

# Wild Equids at Neolithic Tepecik-Çiftlik: A Preliminary Stable Isotope Study\*

*Tepecik-Çiftlik Yabani Atgilleri: Kararlı İzotop Analizi Ön Sonuçları*



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**Keywords:** Stable isotope analysis, *Equus ferus*, *Equus hemionus hydruntinus*, Tepecik-Çiftlik, Paleodiet

**Abstract:** This study presents stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope analyses of bone collagen from wild equids (*Equus ferus* and *Equus hemionus hydruntinus*) recovered from the Neolithic and Early Chalcolithic layers (ca. 7000-5800 cal. BC) of Tepecik-Çiftlik, located in the Volcanic Cappadocia region of Central Anatolia. As no prior isotopic study of wild equids from this region has been conducted, the research is preliminary in nature and aims to fill a significant gap in the Central Anatolian Neolithic paleoenvironmental literature. The  $\delta^{13}\text{C}$  values are consistent with a diet primarily based on  $\text{C}_3$  plants, which is in line with the open grassland and steppe-type vegetation around the Çiftlik Plain during the Neolithic Period. The  $\delta^{15}\text{N}$  values appear to be higher than those reported for northwest European Holocene horses. This may be consistent with the semi-arid environmental conditions and soil nitrogen dynamics characteristic of the region, although  $\delta^{15}\text{N}$  values are influenced by multiple environmental and physiological factors. As one of the first studies presenting isotopic results from equids in Asia Minor, the findings should be considered a preliminary baseline dataset for building a comparative isotopic framework to understand the ecological role of wild equids in Anatolia.

**Anahtar Kelimeler:** Kararlı izotop analizi, *Equus ferus*, *Equus hemionus hydruntinus*, Tepecik-Çiftlik, Paleodiyet

**Özet:** Bu çalışma, Orta Anadolu'nun Volkanik Kapadokya bölgesinde yer alan Tepecik-Çiftlik yerleşmesinin Neolitik ve İlk Kalkolitik tabakalarındaki (yaklaşık MÖ 7000-5800) yabani atgillere (*Equus ferus* ve *Equus hemionus hydruntinus*) ait kemik kolajeninden elde edilen kararlı karbon ( $\delta^{13}\text{C}$ ) ve azot ( $\delta^{15}\text{N}$ ) izotop analizlerini sunmaktadır. Ön çalışma niteliği taşıyan bu araştırma, bölgede yabani atgillere yönelik izotopik bir çalışmanın henüz yapılmamış olması nedeniyle, Orta Anadolu Neolitik paleoçevre literatüründeki önemli bir boşluğu doldurmayı amaçlamaktadır.  $\delta^{13}\text{C}$  değerleri, bu hayvanların ağırlıklı olarak  $\text{C}_3$  bitkilerine dayanan bir beslenme düzenine sahip olduğuna işaret etmekte olup bu bulgu, Neolitik Dönem'de Çiftlik Ovası çevresindeki açık otlak ve step tipi bitki örtüsüyle uyumludur.  $\delta^{15}\text{N}$  değerlerinin ise Kuzeybatı Avrupa Holosen atlarına ait yayımlanmış verilerden daha yüksek olduğu görülmektedir. Bu durum, bölgenin karakteristik yarı kurak iklim koşulları ve toprak azot dinamikleriyle uyumlu olabilir. Yabani atgillerden elde edilen ilk izotopik sonuçları içeren bu çalışma, Anadolu'daki yabani atgillerin ekolojik ortamdaki rolünün anlaşılmasına yönelik karşılaştırmalı bir izotopik çerçevenin oluşturulması için bir başlangıç noktası olarak değerlendirilebilir.

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## Introduction

Stable isotope studies of wild and domestic equids have largely focused on the Eurasian steppes and northwest Europe, addressing questions of domestication, mobility, and feeding strategies (Stevens, Hedges, 2004; Kaczensky et al. 2017; Grandal-d'Anglade et al. 2021). In Central Anatolian archaeology, however, isotopic research has concentrated primarily on domestic species such as sheep and goat (Pearson et al. 2007; Makarewicz et al. 2017; 2018), leaving wild equid (*Equus* sp.) data remarkably scarce. Guimaraes et al. (2020) confirmed at the genetic level the presence of both wild horse (*Equus ferus*) and wild ass (*Equus hemionus hydruntinus*) in Anatolia during the Neolithic and Chalcolithic periods, providing important context for the equid fauna at the site. To date, isotopic studies specifically focused on wild equid diet in Anatolia remain extremely limited.

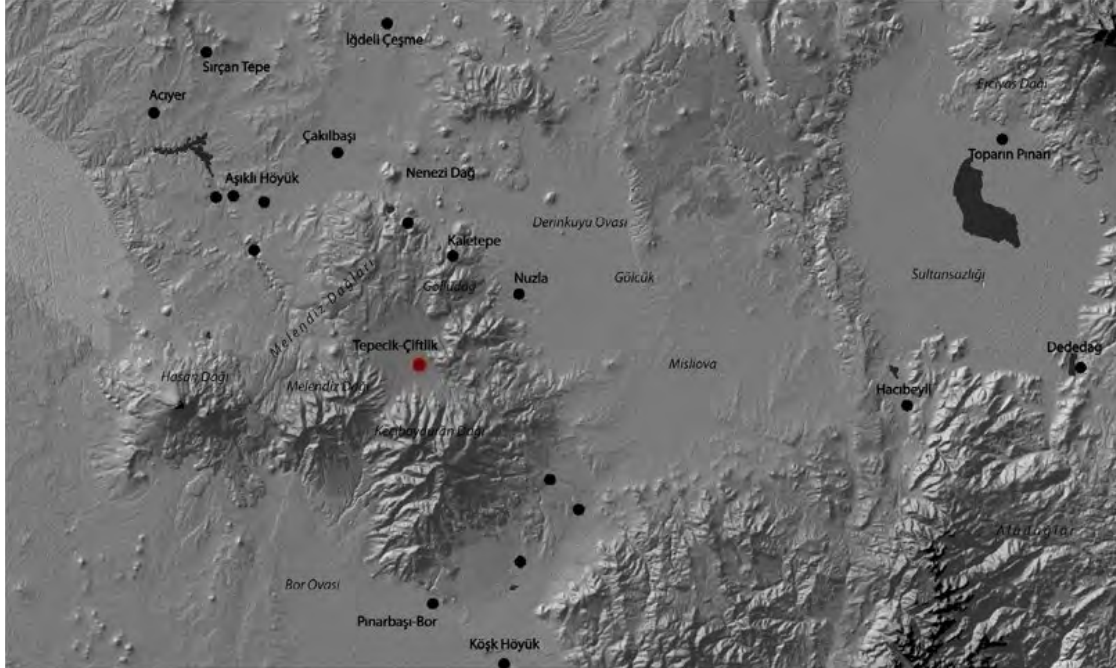
Stable carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) isotope analyses of bone collagen have become widely used methods in archaeological paleodiet and paleoenvironmental research, following the recognition that biological tissues record environmental and dietary signals (DeNiro, Epstein 1978; Schoeninger, DeNiro 1984; Ambrose 1986; Tykot 2004). This approach relies on the principle that different food sources carry distinct isotopic compositions which are in turn, transferred to consumer tissues along the food chain. The isotopic variation observed within a food web is primarily shaped by the environmental conditions an individual lived in and the food sources it consumed within that setting. Because bone tissue undergoes continuous remodeling, the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values obtained from collagen reflect an average diet over an individual's life (Ambrose 1986; Tykot 2004; Hedges et al. 2007).

Tepecik-Çiftlik is one of the key sites for understanding the Central Anatolian Neolithic. Located in the Volcanic Cappadocia region, within the Çiftlik (Melendiz) Plain, the site saw continuous occupation from the Neolithic (7000 BC and earlier) through to the Early Chalcolithic (6100-5800 BC) (Bıçakçı 2022; Çakan 2024). This study presents the  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from the bone collagen of wild equids (*Equus ferus* and *Equus hemionus hydruntinus*) recovered from Tepecik-Çiftlik and situates them within the broader context of Central Anatolian Neolithic paleoenvironments. With a total of seven specimens, the study is explicitly preliminary. Its primary contribution is an initial isotopic baseline for wild equids in a region where such data are currently absent.

## Tepecik-Çiftlik

Tepecik-Çiftlik is located in the Çiftlik (Melendiz) Plain within the province of Niğde, in the southeastern part of Central Anatolia (Fig. 1). The site sits at the edge of a broad alluvial fan fed by the northern slopes of the Melendiz Mountains and is one of the major Neolithic settlements in the Volcanic Cappadocia region (Bıçakçı 2022). The Çiftlik Plain forms a closed basin enclosed by the Melendiz and Keçiboyduran mountain ranges.

Along with the volcanic massif of Göllüdağ, this geomorphological configuration has facilitated the development of distinct ecological habitats across the region (Kuzucuoğlu et al. 2013).



**Figure 1.** Neolithic and Chalcolithic settlements in the Volcanic Cappadocia region (Bıçakçı 2022; fig. 6.2)

Excavations at Tepecik-Çiftlik, covering approximately six hectares, have identified four main periods and a total of ten cultural layers (Fig. 2). The earliest cultural layer at the site dates to the beginning of the 7th millennium BC, representing an uninterrupted sequence of occupation from the Neolithic through to the Early Chalcolithic (Bıçakçı 2022).

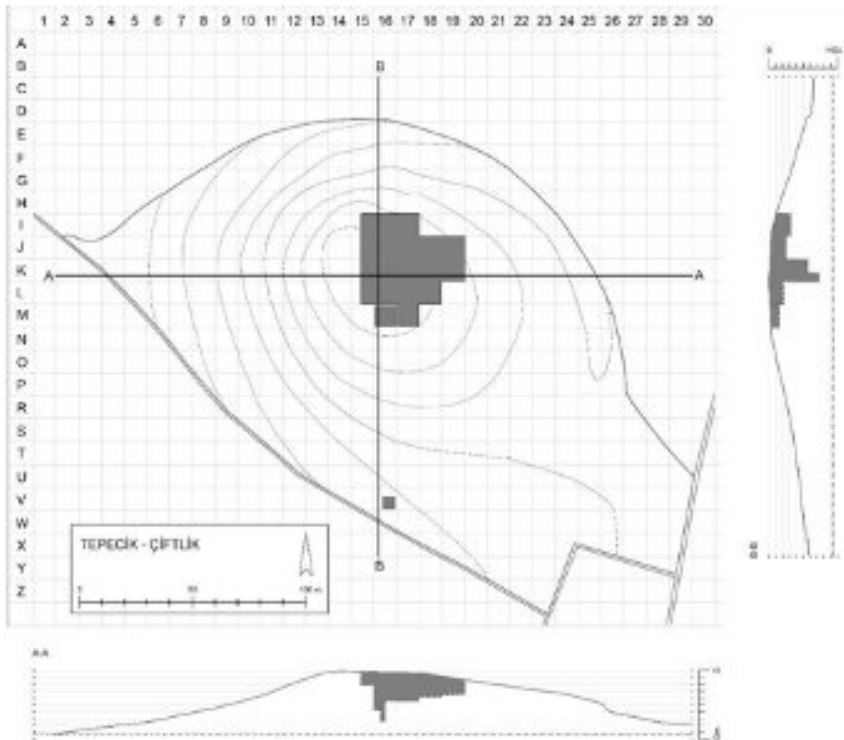
The fauna of Tepecik-Çiftlik displays considerable diversity, encompassing both domestic and wild taxa. Zooarchaeological analyses have been able to identify domestic sheep (*Ovis aries*), goat (*Capra hircus*), and cattle alongside wild sheep (*Ovis orientalis*), red deer (*Cervus elaphus*), wild boar (*Sus scrofa*), and wild equids (*Equus ferus* and *Equus hemionus hydruntinus*) (Gündem 2019). Wild equids, in particular, occupy a notable position among the hunted fauna.

The geological and ecological diversity of the Volcanic Cappadocia region has enabled species adapted to a range of habitats to coexist. While taxa such as red deer and wild boar favor more humid, wooded environments, wild sheep and goats are associated with rocky and open terrain. However, wild equids tend to prefer open landscapes with extensive grazing grounds. This would, therefore, suggest that multiple ecological settings were

Layer	Period	Phase	Date (cal BCE)
Layer 1	Late Roman-Early Byzantine	Burials only	—
Layer 2	Early Chalcolithic	Phase 1	6100-5800
		Phase 2	—
Layer 3	Final Neolithic	Phase 1	6400-6100
		Phase 2	—
Layer 4	Neolithic	—	6600-6400
Layer 5	Neolithic	Phase 1	6800-6600
		Phase 2	—
Layer 6	Neolithic	—	—
Layers 7-9	Neolithic	—	7000-6800
Layer 10	Neolithic	—	7000 and earlier

\* Dates are based on calibrated radiocarbon data and given as cal BCE.

**Figure 2.** Schematic plan of Tepecik-Çiftlik Höyük and the chronological distribution of cultural layers by period, phase, and date.



present in and around Tepecik-Çiftlik during the Neolithic Period (Erdal et al. 2018). The faunal evidence from the site demonstrates that Neolithic communities maintained a mixed subsistence economy combining domestic animal husbandry with the hunting of wild species. Wild equids likely held a prominent place among hunted game, and isotopic data from these animals constitute a potentially informative proxy for paleoenvironmental reconstruction, provided that the dataset is substantially expanded and interpreted in conjunction with complementary evidence.

## Faunal Stable Isotope Analysis

Faunal isotope datasets have long served as a valuable research tool for understanding past animal management strategies, grazing systems, and the environmental impact of human activities (Sharpe, Krigbaum 2022). Carbon isotope values are primarily used to distinguish the consumption of C<sub>3</sub> and C<sub>4</sub> plants (Van der Merwe, Vogel 1978). C<sub>3</sub> plants include most staple food crops, among them trees (fruit and nut-bearing), temperate grasses, legumes, wheat, barley, and rye. C<sub>4</sub> plants comprise grass species adapted to higher temperatures and/or saline conditions (*Aeluropus* sp.), chenopodiaceous taxa (*Salsola* sp.). Globally, the carbon isotope values of C<sub>3</sub> plants typically range from -34‰ to -22‰, while C<sub>4</sub> plants fall between -20‰ and -7‰ (O’Leary 1981). C<sub>3</sub> plants in closed, forested habitats tend to show more negative values, whereas more open and arid habitats are associated with less negative isotopic signatures (Farquhar et al. 1989; Heaton 1999; Cerling et al. 2004).

Nitrogen enters the food chain as it is absorbed by plants from the soil or atmosphere and becomes progressively enriched at each trophic level at a relatively constant rate (DeNiro, Epstein 1981). Animal studies have also demonstrated a relationship between precipitation levels and the  $\delta^{15}\text{N}$  values of bone collagen (Ambrose 2000). The principal drivers of  $\delta^{15}\text{N}$  enrichment in plants include drought (Heaton 1987; Ambrose 1991; Cormie, Schwarcz 1994) and soil salinity (Robinson et al. 2000; Van Groenigen, Van Kessel 2002), while in animals the main influencing factors are body water conservation mechanisms (Ambrose 2000), rumen fermentation in ruminants (Macko et al. 1982; Sealy et al. 1987), and periods of nutritional stress (Fuller et al. 2005). Organic manuring is also known to contribute to  $\delta^{15}\text{N}$  enrichment (Bogaard et al. 2007; Fraser et al. 2013a; 2013b).

## Material and Method

### *Samples*

The material for this study comprises seven wild equid (*Equus* sp.) bone samples recovered from the Neolithic layers at Tepecik-Çiftlik. Zooarchaeological data document the presence of both wild horse (*Equus ferus*) and wild ass (*Equus hemionus hydruntinus*) at the site (Gündem 2019). Species identification was carried out using published reference materials and osteometric analysis. Although few reliable morphological criteria exist for

distinguishing *Equus ferus* from *Equus hemionus hydruntinus*, particularly for post-cranial remains, it has been demonstrated that the two species are distinguishable by element size (Arbuckle and Öztan 2018: 46). Species determination was therefore based on comparison of element dimensions with published measurements from the nearby site of Köşk Höyük (Arbuckle and Öztan 2018: 47, Table 3), supplemented by measurements taken from two comparative specimens held in the Bavarian State Collection for Palaeoanatomy (BSPG): a female Przewalski's horse (*Equus caballus przewalskii*, specimen no. BSPG-MA-02678) and a female Kulan (*Equus hemionus kulan*, specimen no. BSPG-MA-00817). Kulan was used as a size proxy for the now-extinct hydruntine, as the two forms are considered broadly comparable in body size (Arbuckle and Öztan 2018: 45). Post-cranial measurements followed von den Driesch (1976); mandibular measurements followed Eisenmann (1986) (see Appendix). Of the seven samples, two (TP 184 and TP 188) were identified as *Equus hemionus hydruntinus* on the basis of their smaller element dimensions. The remaining five specimens were classified as *Equus ferus*; for sample TP 085.2, no measurements could be taken from the mandible fragment, but its size is most consistent with *E. ferus*. Sample selection was made from compact cortical bone elements that were considered most suitable for collagen preservation, with the aim of representing both taxa and the chronological range of the site's occupation sequence.

#### Collagen Extraction

Preparatory stages for bone collagen extraction were carried out in the Archaeology Laboratory of Koç University. A modified version of the method described by Longin (1971) was applied. Approximately 1 g fragments of compact cortical bone were removed using a diamond-coated cutting disc from the broken end of the bone diaphysis, avoiding articular surfaces, cut marks, pathological lesions, adhesive residues, and labeling areas. All acids used were of analytical grade, and ultrapure water with a resistivity of 18.2 M $\Omega$  was used throughout.

The fragments were demineralised in regularly changed 0.5 M HCl solution at 4 °C for approximately one week. Following demineralisation, the samples were rinsed three times with Milli-Q water. Gelatinisation was carried out in 10 ml of pH 3 HCl solution at 70 °C for 48 hours. The samples were then filtered using EZee® filters, freeze-dried, and weighed.

#### *Isotope Measurements and Data Quality Control*

The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotope ratios of the prepared collagen samples were measured at TENMAK (Turkish Energy, Nuclear and Mineral Research Agency) using a Continuous Flow Isotope Ratio Mass Spectrometer (EA-IRMS) coupled with an elemental analyser.  $\delta^{13}\text{C}$  values are reported in ‰ relative to VPDB, and  $\delta^{15}\text{N}$  values relative to AIR. Measurements were calibrated against internationally recognised reference materials included in each analytical run; the laboratory's analytical precision is  $\pm 0.1\text{‰}$  for  $\delta^{13}\text{C}$  and  $\pm 0.2\text{‰}$  for  $\delta^{15}\text{N}$ . Collagen yield was calculated by comparing the post-freeze-drying

weight with the initial dry bone weight. All samples exceeded the  $\geq 1\%$  collagen yield threshold (Van Klinken 1999), although one sample (TP 085.2) fell below the recommended %C and %N ranges. Collagen integrity was assessed using C/N ratio (2.9-3.6), %C (22.6-47.0), and %N (8.1-16.6) reference ranges (DeNiro 1985; Ambrose 1993).

Given the limited sample size of this preliminary study, parametric statistical tests were not applied. Instead, the data were evaluated using a comparative approach, in which isotopic values were compared with published reference datasets from geographically and ecologically relevant contexts and examined for chronological patterning across stratigraphic layers.

Sample No	Layer	Date (cal. BC)	Species ( <i>Equus</i> sp.)	Bone Element	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	%C	%N	C/N
TP 205	2	6100-5800	<i>Equus ferus</i>	Phalanx	-21.1	7.1	31.9	11.1	3.37
TP 151	3	6400-6100	<i>Equus ferus</i>	Phalanx	-20.3	8.3	37.3	13.6	3.19
TP 115.2	4	6600-6400	<i>Equus ferus</i>	Metapodial	-21.3	6.9	34.4	12.7	3.16
TP 085.2	5	6800-6600	<i>Equus ferus</i>	Mandible	-21.7	8.5	14.3*	5.3*	3.18
TP 019.2	5	6800-6600	<i>Equus ferus</i>	Tibia	-20.9	8.8	19.9	7.3	3.17
TP 188	10	ca. 7000	<i>Equus h. hydruntinus</i>	Cranium	-21.1	8.4	22.6	7.9	3.36
TP 184	10	ca. 7000	<i>Equus h. hydruntinus</i>	Metapodial	-20.7	8.4	34.6	12.1	3.33
<b>Mean</b>					<b>-21.0 ± 0.4</b>	<b>8.05 ± 0.67</b>	<b>14.3-37.3 / 5.3-13.6</b>	<b>3.16-3.37</b>	

\* The %C and %N values of sample TP 085.2 fall below the threshold values recommended by Ambrose (1993); however, the C/N ratio (3.18) falls within the accepted range (2.9-3.6), indicating that the structural integrity of the collagen matrix is preserved.  $\delta^{13}\text{C}$  values are reported relative to VPDB;  $\delta^{15}\text{N}$  values relative to AIR.

**Figure 3.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values and collagen quality indicators for wild equid (*Equus* sp.) specimens from the Neolithic layers of Tepecik-Çiftlik Höyük. Samples are ordered from earliest to latest by layer number.

## Results

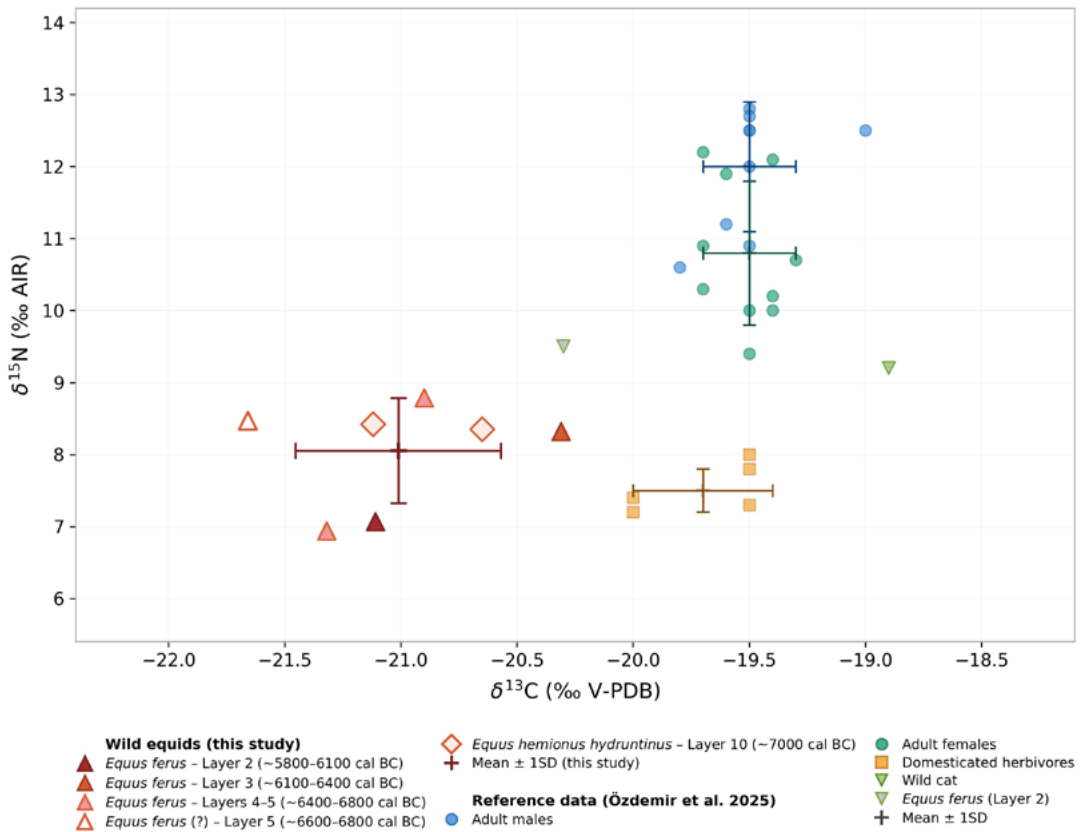
Collagen isotope analysis of the seven wild equid (*Equus* sp.) bone samples from Tepecik-Çiftlik yielded  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from specimens representing different stratigraphic layers dated to the Neolithic and Early Chalcolithic periods at the site. Five specimens were identified as *Equus ferus* (Layers 2-5) and two as *Equus hemionus hydruntinus* (Layer 10).

The  $\delta^{13}\text{C}$  values of the samples range from -21.7‰ to -20.3‰. The lowest  $\delta^{13}\text{C}$  value was measured in sample TP 085.2 from Layer 5 (-21.7‰), while the highest was recorded in sample TP 151 from Layer 3 (-20.3‰). The mean  $\delta^{13}\text{C}$  value for the analysed specimens is -21.0 ± 0.4‰; the median is -21.1‰, and the interquartile range (IQR) is 0.7‰.

The  $\delta^{15}\text{N}$  values range from 6.9‰ to 8.8‰. The lowest  $\delta^{15}\text{N}$  value was recorded in sample TP 115.2 from Layer 4 (6.9‰), and the highest in sample TP 019.2 from Layer 5 (8.8‰). The mean  $\delta^{15}\text{N}$  value across all samples is 8.1 ± 0.67‰; the median is 8.35‰ and the interquartile range (IQR) is 1.4‰.

When the two identified taxa are considered separately, *Equus ferus* specimens (n=5; Layers 2–5) yield  $\delta^{13}\text{C}$  values ranging from  $-21.7\text{‰}$  to  $-20.3\text{‰}$  (mean  $-21.1 \pm 0.49\text{‰}$ ) and  $\delta^{15}\text{N}$  values ranging from  $6.9\text{‰}$  to  $8.8\text{‰}$  (mean  $7.9 \pm 0.73\text{‰}$ ). *Equus hemionus hydruntinus* specimens (n=2; Layer 10) yield  $\delta^{13}\text{C}$  values of  $-21.1\text{‰}$  and  $-20.7\text{‰}$  (mean  $-20.9 \pm 0.33\text{‰}$ ) and  $\delta^{15}\text{N}$  values of  $8.4\text{‰}$  and  $8.3\text{‰}$  (mean  $8.4 \pm 0.05\text{‰}$ ). The  $\delta^{13}\text{C}$  ranges of the two taxa broadly overlap, and both groups are consistent with a  $\text{C}_3$ -dominated diet. The  $\delta^{15}\text{N}$  mean of *E. h. hydruntinus* ( $8.4\text{‰}$ ) is approximately  $0.5\text{‰}$  higher than that of *E. ferus* ( $7.9\text{‰}$ ). However, the value ranges of the two taxa overlap substantially, and the difference cannot be tested statistically, given the small sample sizes. This observation is therefore reported descriptively and should be treated with caution pending larger datasets.

The  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and collagen quality indicators for all analysed samples are presented in Fig. 3. C/N ratios range from 3.16 to 3.37, with all values falling within the accepted range of 2.9–3.6. The bivariate distribution of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for all samples, including reference data from Özdemir et al. (2025), is shown in Fig. 4.



**Figure 4.** Scatter plot of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for wild equid (*Equus* sp.) specimens from the Neolithic layers of Tepecik-Çiftlik.

## Discussion

### Collagen Quality Assessment

Six of the seven samples analysed meet all collagen quality criteria proposed by DeNiro (1985) and Ambrose (1993). Sample TP 085.2, a mandible fragment, falls below the recommended threshold values for %C and %N; however, its C/N ratio (3.18) lies within the accepted range of 2.9-3.6, indicating that the structural integrity of the collagen matrix is preserved despite some degree of collagen loss. The retention of an acceptable C/N ratio in samples with low %C and %N values has been discussed in the literature as a basis for cautious inclusion (van Klinken 1999; Guiry, Szpak 2021), and comparable borderline specimens have been retained in published isotopic studies of archaeological equids (Stevens, Hedges 2004). Given the already limited sample size of this preliminary study, the exclusion of this specimen would further reduce the dataset to six individuals, thereby eliminating the sole sample from Layer 5 Phase 1 and compromising the chronological coverage of the assemblage. Accordingly, the sample was retained in the analysis, and its isotopic values have been interpreted with appropriate caution throughout.

### *Carbon Isotopes and Palaeoenvironment*

The  $\delta^{13}\text{C}$  values obtained (-21.7‰ to -20.3‰) are consistent with a diet predominantly based on plants that follow the  $\text{C}_3$  photosynthetic pathway.  $\text{C}_3$  plants are commonly associated with wooded environments, shrubby habitats, and plant communities typical of temperate climates (O'Leary 1981; Tykot 2004). That said, determining which specific plant type these values reflect cannot be reconstructed from the animal isotopes alone; verification with the support of additional environmental evidence is necessary.  $\text{C}_3$  plants in closed forest habitats typically display markedly more negative  $\delta^{13}\text{C}$  values, generally between -26‰ and -34‰, owing to the canopy effect, while  $\text{C}_3$  grasses and steppe vegetation in open, arid, and water-stressed habitats approach less negative values (Farquhar et al. 1989; Cerling et al. 2004; Heaton 1999).

The positioning of the Tepecik-Çiftlik samples between -21.7‰ and -20.3‰, toward the positive end of the  $\text{C}_3$  reference band, falls within a range broadly compatible with open, sun-exposed plants likely subject to water stress, though it does not in itself identify specific plant communities. It should be noted that equids are not strict grazers; they exhibit considerable dietary flexibility, including facultative browsing under certain environmental conditions (Schoenecker et al. 2016), a consideration that complicates direct environmental inference from single-taxon isotopic data. On balance, the isotopic signal is compatible with open landscape conditions, but this reading should be regarded as a working hypothesis rather than a conclusion, pending multi-species isotopic comparison and independent palaeobotanical evidence. A key limitation of the present study is the absence of isotopic data from co-existing faunal taxa, such as red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*), which would be crucial to gain insights into the

presence of a mosaic landscape in the Neolithic Çiftlik Plain. Other fauna would be expected to show more negative  $\delta^{13}\text{C}$  values given their preference for more closed habitats. This interpretation should therefore be regarded as a working hypothesis, pending further multi-proxy evidence.

A degree of contextual support for the  $\text{C}_3$ -dominated open environment interpretation is provided by the stable isotope dataset published by Özdemir et al. (2025) for the Neolithic population of Tepecik-Çiftlik. That study reports  $\delta^{13}\text{C}$  values for domesticated caprines (mean  $-19.5 \pm 0.0\%$ ), cattle (mean  $-20.0 \pm 0.1\%$ ), and a single wild equid specimen (*Equus ferus*,  $\delta^{13}\text{C}$   $-20.3\%$ ;  $\delta^{15}\text{N}$   $9.5\%$ ) from Layer 2 of the site. Although these faunal samples derive from Layer 2 and are therefore not directly contemporary with the present study's assemblage, which spans Layers 2 through 10, they constitute the closest available local isotopic baseline for Tepecik-Çiftlik. The  $\delta^{13}\text{C}$  values of all herbivore taxa in that dataset cluster between  $-19.5\%$  and  $-20.3\%$ , consistently indicating  $\text{C}_3$ -dominated vegetation. The single wild equid specimen's  $\delta^{13}\text{C}$  value of  $-20.3\%$  falls within the range recorded in the present study ( $-21.7\%$  to  $-20.3\%$ ), lending further support to the interpretation of a  $\text{C}_3$ -dominant dietary signal in equids from this site across different occupation phases. It should be noted, however, that the Özdemir et al. (2025) faunal dataset is small ( $n = 7$  animals across multiple species) and that the absence of direct contemporaneity limits the strength of this comparison; it is treated here as contextual evidence rather than a definitive baseline.

Compared to published data from geographically distant contexts, Stevens and Hedges (2004) report a mean  $\delta^{13}\text{C}$  value of approximately  $-22.1\%$  for bone collagen from Holocene horses in northwest Europe. The fact that the Tepecik-Çiftlik samples are approximately  $1\%$  more positive than this European average is consistent with the relative  $\delta^{13}\text{C}$  enrichment observed in  $\text{C}_3$  plants under the more open and semi-arid conditions of Central Anatolia (Heaton 1999). It should also be noted that geographical and temporal variation in atmospheric  $\text{CO}_2$  concentrations may have contributed to this difference (Stevens, Hedges 2004). The mean  $\delta^{13}\text{C}$  value reported for Przewalski's horses in the Mongolian Gobi is  $-23.4\%$  (Burnik Šturm et al. 2017). This divergence reflects the fundamental ecological contrast between Central Asian steppe flora and the  $\text{C}_3$ -dominated semi-arid environment of Central Anatolia. Direct numerical comparison with these and other published datasets is methodologically challenging, as many studies cover different tissue types, dental enamel, dentine, and bone collagen and different chronological periods. Since the isotopic fractionation difference between dental enamel and bone collagen is approximately  $12\text{-}14\%$  (Lee-Thorp, Van der Merwe 1987), the fossil horse dental enamel data reported by Wang et al. (1994) for North America cannot be directly compared with the bone collagen values presented here. The absence of a reference dataset for wild equid bone collagen specific to southwest Asia and Anatolia during the Neolithic positions this study as one of the necessary pioneering contributions toward building such a framework.

### **Nitrogen Isotopes and Environmental Conditions**

The  $\delta^{15}\text{N}$  values of the analysed samples range from 6.9‰ to 8.8‰. Since  $\delta^{15}\text{N}$  values in herbivorous mammals generally reflect the isotopic composition of the plants consumed, these values may provide information about prevailing environmental conditions, although their interpretation requires consideration of multiple interacting factors (Szpak 2014). Drought, soil nitrogen cycling, and micro-ecological variation influence  $\delta^{15}\text{N}$  values in plants, causing these signals to be transmitted to herbivore tissues. Additional factors that may influence  $\delta^{15}\text{N}$  values in animal bone collagen include physiological stress, body water conservation mechanisms, seasonal variability in plant nitrogen uptake, and species-specific digestive physiology. While equids are generally associated with grazing behaviour, the  $\delta^{15}\text{N}$  variation measured in collagen most likely reflects a combination of environmental and physiological influences rather than trophic level differences alone; disentangling these factors is not possible from the present dataset.

Compared to the mean  $\delta^{15}\text{N}$  value of approximately 6.5‰ reported for northwest European Holocene horses by Stevens and Hedges (2004), the Tepecik-Çiftlik specimens (6.9-8.8‰; mean 8.1‰) display a relatively enriched pattern. This relative enrichment is broadly compatible with the semi-arid environmental conditions and soil nitrogen dynamics characteristic of the region, yet it cannot be attributed to any single environmental driver, since  $\delta^{15}\text{N}$  values are influenced by multiple environmental and physiological factors, including soil nitrogen cycling, seasonal variability, and physiological stress, and no single-factor explanation should be assumed (Szpak 2014; Ambrose 2000). In this regard, the single wild equid specimen (*Equus ferus*) reported by Özdemir et al. (2025) from Layer 2 of Tepecik-Çiftlik yielded a  $\delta^{15}\text{N}$  value of 9.5‰, which is slightly higher than the mean of the present study's assemblage (8.05‰) but falls within a broadly comparable range, tentatively supporting the interpretation of elevated  $\delta^{15}\text{N}$  values as a recurrent feature of equids at this site. This observation should, however, be treated with caution, given that it is based on a single specimen from a different stratigraphic context. The relatively narrow spread of  $\delta^{15}\text{N}$  values across the present assemblage (a range of 1.9‰) and the absence of pronounced variation between layers do not, in themselves, provide evidence for environmental stability; given the limited number of individuals per layer (one to two specimens), and the multiple environmental and physiological factors that influence  $\delta^{15}\text{N}$  values in equids, no meaningful chronological pattern can be extracted from the present dataset.

### **Chronological Assessment and Faunal Context**

The isotopic evidence from Tepecik-Çiftlik can be situated within a broader regional framework by reference to stable isotope datasets from contemporaneous and near-contemporaneous Central Anatolian sites. At Aşıklı Höyük, located approximately 35 km to the northwest and predating Tepecik-Çiftlik by several centuries to over a millennium

(ca. 8400-7350 cal. BC), multi-isotopic analyses of human bone collagen by Itahashi et al. (2021) documented a diet dominated by C<sub>3</sub> terrestrial resources throughout the occupation sequence, with the ratio of animal to plant protein remaining broadly stable despite the gradual transition from broad-spectrum hunting to caprine management. Sheep bone collagen from the later levels of Aşıklı Höyük shows a minor positive shift in  $\delta^{13}\text{C}$  values, interpreted as a tentative signal of incipient C<sub>4</sub> plant input into caprine diets, possibly associated with early foddering or pasture diversification (Peters et al. 2018, cited in Stiner et al. 2022). At Çatalhöyük on the Konya Plain (ca. 7100-6000 cal. BC), stable isotope analyses of domesticated caprines by Pearson et al. (2007) and Middleton (2018) indicate a predominantly C<sub>3</sub>-based diet, though with evidence of C<sub>4</sub> plant consumption, attributed to grazing on saline marsh vegetation in the wetland margins of the plain. At the later site of Köşk Höyük in the Bor Plain (ca. 6200-4500 cal. BC), located approximately 50 km to the southeast of Tepecik-Çiftlik, intra-tooth sequential  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  analyses of caprine tooth enamel by Makarewicz et al. (2017) document a predominantly C<sub>3</sub>-based diet with inverse seasonal cycling in carbon and oxygen isotopes, interpreted as evidence for vertical transhumance between lowland winter pastures and highland summer pastures in the Melendiz and Aladağ mountain ranges. Taken together, these datasets consistently indicate C<sub>3</sub> plant dominance across Central Anatolia throughout the Neolithic and Chalcolithic periods, with the  $\delta^{13}\text{C}$  values of wild equids at Tepecik-Çiftlik falling within the broader regional range established by these herbivore assemblages. The absence of any C<sub>4</sub> signal in the Tepecik-Çiftlik equid dataset is consistent with the interpretation of a predominantly open C<sub>3</sub> grassland environment and distinguishes the site from lowland contexts such as Çatalhöyük, where C<sub>4</sub> saline marsh plants were accessible. This regional comparison, while necessarily limited by differences in taxa, tissue type, and chronological period, provides useful contextual support for the environmental interpretations offered in the present study.

When samples from different layers are compared, both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values are found to cluster within similar ranges throughout the approximately 1,200-year span from ca. 7000 to 5800 cal. BC. At the level of the two identified taxa, the  $\delta^{13}\text{C}$  values of *Equus ferus* (Layers 2-5; mean -21.11‰) and *Equus hemionus hydruntinus* (Layer 10; mean -20.89‰) overlap substantially, indicating that both taxa exploited the same C<sub>3</sub>-dominated open vegetation. The  $\delta^{15}\text{N}$  mean of *E. b. hydruntinus* (8.4‰) is approximately 0.5‰ higher than that of *E. ferus* (7.9‰), a difference that could in principle reflect slight differences in grazing niche, water access, or physiological nitrogen cycling between the two taxa. Equids are hindgut fermenters and wild asses are known to tolerate more xeric conditions than horses and exhibit higher water use efficiency, a pattern reflected in their higher  $\delta^{15}\text{N}$  values (Burnik Šturm et al. 2017; Schoenecker et al. 2016), which may in turn influence  $\delta^{15}\text{N}$  values through body water conservation and associated nitrogen retention (Ambrose 1991). However, the values of the two taxa broadly overlap, the hydruntinus sample size is only two individuals, and both chronological and inter-individual variation cannot be

excluded. This tentative observation is therefore presented purely as a descriptive baseline and cannot be interpreted as evidence of niche differentiation without larger, species-stratified datasets. Human skeletal collagen data from Tepecik-Çiftlik provide independent contextual support for the paleoenvironmental interpretation of C<sub>3</sub> plant dominance. Özdemir et al. (2025) report mean  $\delta^{13}\text{C}$  values of  $-19.5 \pm 0.2\text{‰}$  for Neolithic individuals from the site; together with the wild equid data, these values consistently point to C<sub>3</sub> vegetation dominance and mutually reinforce the regional paleoenvironmental interpretation. It should be noted, however, that the human isotope data reflect dietary intake integrated over an individual's lifetime and therefore do not constitute direct environmental evidence independent of the faunal record. The possibility of a stable environmental background throughout the 7th millennium BC should be regarded as a working hypothesis to be tested in future work with larger sample sizes, preferably three to five individuals per layer, and ideally in conjunction with contemporaneous palaeobotanical or sedimentological evidence.

Zooarchaeological analyses at Tepecik-Çiftlik demonstrate that wild equids were among the most important large mammals hunted at the site, alongside red deer (*Cervus elaphus*), wild boar (*Sus scrofa*), and wild sheep (*Ovis orientalis*) (Gündem 2019).

The co-occurrence of multiple taxa raises the possibility of a mosaic landscape around the Çiftlik Plain during the Neolithic Period, potentially encompassing both wooded/moist and open/dry habitats, an interpretation that finds partial support in the open grassland signal suggested by the  $\delta^{13}\text{C}$  data, although it requires further testing with multi-species isotopic data. The paleogenetic study by Guimaraes et al. (2020), which genetically confirms the widespread presence of wild horses and hydruntines in Anatolia during the Neolithic and Chalcolithic periods, provides an important archaeological context for the isotope data presented here. All environmental interpretations offered in this study should therefore be treated as preliminary findings in need of testing through broader datasets incorporating multi-species isotopic comparisons, larger sample sizes, and complementary palaeoenvironmental proxies.

## Conclusion

This preliminary study presents one of the first region-specific datasets of  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values from the bone collagen of wild equids (*Equus ferus* and *Equus hemionus hydruntinus*) recovered from the Neolithic and Early Chalcolithic layers (ca. 7000-5800 cal. BC) of Tepecik-Çiftlik.

Based on the  $\delta^{13}\text{C}$  data, the results are consistent with a diet based predominantly on C<sub>3</sub> plants and broadly compatible with open grassland and steppe-type vegetation around the Çiftlik Plain during the Neolithic Period, although this interpretation requires further testing with larger datasets and multi-species isotopic comparisons. The  $\delta^{15}\text{N}$  values are elevated relative to northwest European Holocene equid averages. This enrichment

is broadly compatible with the region's semi-arid conditions and soil nitrogen dynamics, though no causal inference is warranted, as  $\delta^{15}\text{N}$  values are influenced by multiple environmental and physiological factors. Given the sample size of one to two individuals per layer, no chronological trends can be reliably identified within the present dataset. The human isotope results from Tepecik-Çiftlik show a similarly restricted range through time, and since both datasets independently indicate  $\text{C}_3$  dominant environment, together they tentatively support the possibility of a relatively stable ecological setting throughout the Neolithic Period. This interpretation should be treated as provisional, pending broader faunal isotopic coverage and complementary palaeoenvironmental evidence.

These findings are of significant importance as a preliminary baseline dataset for building broader comparative isotopic frameworks and for tracking the ecological role of wild equids in Anatolia during the Neolithic and Chalcolithic periods.

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## References

**Ambrose, S.H. 1991**

Effects of Diet, Climate, and Physiology on Nitrogen Isotope Abundances in Terrestrial Food Webs. *Journal of Archaeological Science* 18: 293–317.

- 1993

Isotopic Analysis of Paleodiets: Methodological and Interpretive Considerations. *Investigations Of Ancient Human Tissue: Chemical Analyses in Anthropology*, M. K. Sandford (ed.), Gordon and Breach, Langhorne, PA: 59–130.

- 2000

Controlled Diet and Climate Experiments on Nitrogen Isotope Ratios of Rats. *Biogeochemical Approaches to Paleodietary Analysis*, S.H. Ambrose, M.A. Katzenberg (ed.), Kluwer Academic/Plenum Publishers, New York: 243–263.

**Arbuckle, B.S., Öztan, A. 2018**

Horse and Hemione Hunting at Late Neolithic/Chalcolithic Köşk Höyük, Central Turkey. *Archaeozoology of the Near East XII*: 41–58.

**Bıçakçı, E. 2022**

A Conspectus on the Status of Tepecik-Çiftlik Excavation (Cappadocia): Intersite and Regional Outcomes and Prospects. *6000 BC: Transformation and Change in the Near East and Europe*, P.F. Biehl, E. Rosenstock (ed.), Cambridge University Press, Cambridge: 83–103.

**Bogaard, A., Heaton, T.H.E., Poulton, P., Merbach, I. 2007**

The Impact of Manuring on Nitrogen Isotope Ratios in Cereals: Archaeological Implications for Reconstruction of Diet and Crop Management Practices. *Journal of Archaeological Science* 34: 335–343.

**Burnik -Šturm, M., Ganbaatar, O., Voigt, C.C., Kaczensky, P. 2017**

Sequential Stable Isotope Analysis Reveals Differences in Dietary History of Three Sympatric Equid Species in the Mongolian Gobi. *Journal of Applied Ecology* 54: 1110–1119.

**Cerling, T.E., Hart, J.A., Hart, T.B. 2004**

Stable Isotope Ecology in the Ituri Forest. *Oecologia* 138 (1): 5–12.

**Cormie, A.B., Schwarcz, H.P. 1994**

Stable Isotopes of Nitrogen and Carbon of North American White-Tailed Deer and Implications for Paleodietary and Other Food Web Studies. *Paleogeography, Paleoclimatology, Palaeoecology* 107: 227–241.

**Çakan, Y.G. 2024**

Orta Anadolu Volkanik Kapadokya Bölgesi'nde MÖ 7. Binyıl: Tepecik-Çiftlik Höyük'te Mimari ve Yerleşim Düzeninde Kültürel Değişim Süreci. İstanbul Üniversitesi, Sosyal Bilimler Enstitüsü, Arkeoloji Anabilim Dalı, Tarihöncesi Arkeolojisi Bilim Dalı, (Yayınlanmamış Doktora Tezi), İstanbul.

**DeNiro, M.J. 1985**

Postmortem Preservation and Alteration of In Vivo Bone Collagen Isotope Ratios in Relation to Palaeodietary Reconstruction. *Nature* 317: 806–809.

**DeNiro, M.J., Epstein, S. 1978**

Influence of Diet on the Distribution of Carbon Isotopes in Animals. *Geochimica et Cosmochimica Acta* 42 (5): 495–506.

**DeNiro, M.J., Epstein, S. 1981**

Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45: 341–351.

**Erdal, O., Şen, Ş., Erturaç, M.K., Bıçakçı, E. 2018**

The Rodent Fauna from the Neolithic Human Settlement of Tepecik-Çiftlik (Niğde, Turkey). *Mammalia* 83 (2): 157–179.

**Eisenmann, V. 1986**

Comparative Osteology of Modern and Fossil Horses, Half-Asses, and Asses. *Equids in the Ancient World* 1: 67–116.

**Farquhar, G.D., Ehleringer, J.R., Hubick, K.T. 1989**

Carbon Isotope Discrimination and Photosynthesis. *Annual Review of Plant Biology* 40 (1): 503–537.

**Fraser, R., Bogaard, A., Schäfer, M., Arbogast, R., Heaton, T.H.E. 2013**

Integrating Botanical, Faunal and Human Stable Carbon and Nitrogen Isotope Values to Reconstruct Land Use and Palaeodiets at LBK Vaihing an der Enz, Baden-Württemberg. *World Archaeology* 45: 492–517.

- Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O'Connell, T.C., Hedges, R.E.M.** 2005  
Nitrogen Balance and  $\delta^{15}\text{N}$ : Why You're Not What You Eat During Nutritional Stress. *Rapid Communications in Mass Spectrometry* 19: 2497–2506.
- Grandal-d'Anglade, A., Albizuri, S., López-Cachero, F.J.** 2021  
Equine Diet During Protohistoric Times in the Northeast of the Iberian Peninsula: Stable Isotope Data (C, N) from Bone Collagen. *Data in Brief* 38: 107374.
- Guiry, E.J., Szpak, P.** 2021  
Improved Quality Control Criteria for Stable Carbon and Nitrogen Isotope Measurements of Ancient Bone Collagen. *Journal of Archaeological Science* 132: 105416.
- Guimaraes, S., Arbuckle, B.S., Peters, J., Adcock, S.E., Buitenhuis, H., Chazin, H., Manaseryan, N., Uerpmann, H.P., Grange, T., Geigl, E.M.** 2020  
Ancient DNA Shows Domestic Horses Were Introduced in the Southern Caucasus and Anatolia During the Bronze Age. *Science Advances* 6 (38): eabb0030.
- Gündem, C.Y.** 2019a  
Archaeozoological Study of a Unique Late Neolithic Pit From Tepecik-Çiftlik, Central Turkey. *Anthropozoologica* 54 (11): 97–110.
- 2019b  
MÖ 7. Binyılda Tepecik-Çiftlik Höyük'te Hayvan Ekonomisi'nin Gelişimi ve Evcil Sığırın İç Anadolu Platosu'nda Ortaya Çıkışı. *TÜBA-AR* 25: 27–45.
- Heaton, T.H.E.** 1987  
 $^{15}\text{N}/^{14}\text{N}$  Ratios of Nitrate and Ammonium in Rain at Pretoria, South Africa. *Atmospheric Environment* 21: 843–852.
- 1999  
Spatial, Species, and Temporal Variations in the  $^{13}\text{C}/^{12}\text{C}$  Ratios of  $\text{C}_3$  Plants: Implications for Palaeodiet Studies. *Journal of Archaeological Science* 26: 637–649.
- Hedges, R.E., Clement, J.G., Thomas, C.D.L., O'Connell, T.C.** 2007  
Collagen Turnover in the Adult Femoral Mid-Shaft: Modeled from Anthropogenic Radiocarbon Tracer Measurements. *American Journal of Physical Anthropology* 133 (2): 808–816.
- Itahashi, Y., Stiner, M.C., Erdal, O.D., Duru, G., Erdal, Y.S., Miyake, Y., Güral, D., Yoneda, M., Ozbaşaran, M.** 2021  
The Impact of the Transition from Broad-Spectrum Hunting to Sheep Herding on Human Meat Consumption: Multi-Isotopic Analyses of Human Bone Collagen at Aşıklı Höyük, Turkey. *Journal of Archaeological Science* 136: 105505.
- Kaczensky, P., Burnik Šturm, M., Sablin, M.V. vd.** 2017  
Stable Isotopes Reveal Diet Shift from Pre-Extinction to Reintroduced Przewalski's Horses. *Scientific Reports* 7: 5950.
- Kuzucuoğlu, C., Mouralis, D., Türkecan, A.** 2013  
Geomorphological Mapping As An Illustration of Geomorphological Evolution Reconstruction: The Example of the Çiftlik Plain In Cappadocia (Niğde). *Profesör Doktor İlhan Kayan'a Armağan*, E. Öner (ed.), Ege Üniversitesi Yayınları, İzmir: 134–144.
- Lee-Thorp, J.A., Van der Merwe, N.** 1987  
Carbon Isotope Analysis of Fossil Bone Apatite. *South African Journal of Science* 83 (11): 712–715.

**Longin, R. 1971**

New Method of Collagen Extraction for Radiocarbon Dating. *Nature* 230 (5291): 241–242.

**Macko, S.A., Estep, M.L.F., Hare, P.L., Hoering, T.C. 1982**

Stable Nitrogen and Carbon Isotopic Composition of Individual Amino Acids Isolated from Cultured Microorganisms. *Annual Report of the Director, Geophysical Laboratory, Carnegie Institution*, Washington: 404–410.

**Middleton, C. 2018**

The Beginning of Herding and Animal Management: The Early Development of Caprine Herding on the Konya Plain, Central Anatolia. *Anatolian Studies* 68: 1–31.

**Makarewicz, C.A., Arbuckle, B.S., Öztan, A. 2017**

Vertical Transhumance of Sheep And Goats Identified by Intra-Tooth Sequential Carbon ( $\delta^{13}\text{C}$ ) and Oxygen ( $\delta^{18}\text{O}$ ) Isotopic Analyses: Evidence From Chalcolithic Köşk Höyük, Central Turkey. *Journal of Archaeological Science* 86: 68–80.

- 2018

Carbon And Nitrogen Isotopic Evidence for Sheep And Goat Pastoral Management Practices at Chalcolithic Köşk Höyük, Central Turkey. *Isotopic Investigations of Pastoralism in Prehistory*, 2018: 113–122.

**O’Leary, M.H. 1981**

Carbon Isotope Fractionation in Plants. *Phytochemistry* 20: 553–567.

**Özdemir, K., Irvine, B., Doğan, T., Büyükkarakaya, A.M., Çakan, Y.G., Gündem, C.Y., Kulak, F., Bıçakçı, E. 2025**

Investigation of Dietary Habits in the Neolithic Tepecik-Çiftlik Population. *Journal of Archaeological Science: Reports* 61: 104919.

**Peters, J., Nüeberger, F., Wiechmann, I., Zimmermann, M., Balasse, M., Pöllath, N. 2018**

Shaping the Sheep: Human Management and Decision-Making at Aşıklı Höyük, Central Anatolia. In: Ozbaşaran, M., Duru, G., Stiner, M.C. (ed.), *The Early Settlement of Aşıklı Höyük: Essays in Honor of Ufuk Esin*. Ege Yayınları, İstanbul: 325–344.

**Pearson, J.A., Buitenhuis, H., Hedges, R., Martin, L., Russell, N., Twiss, K.C. 2007**

New Light on Early Caprine Herding Strategies from Isotope Analysis: A Case Study from Neolithic Anatolia. *Journal of Archaeological Science* 34 (12): 2170–2179.

**Robinson, D., Handley, L.L., Scrimgeour, C.M., Gordon, D.C., Forster, B.P., Ellis, R.P.**

2000

Using Stable Isotope Natural Abundances ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ) to Integrate the Stress Responses of Wild Barley (*Hordeum spontaneum* C. Koch) Genotypes. *Journal of Experimental Botany* 51: 41–50.

**Schoeninger, M.J., DeNiro, M.J. 1984**

Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica et Cosmochimica Acta* 48 (4): 625–639.

**Schoenecker, K.A., King, S.R.B., Nordquist, M.K., Nandintsetseg, D., Cao, Q. 2016**

Habitat and Diet of Equids. *Wild Equids – Ecology, Management, and Conservation*, J.I. Ransom, P. Kaczensky (ed.), Johns Hopkins University Press, Baltimore: 41–57.

**Sealy, J., Van der Merwe, N.J., Lee-Thorp, J.A., Lanham, J.L. 1987**

Nitrogen Isotope Ecology in Southern Africa: Implications for Environmental and Dietary Tracing. *Geochimica et Cosmochimica Acta* 51: 2707–2717.

**Sharpe, A.E., Krigbaum, J. 2022**

Introduction: Applications of Isotope Research in Zooarchaeology. *Isotope Research in Zooarchaeology: Methods, Applications, and Advances*, A.E. Sharpe, J. Krigbaum (ed.), University Press of Florida, Florida: 15–20.

**Stiner, M.C., Munro, N.D., Buitenhuis, H., Duru, G., Ozbaşaran, M. 2022**

An Endemic Pathway to Sheep and Goat Domestication at Aşıklı Höyük (Central Anatolia, Turkey). *PNAS* 119 (4): e2110930119.

**Stevens, R.E., Hedges, R.E.M. 2004**

Carbon and Nitrogen Stable Isotope Analysis of Northwest European Horse Bone and Teeth from the Late Pleistocene and Early Holocene: Palaeoenvironmental Implications. *Quaternary Science Reviews* 23 (1–2): 177–191.

**Szpak, P. 2014**

Complexities of Nitrogen Isotope Biogeochemistry in Plant-Soil Systems: Implications for the Study of Ancient Agricultural and Animal Management Practices. *Frontiers in Plant Science* 5: 288.

**Tykot, R.H. 2004**

Stable Isotopes and Diet: You are What You Eat. *Physics Methods in Archaeometry*, M. Martini, M. Milazzo, M. Piacentini (ed.), IOS Press, Amsterdam: 433–444.

**Van der Merwe, N., Vogel, J. 1978**

$^{13}\text{C}$  Content of Human Collagen as a Measure of Prehistoric Diet in Woodland North America. *Nature* 276: 815–816.

**Van Groenigen, J.W., Van Kessel, C. 2002**

Salinity-Induced Patterns of Natural Abundance Carbon-13 and Nitrogen-15 in Plant and Soil. *Soil Science Society of America Journal* 66: 489–498.

**Van Klinken, G.J. 1999**

Bone Collagen Quality Indicators for Palaeodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26 (6): 687–695.

**Von den Driesch, A. 1976**

A Guide to the Measurement of Animal Bones from Archaeological Sites. *Peabody Museum Bulletin* 1. Harvard University, Cambridge.

**Wang, Y., Cerling, T.E., MacFadden, B.J. 1994**

Fossil Horses and Carbon Isotopes: New Evidence for Cenozoic Dietary, Habitat, and Ecosystem Changes in North America. *Paleogeography, Paleoclimatology, Palaeoecology* 107: 269–280.

**Appendix. Osteometric Measurements of Wild Equid Specimens:** Measurements used for species identification. Post-cranial measurements follow Von den Driesch (1976); mandibular measurements follow Eisenmann (1986). Abbreviations: GL = greatest length; Bp = breadth of proximal end; BFp = breadth of proximal articular facet; Dp = depth of proximal end; Bd = breadth of distal end; BFd = breadth of distal articular facet; Dd = depth of distal end. (+/-) indicates an approximate measurement.

**Note:** Sample TP 085.2 (mandible) could not be measured due to fragmentation. Species assignment as *Equus ferus* is based on overall morphological impression. Sample TP 085.2\* is retained with caution; %C and %N values fall below recommended thresholds.