 ± 1.6 ‰ (n = 73). The Wilcoxon test indicates that the two sites are not significantly different (p = 0.131). The box plot of sheep for the two sites also show a good similarity (ANOVA test: p = 0.734) (Figure S10). In contrast to the Northern Cemetery, in Djoumboulak Koum the goats have a higher $\delta^{13}C$ value than the sheep (Fig. 4b). However, with only two samples from Djoumboulak Koum examined here, no firm conclusion should be drawn. However, the goats in Djoumboulak Koum may have had a slightly different diet due to the environment. The $\delta^{15}N$ values are generally higher than 7.0 ‰, with a range varying between 5.0 ‰ and 12.5 ‰ (Fig. 3, Table 1). This high ratio can be explained by the aridity of the Taklamakan desert (Hu, 2018) and is consistent with the wide range of $\delta^{15}N$ reported for other Bronze Age sites in China (Atahan et al., 2011; Qu et al., 2018; Eng et al., 2009). The mean caprines $\delta^{15}N$ of both sites is not statistically significant (p = 0.073). Regarding cattle, in the Northern Cemetery, the $\delta^{13}C$ value is lower than that of caprines with a mean value of 21.0 ± 0.5 ‰ and values ranging from −21.5 ‰ to −20.1 ‰ (n = 8). On the other hand, the single cattle from Djoumboulak Koum shows a much higher $\delta^{13}C$ value of −15.5 ‰, while the $\delta^{15}N$ values are similar at both sites (10.1 ‰ and 10.0 ‰ respectively). The camel sample also shows a high $\delta^{13}C$ value of −15.4 ‰, indicating C_4 plant uptake.

Although the difference is not statistically significant (p = 0.132), the distribution variability of cattle and goats $\delta^{13}C$ is lower than that of sheep (Fig. 4a). The $\delta^{13}C$ values for caprine hides are slightly lower than those for textiles (Fig. 4b). This tendency is consistent with the fact that goats have a slightly lower $\delta^{13}C$ value median than sheep (Fig. 4a) and that in textiles there is 1 goat for 38 sheep samples, whereas in hides there are 14 goats for 12 sheep samples. Indeed, comparing sheep fibres in hides and textiles, we observe very similar box plots and medians (Fig. 4c), the distribution seems relatively coherent between both categories. The mean values are also very close with −20.0 ± 1.1 ‰ for textiles (n = 38) and −19.1 ± 2.4 ‰ for hides (n = 12). Therefore, the difference in the $\delta^{13}C$ value between hides and textiles is most likely due to the higher percentage of goats in the hides category. The same phenomenon is observed for the $\delta^{15}N$ values (Fig. 5).

Six samples of animal locks were sampled sequentially (5 from the Northern Cemetery, 1 from Djoumboulak Koum). It is difficult to estimate the hair growth rate as it depends on the species, the time after shearing (generally 1 to 2 cm/month) and environmental factors. Therefore, the results are presented according to the distance from the hair root (Fig. 6). Our samples are 7 to 13 cm long and most of them have been identified as goat hair. The $\delta^{13}C$ varies between −18.0 and −21.8 ‰, indicating a C_3-based diet in agreement with the results obtained on bulk fibres. The range varies from 1 ‰ (P225, P230 and P419) to almost 3 ‰ (P257). Low $\delta^{15}N$ variability (around 1 ‰ or less) was observed for

Table 1
Summary of seeds and twigs $\delta^{13}C$ values and fibre keratin carbon and nitrogen isotope results for samples from the Northern Cemetery (NC) and Djoumboulak Koum (DK) study sites. Archaeobotanical identification by C. Newton (Debaine-Francfort and Idriss, 2001; Debaine-Francfort et al., 2010).

Period	Site	Identification		number	$\delta^{13}C$(‰)				$\delta^{15}N$(‰)			
					Mean	SD	Min	Max	Mean	SD	Min	Max
Bronze Age	NC	Plant	Millet	1	−12,1							
			Tamaris	1	−25.8							
			Barley	2	–23,7	0,5						
			Reed	1	–22,8							
		Caprine	All	73	−19.8	1.6			8.0	1.3		
			Sheep	50	−19.7	1.6	−21.6	−13.3	8.1	1.2	5.0	10.8
			Goat	15	−20.1	1.9	−21.6	−13.6	7.4	1.2	5.8	9.7
			Undetermined	8	−19.7	0.7	−20.9	−18.1	7.8	1.4	5.1	10.2
		Cattle		8	−21.0	0.5	−21.5	−20.1	10.0	1.5	8.0	12.5
		?		2	−17.2	1.4			12.1			
Iron Age	DK	Caprine	All	11	−19.6	0.9			8.7	1.0		
			Sheep	8	−19.9	0.6	−20.6	−19.1	8.5	1.0	7.2	11.0
			Goat	2	−18.1	0.3	−18.4	−17.8	9.1	0.6	8.5	9.7
			Undetermined	1	−19.8				8.8			
		Cattle		1	−15.5				10.2			
		Camel		1	−15.4				9.0			

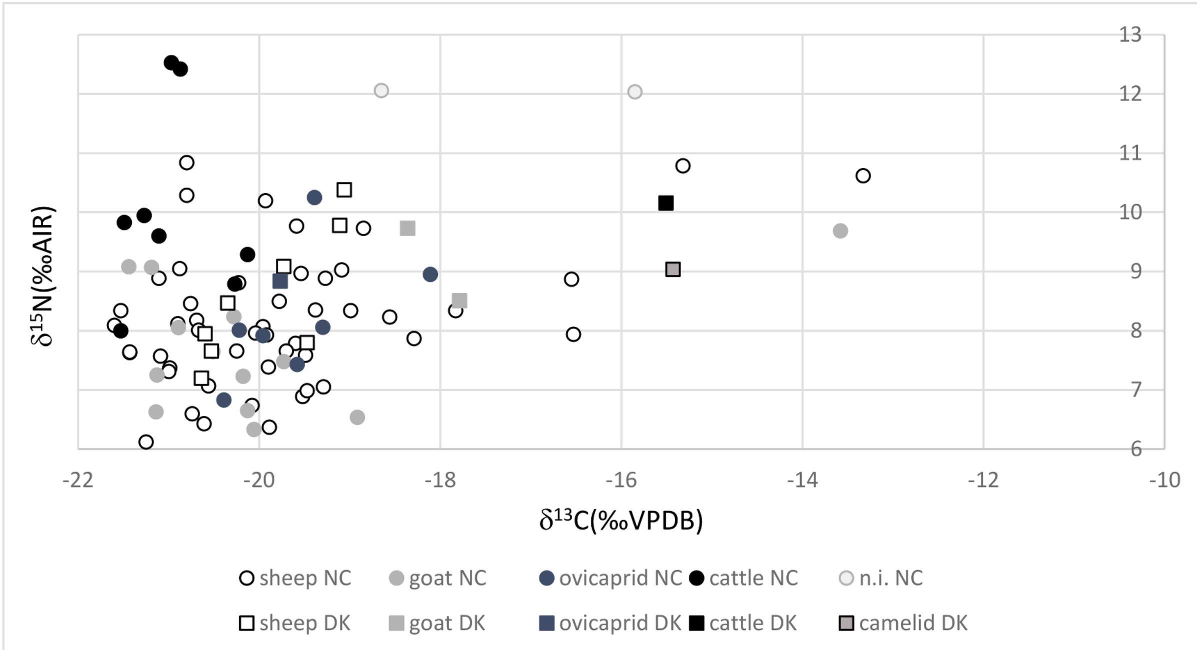

Fig. 3. Comparison of isotope ratios according to animal species and archaeological site (o: NC, □: DK).

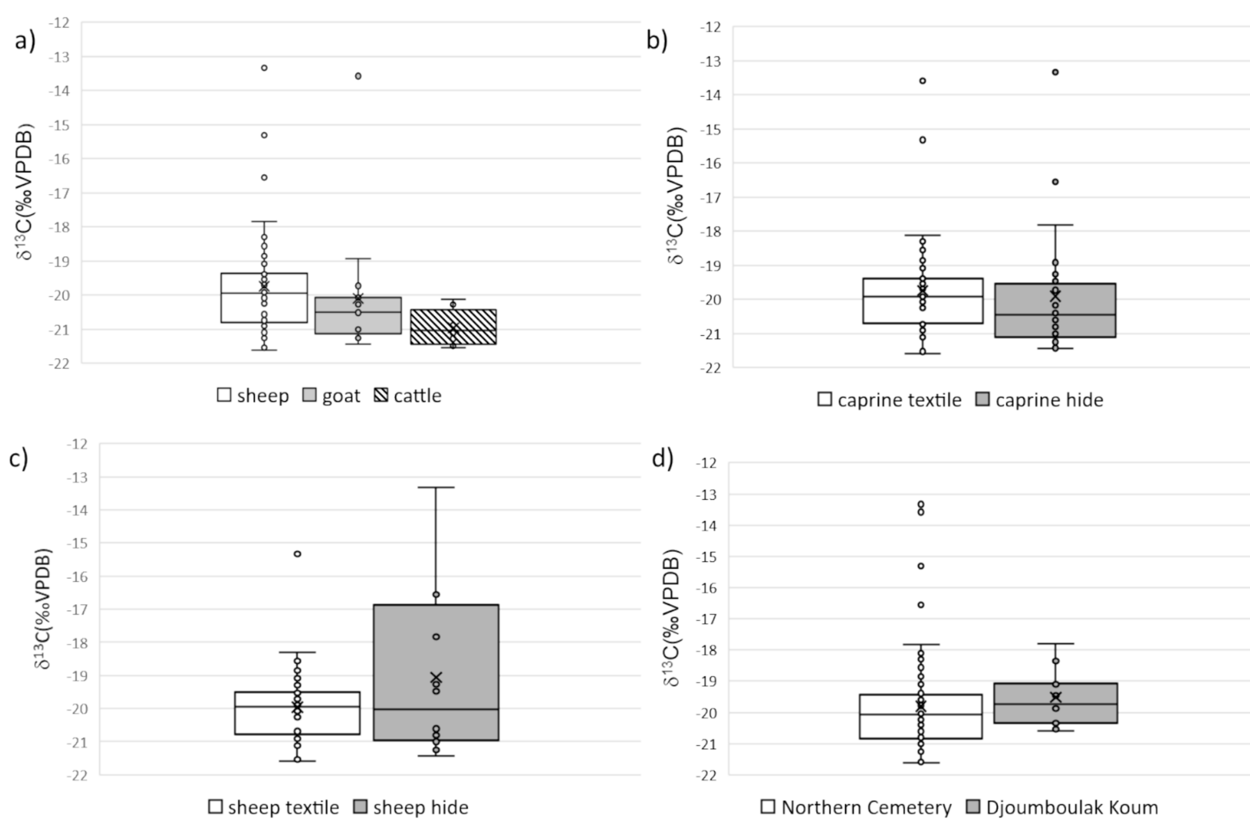

Fig. 4. Box plot of $\delta^{13}C$ repartition in the Northern Cemetery a) for the different species, b) for caprines textiles and hides, c) for sheep textiles and hides, and d) comparison of caprines $\delta^{13}C$ in Northern Cemetery and Djoumboulak Koum.

three samples (P257, P261 and P419). One sample (P216) showed an increase of 3.5 ‰ just before death, while P225 and P230 show a rapid decrease and increase 6–12 months before death.

4. Discussion

4.1. Herding practices in the Keriya valley

Before discussing pastoral practices in the Keriya Valley, the question of possible trade in textiles and hides must be addressed. Textile

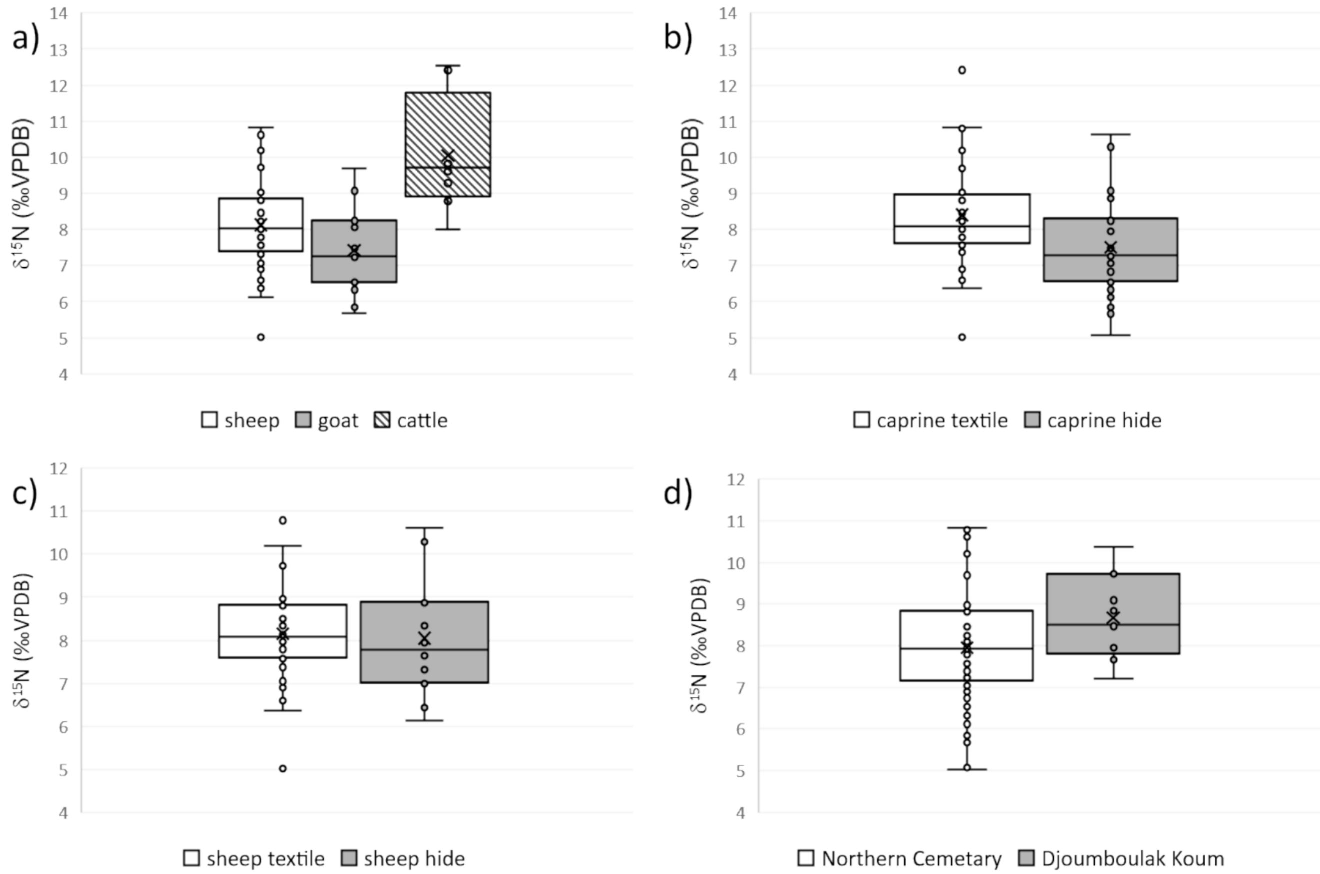

Fig. 5. Box plot of $\delta^{15}N$ repartition in the Northern Cemetery a) for the different species, b) for caprines textiles and hides, c) for sheep textiles and hides, and d) comparison of caprines $\delta^{15}N$ in the Northern Cemetery and Djoumboulak Koum.

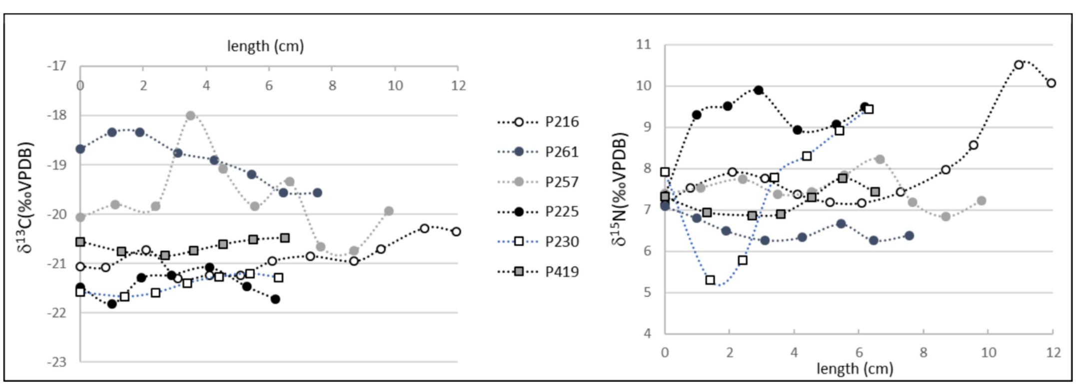

Fig. 6. $\delta^{15}N$ and $\delta^{13}C$ sequential analysis of animal fibres from the Northern Cemetery except P419 (Djoumboulak Koum). Length is given from tip to base (death of the animal). Sheep: □, goat: o.

production is attested in the Keriya Valley by the presence of sewing, weaving and spinning tools, suggesting that wool and textile production was developed in this region. However, trade cannot be completely ruled out. In fact, textile trade with the south (Keriya Delta) and the north (along the Tarim River or in Tianshan) was possible, and trade in other materials such as ceramics has been demonstrated (monograph in preparation). However, only a few textiles seem to be of foreign origin: there is some cotton, probably threads imported from India, and textiles dyed with a specific non-vegetable dye (cochineal) (Debaine-Francfort and Idriss, 2001). The hypothesis of trade was also put forward for certain furs (fox, wild cat) and decorative elements embroidered on garments similar to those found elsewhere in Xinjiang. However, none of these textiles were included in our study. It should also be noted that the hides used to cover the coffins were freshly cut, which means that they came from local animals. It is highly likely that most of our corpus is of local production, but the possibility of an alternative origin is considered.

4.1.1. *Caprines*

The $\delta^{13}C$ values of the caprines at both sites are consistent with a diet dominated by C_3 plants with a low C_4 intake. Five individuals are above −17.0 ‰ and are representative of a mixed C_3/C_4 diet (Fig. 3). It is not possible to determine the precise origin of this C_4 intake from stable isotope evidence alone. Although textile production took place in the Keriya valley, O or S isotope analysis could give us more insight into the origin of the samples to check if some of them could be imported goods.

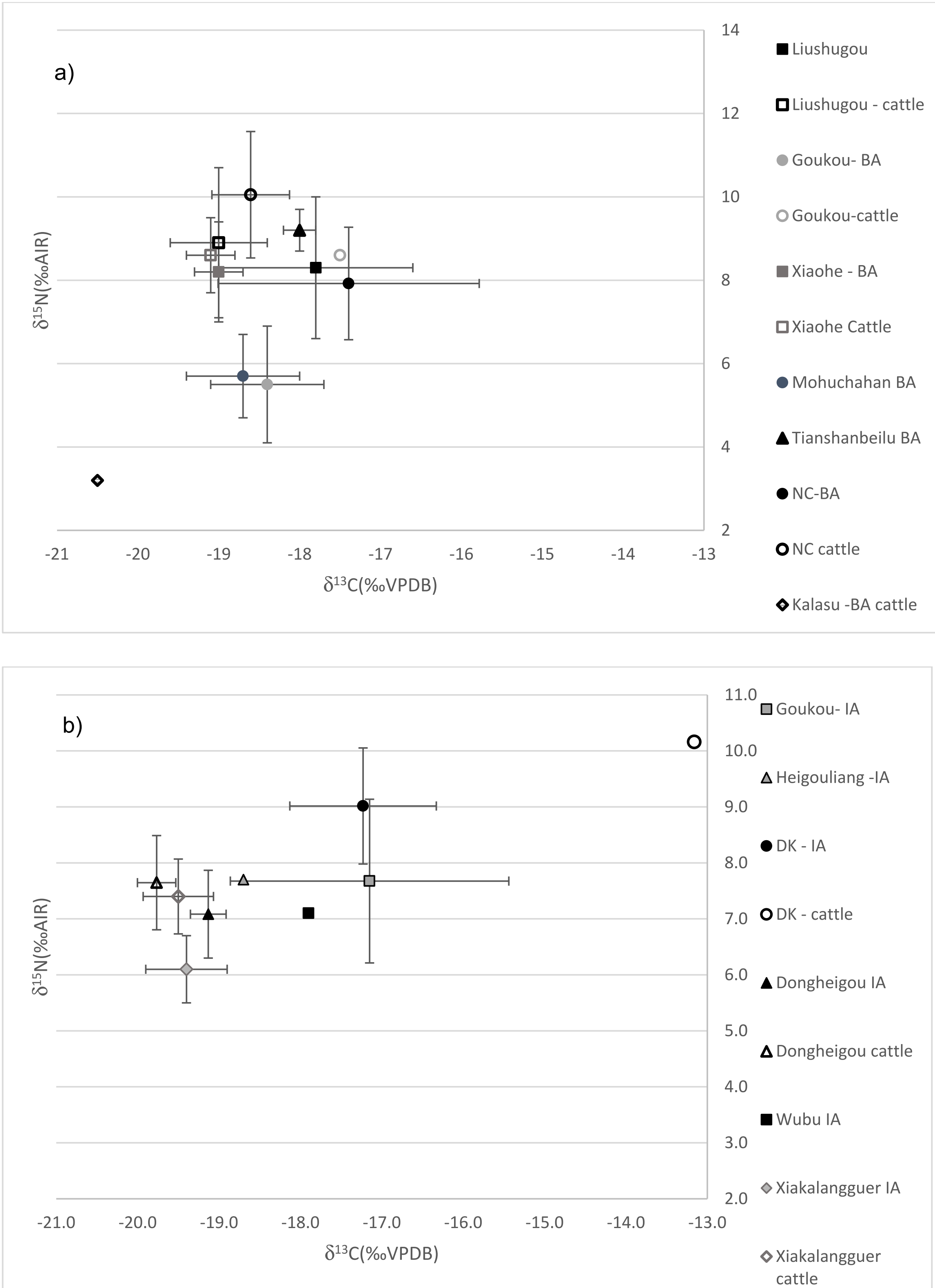

Fig. 7. Mean + SD plot of isotope ratios for caprine (full) and cattle (empty) from different sites in Xinjiang dating to a) the Bronze Age and b) the Iron Age (top and bottom, respectively).

Three different cereals were cultivated by the ancient populations of prehistoric Xinjiang: barley (C_3), wheat (C_3) and millet (C_4) (Hu, 2018; Li, 2020). They were all found in Djoumboulak Koum and the last two in the Northern Cemetery. However, the vegetation surrounding the delta must also be taken into account. Despite its arid environment, Xinjiang used to be home to many wild plants. In fact, deserts and oases offer a mixed vegetation composed mainly of C_3 plants (*Tamarix*, *Phragmites*, *Populus*, *Typha, Ephedra, Artemisia*, Chenopodiaceae, *Morus* …) with a few C_4 plants (*Eragrostis*, various other species of Chenopodiaceae and Poaceae) (Li, 2020; Debaine-Francfort et al., 2010; Li et al., 2013; Qiu et al., 2014). The C_4 most likely comes from this vegetation at low intakes, as shown by Qiu et al. in cow dung from Xiaohe cemetery (Qiu et al., 2014), but may also be provided by the herders as millet fodder. Alternatively, these five samples could have been imported goods.

The comparison between Djoumboulak Koum and the Northern Cemetery shows no significant diachronic variation for caprines (Fig. 4d and 5d), so they are considered as one group for following regional comparisons. The continuity in caprine diet is interesting as millet became more dominant in Xinjiang over time, but this does not seem to have affected the diet of domestic animals (Li, 2020; Qu et al., 2018). Settlements along the Keriya valley were concentrated in and around oases, and both sites probably had similar environments and vegetation. The severe desertification of the Keriya valley is more recent, partly due to anthropisation (Debaine-Francfort et al., 2010). Consequently, a close $\delta^{13}C$ seems consistent with a grazing diet. Sequential isotopic analyses can provide information on the intra-individual/seasonal evolution of isotopic ratios through time. Most samples show a variation of 1 ‰ or more in their $\delta^{13}C$ values. The $\delta^{15}N$ values are more variable, but there is no correlation between the variations in $\delta^{13}C$ and $\delta^{15}N$ values of these samples (Fig. 6). Seasonal variations due to plant availability, drought/monsoon or transhumance could explain these small variations during the life of the herbivores.

4.1.2. Cattle and camel

Cattle are almost exclusively dependent on C_3 plants and also have a higher $\delta^{15}N$ value than caprines. They graze preferentially, whereas caprines graze and browse equally (Coppock et al., 1986). Preferential feeding or specific forage in addition to grazing can both explain the difference observed between the species (Fig. 4a, 5a). The only cattle in the Djoumboulak Koum corpus and the camel have very high $\delta^{13}C$ values compared to other samples from this site and also to the vast majority of the Northern Cemetery samples (−15.5 ‰ and −15.4 ‰ respectively). Cattle and camels usually rely on different plants, as cattle are grazers and camels browsers (Coppock et al., 1986; Iqbal and Khan, 2001), so a similarity in $\delta^{13}C$ values may indicate that they were supplied locally with millet fodder (if the camel is domesticated). Another possibility is that these animals or their hides may have been imported as commodities. The question of origin is particularly interesting in the case of the camel fibre sample, as camels were often part of caravans and were also present as wild animals at the time. Finally, with only one cattle and one camelid sample from Djoumboulak Koum, no conclusions should be drawn as these specific samples may not be representative of farming practices.

4.2. Faunal isotopic analysis in Xinjiang

4.2.1. Herding practices in Xiaohe culture

In order to gain a better understanding of herding practices in Xinjiang during the Bronze and Iron Ages, our results need to be integrated and compared with the other studies already published. Isotopic analyses have been carried out by other teams at various archaeological sites throughout Xinjiang dating to this period (Qu et al., 2018; Wang et al., 2018; Wang et al., 2019; Eng et al., 2009; Wang et al., 2016; Dong et al., 2021) (Figs. 1 and 7;Table S2). Our two sites are part of the Xiaohe culture, whose main site, Xiaohe, is located 600 km away on the eastern edge of the Taklamakan desert (Fig. 1). The Xiaohe cemetery dates from the Bronze Age and shares many similarities in funerary architecture and practices with the Northern Cemetery (Debaine-Francfort and Idriss, 2001; Qu et al., 2018). The carbon isotope values of caprines and bovids are similar (−19.0 ± 0.3 ‰ and −19.1 ± 0.3 ‰, respectively) (Qu et al., 2018) and lower than those of caprines in the Northern Cemetery, which have a mean $\delta^{13}C$ value close to −17.4 ‰ (Fig. 7, Table S2). The variability of $\delta^{13}C$ values in the Keriya valley is slightly higher than in Xiaohe (Fig. 7), probably due to the 5 samples discussed in part 4.1.1. Despite the distance, communication and proximity with Xiaohe is likely, and it is not surprising to see similarities in animal diet. In addition to isotopic studies, analysis of cow dung at Xiaohe revealed a diet of reeds, lovegrass and Asteraceae, and no cereal intake for cattle, although millet was probably cultivated there (Qiu et al., 2014). It is interesting to note that if the cattle from Djoumboulak Koum are not an imported commodity, but are of local production with a millet diet, then this supports the development of a specific herding practice during the Iron Age in the Keriya Valley.

4.2.2. Herding in Xinjiang during the Bronze and Iron Ages

During the Bronze Age, herbivores from all Xinjiang sites studied have an average $\delta^{13}C$ value between −17.0 ‰ and −19.5 ‰ (Fig. 7, Table S2). Above −18 ‰, herbivores are considered to be partially dependent on C_4 plants. A study by Wang et al. showed that the altitude of archaeological sites in the Inner Asian Mountain Corridor had no significant effect on faunal isotope ratios (Wang et al., 2020). The variations observed between sites are small and may be due to differences in available vegetation. Indeed, with the exception of Xiakalangguer in the north, all the other sites studied are located in the Tianshan mountain range (Fig. 2). The Tianshan Mountains divide Xinjiang into two arid regions with different climates. The northern part is a cold steppe with low temperatures but some rainfall, while the southern part is a cold desert that is drier but with higher temperatures (Zhao et al., 2020). The climatic differences between the different parts of Xinjiang imply a diversity of vegetation. For caprines, the $\delta^{13}C$ and $\delta^{15}N$ values of the Northern Cemetery are close from that of Tianshanbeilu and Liushugou − situated at the east of the Tianshan mountains region. These sites are far from the Keriya Valley, but being south of the Tianshan Mountains, they also have a cold desert climate (Zhao et al., 2020). On the other hand, Goukou in the Yili Valley and Mohuchahan in Heijing County, both on the terrace of the Tianshan Mountains, have lower $\delta^{15}N$ values. This difference is probably due to the higher average rainfall (especially in Goukou, which has a temperate climate (Wang et al., 2018). The same effect is observed for cattle during the Iron Age at Kalasu, a site adjacent to Goukou. For $\delta^{13}C$ cattle during the Bronze Age, Goukou is the only site with a mixed C_3-C_4 diet in cattle, but with only one sample analysed it may not be representative. The cattle from the Northern Cemetery have an isotopic value close to that of Xiaohe and Liushugou. Therefore, the diet of herbivores in the Keriya Valley during the Bronze and Iron Ages is similar to the diet at other sites in Xinjiang, with small variations between sites most likely due to climate and/or vegetation. There is no strong variation in caprine diet across Xinjiang between the Bronze and Iron Ages. More interestingly, there is no increase in C_4 plants in the caprine diet between the Bronze and Iron Ages, unlike what is observed in human populations (Li, 2020). If millet seems to have been integrated into the human diet during this period, this is not the case for caprines and cattle.

It is clear from Fig. 6 that the bovid sample from Djoumboulak Koum has a very different diet compared to all other corpuses presented here. If it is an imported hide or an animal from a travelling caravan, then it most likely comes from further afield than the Xinjiang region. Millet feeding has been shown to play an important role in cattle husbandry from the Neolithic onwards in other regions of China: in northern China (Dongying, Yellow River basin, Shaanxi Province) during the Bronze Age (Chen et al., 2016), in eastern China at the site of Liuzhuang, Henan Province (2000–1600 BCE)13 and at Yuezhuang, Shandong Province (8000 BCE) (Hu et al., 2008). Millet was also popular as a staple food from the Early Bronze Age to the Iron Age just west of Xinjiang, as demonstrated at the Dali/Tasbas and Begash sites (Kazakhstan − Fig. 1) (Hermes et al., 2019). However, as noted above, the ingestion of millet (grown in the valley) as a local practice may also be possible.

Although camelid remains have been found at various Chinese sites (Olsen, 1988; Yue et al., 2014), only two isotopic results from the Dongheigou site have been published to date (Yue et al., 2014). The isotopic studies of two domesticated Bactrian camels, dating from 360-

170 BCE and 300–50 BC respectively, yielded $\delta^{13}C$ at −16.8 ‰ and −18.5 ‰ and $\delta^{15}N$ at 9.9 ‰ and 10.0 ‰. The differences with the camel at the Djoumboulak Koum site (collagen equivalent: $\delta^{13}C$ = -13.1 ‰ and $\delta^{15}N$ = 9.0 ‰, see Materials and Methods) can be explained by a different geographical origin, a different context or a wild camel at the Keriya site. In fact, not only the antiquity, but also the environment of the two camels are different. The Dongheigou site is located on the northern side of the Tianshan Mountains, more than a thousand kilometres away, and is characterised by wetter and colder temperatures than Djoumboulak Koum. These differences may explain a lower $\delta^{13}C$ as C_3 plants are more likely to grow than C_4 plants under these conditions (Zhao et al., 2020). It is noticeable that for caprines and cattle, this site already had lower $\delta^{13}C$ values compared to the Keriya valley (Fig. 7). In addition to carbon and nitrogen isotopes, a study of strontium isotopes could be useful to document the mobility of cattle and camelids. With almost no comparison possible, it is difficult to interpret our result in this context. However, it shows that more isotopic data through time and across the Xinjiang region are needed to understand camelid herding practices. Hopefully, it will encourage further studies of camelid remains in the future.

5. Conclusion

In the Keriya valley during the Bronze Age, people probably allowed goats, sheep and cattle to graze on the vegetation, mostly C_3 plants, offered by the oases. The caprines also sometimes relied on the few C_4 plants that grew in this environment. There is some variability in the diet of caprines, which could be explained by trade in fibre/textiles with other regions or by seasonal variations, possibly reflecting the mobility of herds and the seasonal availability of plants although no specific seasonal variation is visible in the sequential analysis. While an increase in millet cultivation was observed in Xinjiang between the Bronze and Iron Ages, there is no significant difference in caprine diet in the Keriya Valley and no millet foddering was introduced during these periods. These practices are consistent with other contemporary sites of the Xiaohe culture and, more generally, with Xinjiang. However, the only cattle and camel studied in Djoumboulak Koum show high $\delta^{13}C$ values, reflecting the consumption of C_4 plants. This is an unusual diet for cattle in this region during the Iron Age and may reflect a specific local practice or trade. Data on camel diet in this context are scarce and no conclusions can be drawn, further isotopic studies of cattle remains from this site and camels from the region would be required. Otherwise, the animal diet in the Keriya Valley is consistent with previously published results and integrates Bronze and Iron Age practices in Xinjiang.

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CRediT authorship contribution statement

Clara Azémard: Writing – original draft, Investigation, Formal analysis, Data curation. **Sebastien Lepetz:** Writing – review & editing, Visualization, Resources. **Corinne Debaine-Francfort:** Writing – review & editing, Resources. **Idriss Abduressul:** Resources. **Denis Fiorillo:** Validation, Supervision. **Séverine Zirah:** Writing – review & editing, Supervision, Project administration, Funding acquisition. **Antoine Zazzo:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104920.

Data availability

Data is presented in the supplementarty files.

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