



HAL
open science

Discriminating dietary behaviour between wild and domestic goats using dental microwear texture: first results from a modern reference set and early Neolithic goat exploitation in the southern Levant

Sergio Jiménez-Manchón, Lionel Gourichon, Juan Muñiz, Juan José Ibáñez

► To cite this version:

Sergio Jiménez-Manchón, Lionel Gourichon, Juan Muñiz, Juan José Ibáñez. Discriminating dietary behaviour between wild and domestic goats using dental microwear texture: first results from a modern reference set and early Neolithic goat exploitation in the southern Levant. *Journal of Archaeological Science*, 2023, 155, pp.105779. 10.1016/j.jas.2023.105779 . hal-04120633

HAL Id: hal-04120633

<https://hal.science/hal-04120633>

Submitted on 7 Jun 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Discriminating dietary behaviour between wild and domestic goats using dental microwear texture: first results from a modern reference set and early Neolithic goat exploitation in the southern Levant

Jimenez-Manchon Sergio^{a,*}, Lionel Gourichon^b, Juan Muñoz^c, Juan José Ibáñez^a

^a Archaeology of Social Dynamics (ASD), Consejo Superior de Investigaciones Científicas, Institució Milà I Fontanals, Barcelona, Spain

^b Université Côte d'Azur, CNRS, CEPAM, Nice, France

^c Pontificia Facultad de San Esteban en Salamanca, Salamanca, Spain

ARTICLE INFO

Keywords:

Zooarchaeology
Confocal microscopy
Goat management
Pre-pottery neolithic
Near east

ABSTRACT

Current evidence supports the idea that animal domestication occurred in multiple loci and at different time periods throughout the Near East rather than according to a single origin. In this scenario, the southern Levant is being increasingly considered as another presumed primary centre of goat domestication, alongside eastern Anatolia and the Zagros. Assessing the status (i.e. wild or domestic) of this animal in this region, however, is hampered by the difficulty of morphologically distinguishing domestic goats from their wild relatives. Diet reconstruction is a powerful approach to address this issue since the feeding of managed animals is partially controlled by their owners, unlike free-ranging wild populations. For the first time, we propose to contribute to this question through dental microwear texture analysis (DMTA) using confocal microscopy.

Characterising how the dietary behaviour of extant wild and domestic goats is reflected in DMTA is critical. For this purpose, we constructed a reference collection composed of three wild goat species (19 *Capra pyrenaica* from the southern Iberian Peninsula, 12 *Capra ibex* from the Alps and 12 *Capra nubiana* from the Near East) and 15 domestic goats (*Capra hircus*) reared in an extensive system in Mediterranean scrubland areas.

The preliminary results indicate that DMTA allows discrimination of the groups of extant goats. The results obtained were used to characterise the palaeodiet of 16 goats (*Capra format aegagrus*) from two key Early and Middle Pre-Pottery Neolithic B sites in the southern Levant: Kharaysin (Zarqa, Jordan, ca. 8800-7500 cal BC) and Qarassa (As-Suweyda, Syria, 8700-8200 cal BCE). The higher variability in archaeological goats could be an indicator of controlled feedings. It could also support the hypothesis about diverse and experimental management systems at the first steps of animal domestication.

This paper shows the potential of this tool to address the process of early animal domestication. Following this initial work, the reference collection will include a broader spectrum of livestock management strategies and the archaeological corpus will be expanded through new samples during upcoming excavations and the integration of additional sites.

1. Introduction

The transition from hunting to husbandry in southwestern Asia was a complex process that began during the 9th millennium cal BC (e.g., Kuijt and Goring-Morris, 2002; Arbuckle and Atici, 2013; Edwards, 2016). There is a growing consensus that animal domestication was a broad chronological and spatial process being, therefore, neither rapid nor homogeneous (e.g., Arbuckle, 2014; Vigne et al., 2011; Gourichon and Kolska-Horwitz, 2021). This probably occurred locally through

interconnected events occurring at diverse rhythms across the Near East (Ibáñez et al., 2018).

Sheep and goats had certainly been domesticated in the eastern Anatolian and Zagros regions by the 9th millennium cal BC (Zeder and Hesse, 2000; Peters et al., 2005; Zeder, 2008; Stiner et al., 2022). Domestic sheep were probably introduced into the southern Levant (southern Syria, Jordan, Israel, and the Palestinian territory) from the northern Levant during the 8th millennium cal BC, since wild sheep (*Ovis orientalis*) do not appear to have been native to this area at the

* Corresponding author.

E-mail address: sergiojimenezmanchon@gmail.com (J.-M. Sergio).

<https://doi.org/10.1016/j.jas.2023.105779>

Received 15 December 2022; Received in revised form 20 April 2023; Accepted 20 April 2023

Available online 9 May 2023

0305-4403/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

beginning of the Holocene (Horwitz and Ducos, 1998; Martin and Edwards, 2013). Unlike sheep, wild populations of goats did inhabit this region. Many factors suggest that the southern Levant could have been another primary centre of caprine domestication (Horwitz et al., 1999; Ducos and Kolska-Horwitz, 2003; Arbuckle and Atici, 2013; Gourichon and Kolska-Horwitz, 2021). Evidence for this includes a progressive size reduction, as observed in the Tell Aswad site by the 8th millennium cal BC (Helmer and Gourichon, 2008, 2017), and the predominance of goats (*Capra* format *aegagrus*) in Pre-Pottery Neolithic B (PPNB) sites (c. 8500-7100 cal BC) (e.g., Finlayson and Makarewicz, 2020; Gourichon and Kolska-Horwitz, 2021).

However, distinguishing between domestic goats and their wild relatives in the southern Levant is not straightforward using traditional zooarchaeological lines of evidence, since changes in the morphology and size of archaeological goats is hardly perceptible prior to the Late PPNB (Horwitz et al., 1999). Indeed, phenotypic changes tend to be the result of long-term human intervention and they do not appear in the early stages of animal management, and they may be delayed by regular crossbreeding between controlled animals and their wild congeners present in the surrounding environments (Vigne et al., 2011; Zeder, 2006, 2012). Since domestic animals resembled their wild relatives in the early stages of domestication, it is critical to use other approaches to identify these changes (e.g., Pöllath et al., 2019).

We can expect that the diet of the first managed goats was different to that of wild ones. The animals are likely to have been intentionally foddered by their owners (e.g., supplies of fodder), as evidenced by isotope analyses (Peters et al., 2005; Grupe and Peters, 2008). The reduced human-controlled mobility of managed animals compared to wild ones (e.g., Arbuckle and Atici, 2013; Zimmermann et al., 2018), together with the fact that domestic livestock would have been kept near the settlements for long periods of time, where human impact on natural vegetation had probably generated artificially impoverished niches (Arranz-Oategui et al., 2017), could have altered the dietary regimes of first domesticated animals. In addition, studies on the diet of extant wild and domestic goat populations has shown different dietary behaviours, probably due to physiological and/or cognitive modifications brought about by animal domestication (Cuartas and García-González, 1992). Thus, reconstructing an animal's palaeodiet is a powerful approach that can shed new light on the early process of goat domestication since dietary modifications presumably occurred earlier than skeletal morphologies in domesticated animals.

The use of stable isotope analyses has been explored to characterise animal palaeodiets in central Anatolia (e.g., Peters et al., 2005; Pearson et al., 2007), northern Syria (Torneró and Saña, 2011), and the southern Levant (Makarewicz and Tuross, 2009, 2012; Makarewicz et al., 2016). The main constraints of these analyses are the poor preservation of bone collagen at most Neolithic sites in the Near East (e.g., Weiner and Bar-Yosef, 1990; Grupe, 1995; Miller et al., 2019), and the destructive aspect of the technique. For this reason, other methods that enable animal palaeodiet reconstruction must be explored.

Dental microwear texture analysis (DMTA) is a non-destructive method that reveals the most recent foodstuffs of animals by microscopically analysing the microfeatures produced on the tooth enamel surface by the last intakes of food (e.g., Teaford and Walker, 1984; Gordon, 1984; Scott et al., 2005, 2006). This tool has provided information on the diet of a variety of wild and domestic ungulates, allowing dietary behaviour to be classified (e.g., Walker et al., 1978; Berlioz et al., 2017; Rivals and Álvarez-Lao, 2018; Louail et al., 2022), as well as an analysis of intra-specific variability (e.g., Merceron et al., 2010). For this reason, dental microwear texture is a potential method for identifying behavioural changes in diet that could have occurred prior to any morphometric changes.

Here, we present the first application of DMTA to discriminate between wild and domestic goats. Characterising the inter- and intra-specific variability of extant wild and domestic goats is essential for understanding how their dietary behaviours are reflected in DMTA and

identifying the most discriminant microwear texture parameters. Ideally, we should analyse goats from the same study area (southern Levant), living in the same environmental conditions as in the Pre-Pottery Neolithic. However, this is not possible, as the environment has changed since then, and because wild *Capra* f. *aegagrus* is no longer present in this region. In this regard, we sampled three extant wild goat populations from Europe and the Near East (*Capra pyrenaica*, *C. ibex*, and *C. nubiana*), as well as one domestic population (*Capra hircus*) (Fig. 1). In this pilot study, we looked at a specific herd management strategy in terms of domestic goat feeding. This management strategy consists of letting goats feed in wooded areas of the northern Iberian Peninsula, with no additional fodder supplies. The shepherd herds the goats through similar areas throughout the year; consequently, it is a highly anthropised environment.

We tested the hypotheses that DMTA differs (1) among the different extant wild and domestic goat populations, and (2) between domestic animals and the wild specimens combined into a single group. (3) The intra-group variability was explored for each extant goat population. The diet of wild goats can be influenced by sex and age. In extant wild Iberian goats, it has been reported that young individuals select more grasses than adults, and males consume more ligneous plants than females (e.g., Cuartas et al., 1996). For this reason, we also explored the variability according to (4) the sex and (5) age of the animals. In addition, we analysed (6) seasonal variability, a factor that is known to have influenced palaeodiets (e.g., Merceron et al., 2010; Rivals et al., 2015). Our preliminary results strongly suggested that, despite the existence of certain sex-related variability, intragroup homogeneity and intergroup heterogeneity would allow us to discriminate the distinct groups of goats. Subsequently, the results obtained were used to characterise the palaeodiets of the goats (*Capra* format *aegagrus*) from two key Pre-Pottery Neolithic B sites in the southern Levant: Kharaysin (Zarqa, Jordan, ca. 8800-7500 cal BC) and Tell Qarassa (As-Suweida, Syria, 8700-8200 cal BC).

Thus, in this paper, we explore the potential of DMTA to discriminate between the domestic and wild dietary behaviour of extant goats, and its use in reconstructing the diets of *Capra* f. *aegagrus* from PPNB archaeological samples to better understand the early process of goat domestication in the southern Levant.

2. Material and methods

2.1. Extant reference collection

DMTA was conducted on the mesio-lingual facet of the second lower molar (M2) protoconid. When this was not possible, the analysis was extended to the mesio-lingual facet of the hypoconid of the first (M1) and third (M3) lower molars, since the microwear signal is consistent between molars (Xafis et al., 2017) (Fig. 2). Dental facets have different functions during the chewing cycle; this is the reason why only one facet was selected (Ramdarshan et al., 2017). We built up a reference collection comprised of 58 extant goats, of which 15 are domestic and 43 wild (Table 1 and Supplementary material 1).

2.1.1. Wild goats

Three wild goat species from the southern Iberian Peninsula (*Capra pyrenaica*), the Alps (*Capra ibex*), and the Near East (*Capra nubiana*) were sampled (Fig. 1). Firstly, a set of 19 adult Iberian ibexes, also known as Iberian wild goats (García-González et al., 2021) (*Capra pyrenaica*: 14 females and five males) from the Sierra Nevada and Sierra de Cazorla (Southern Iberian Peninsula), curated at the Estación Experimental de Zonas Áridas-CSIC (Almería, Spain), the Estación Biológica de Doñana-CSIC (Jaca, Spain), and the Parque Nacional de Sierra Nevada (Granada, Spain), were sampled. The osteological collection was developed between 1987 and 2007 in spring ($n = 7$), summer ($n = 7$), and autumn-winter ($n = 3$). The season of death is unknown for three individuals. In terms of diet, this species tends to consume ligneous

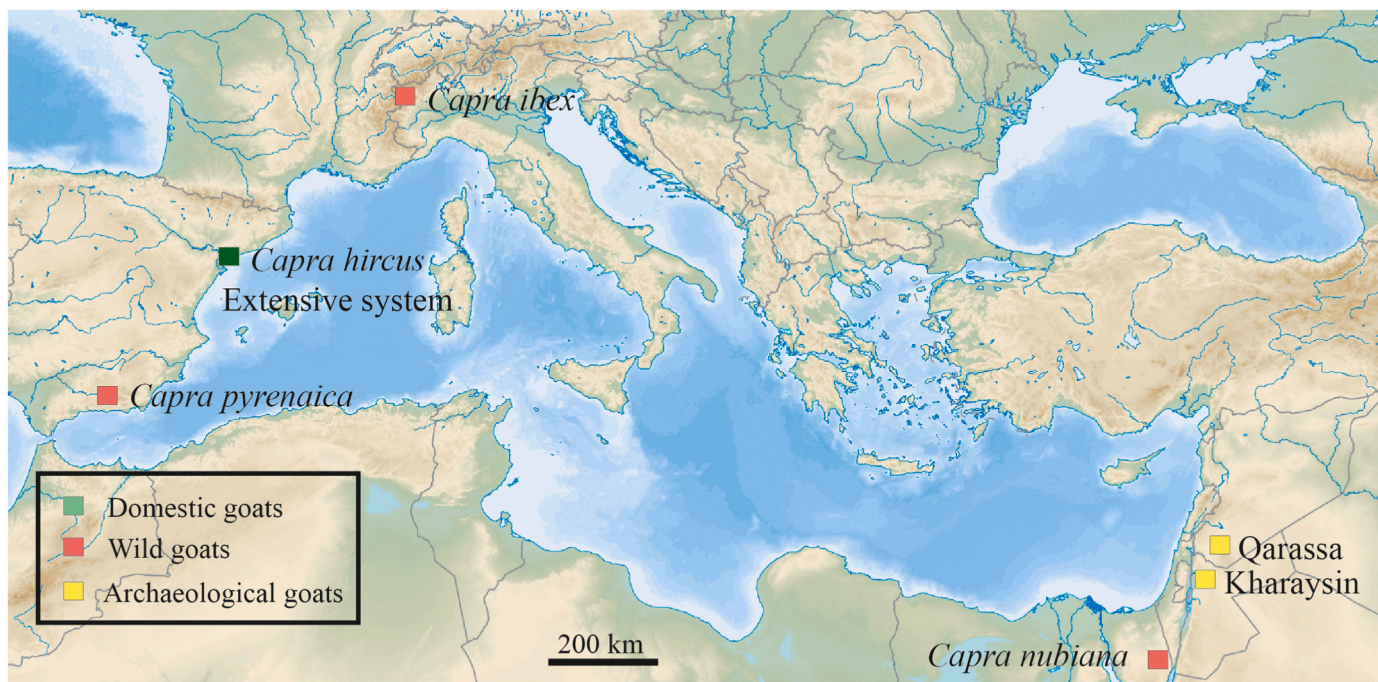


Fig. 1. Location of extant domestic (green), wild (red) and archaeological (yellow) specimens analysed. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

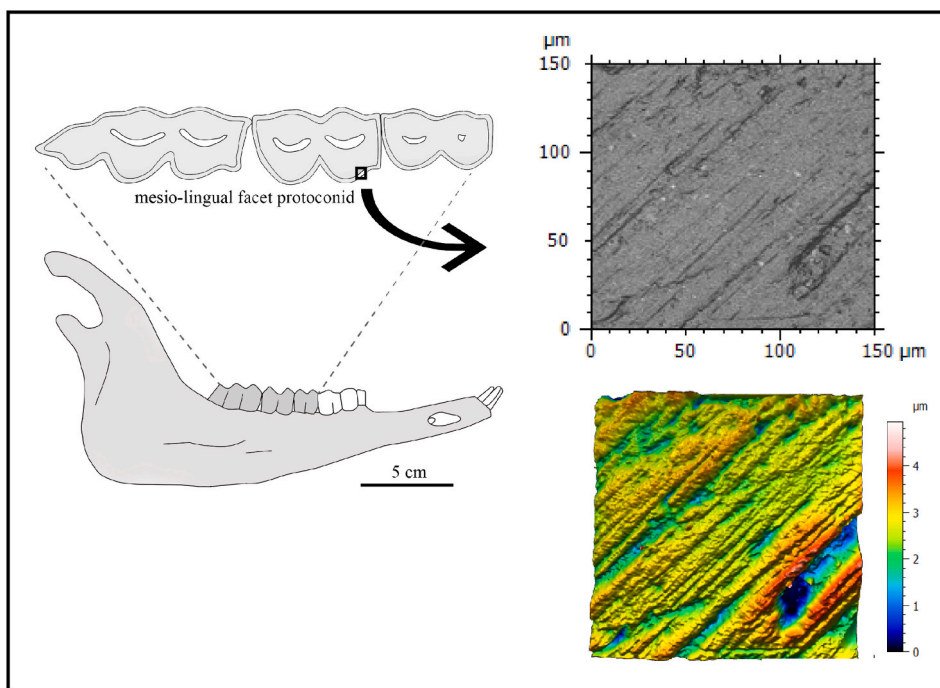


Fig. 2. Examples of central and occlusal views of a right hemimandible of goat, and topography of texture enamel surface of mesio-lingual facet of second lower molar protoconid.

plants, with a representative contribution of graminoids and herbaceous plants (Martinez et al., 1985; Cuartas and García-González, 1992; Cuartas et al., 1996; Martínez, 2000).

Secondly, 12 adult Alpine ibexes (*Capra ibex*: five females and seven males) from Val de Cogne in Val d’Aosta (northwestern Italy) were analysed. The specimens, curated at the Zoological Museum of Strasbourg in France, were collected in 1897 by Hagmann Gottfried. The season of death is not known for any of the specimens. This species has a diet

dominated by herbaceous plants and grasses, although it may vary according to the season (Couturier, 1962; Zingg, 2009; Parrini et al., 2009).

Thirdly, we sampled 12 adult Nubian ibexes (*Capra nubiana*: three females, seven males, and two of unknown sex) from three localities (Wadi Ihmed, Wadi Adani, and Wadi Leithih) on the Sinai Peninsula (Egypt) and in the region of Petra (southern Jordan). The specimens, curated at the Zoological Museum of Strasbourg in France, were collected

Table 1
Number of extant wild and goats studied by species and location.

Species	Number	Status	Location
<i>Capra hircus</i>	15	Domestic (extensive system)	El Pont d'Armentera and Amposta (Tarragona, north-eastern Iberian Peninsula)
<i>Capra pyrenaica</i>	19	Wild	Sierra Cazorla and Sierra Nevada (southern Iberian Peninsula)
<i>Capra ibex</i>	12	Wild	Val de Cogne (Val d'Aosta, north-western Italy)
<i>Capra nubiana</i>	12	Wild	Sinai Peninsula (eastern Egypt) and Petra (southern Jordan)

between 1893 and 1911 between spring ($n = 2$) and summer ($n = 3$). The season of death of the remaining individuals ($n = 7$) is unknown. Nubian goat populations have a flexible diet, with a tendency to graze (Hackham and Ritte, 1991).

2.1.2. Domestic goats

The collection consists of 15 domestic goats (*Capra hircus*: four males and 11 females) of the *Blanca de Rasquera* breed. Four of these were mixed with the *Granadino-Murciana* breed. The specimens, collected in spring ($n = 3$), summer ($n = 9$), and autumn ($n = 3$), come from two nearby areas in southern present-day Catalonia with the same environment (Tarragona province, north-eastern Iberian Peninsula). These goats fed on the vegetation available in wooded areas (500–1000 m), receiving no supplies of additional fodder. The vegetation in the area principally comprises woody plants: holm oak (*Quercus ilex*), kermes oak (*Quercus coccifera*), rosemary (*Salvia rosmarinus*), heather (*Erica* sp.), scorpion broom (*Genista scorpius*), shrubby hare's-ear (*Bupleurum fruticosum*), wild madder (*Rubia peregrina*), and juniper (*Juniperus communis*). Grass plants are also present, e.g., nut grass (*Cyperus rotundus*) and spiny-head mat-rush (*Lomandra longifolia*). The specimens browsed in a similar area throughout the year and, consequently, these goats were fed in an overgrazed environment. Given that the availability of woody plants is poor in this overgrazed environment, the intake of herbaceous plants by goats was representative.

2.2. Archaeological material

The archaeological samples come from two PPNB sites (8800–7500 cal BC) in the southern Levant: Kharaysin (Zarqa, Jordan) and Tell Qarassa (As-Suweyda, Syria) (Fig. 1 and Table 2).

Tell Qarassa is a Pre-Pottery Neolithic site located in the southern part of the region of Leja, 25 km from the Jabal-al-Arab mountains (750 m a.s.l.) and 20 km from the city of As-Suweyda (Ibáñez et al., 2010). The excavations, carried out in 2009 and 2010, uncovered several buildings from the mid-9th millennium cal BC (Early PPNB). The zooarchaeological analysis revealed the predominance of goats (*Capra f. aegagrus*), followed by gazelles, boar, aurochs, carnivores, and other taxa (Ibáñez et al., 2010). A total of three goat teeth, dated to the Early PPNB (8700–8200 cal BC) were available for the dental microwear analysis (Table 2).

Kharaysin is a Pre-Pottery Neolithic site, located in the village of Quneya, in the Zarqa province, covering approximately 25 ha. Four occupation levels have currently been identified from the Late PPNA (beginning of the 9th millennium cal BC) to the beginning of the 7th millennium BC (Late PPNB). The architecture from the Middle PPNB levels is characterised by rectangular houses with lime-plastered floors. The houses were arranged parallel to one another, forming terraced lines on an east-west axis (Ibáñez et al., 2015, 2020). The preliminary zooarchaeological results show the predominance of goats, followed by gazelles, aurochs, and boars. A total of 13 goat teeth, dated to the Middle PPNB (ca. 8300–7600 cal BC), were sampled (Table 2).

The palaeoenvironmental data available for the southern Levant indicates the existence of diverse ecological niches in this region

Table 2

Archaeological specimens studied from Tell Qarassa and Kharaysin. The number of specimens, the taxon, the stratigraphic unit (SU) and the chronology (EPPNB: Early Pre-Pottery Neolithic; MPPNB: Middle Pre-Pottery Neolithic B) are indicated.

Site	Number of specimen	Taxon	SU	Chronology
Kharaysin	2	<i>Capra f. aegagrus</i>	86	MPPNB (8100-7500 cal. BC)
Kharaysin	3	<i>Capra f. aegagrus</i>	134	MPPNB (8100-7500 cal. BC)
Kharaysin	6	<i>Capra f. aegagrus</i>	133	MPPNB (8100-7500 cal. BC)
Kharaysin	8	<i>Capra f. aegagrus</i>	391	MPPNB (8100-7500 cal. BC)
Kharaysin	10	<i>Capra f. aegagrus</i>	402	MPPNB (8100-7500 cal. BC)
Kharaysin	13	<i>Capra f. aegagrus</i>	133	MPPNB (8100-7500 cal. BC)
Kharaysin	18	<i>Capra f. aegagrus</i>	190	MPPNB (8100-7500 cal. BC)
Kharaysin	19	<i>Capra f. aegagrus</i>	385	MPPNB (8100-7500 cal. BC)
Kharaysin	22	<i>Capra f. aegagrus</i>	85	MPPNB (8100-7500 cal. BC)
Kharaysin	25	<i>Capra f. aegagrus</i>	1601	MPPNB (8100-7500 cal. BC)
Kharaysin	29	<i>Capra f. aegagrus</i>	815	MPPNB (8100-7500 cal. BC)
Kharaysin	32	<i>Capra f. aegagrus</i>	391	MPPNB (8100-7500 cal. BC)
Kharaysin	33	<i>Capra f. aegagrus</i>	301	MPPNB (8100-7500 cal. BC)
Tell Qarassa	10	<i>Capra f. aegagrus</i>	25	EPPNB (8500-8100 cal. BC)
Tell Qarassa	17	<i>Capra f. aegagrus</i>	59	EPPNB (8500-8100 cal. BC)
Tell Qarassa	25	<i>Capra f. aegagrus</i>	46	EPPNB (8500-8100 cal. BC)

(Deckers et al., 2009; Asouti et al., 2015). In the inland areas, such as those around Tell Qarassa and Kharaysin, woodland and woodland-steppe formations dominated. This vegetation was mainly composed of eudicotyledons, such as *Pistacia*, *Amygdalus*, and *Quercus* trees; to a lesser extent, there were also patches of grasses (Arranz-Oategui et al., 2017). Another component of the local vegetation at both sites were riparian plants. Mixed Mediterranean deciduous and coniferous forests could have grown in nearby areas, such as Jabal al-Arab Mountain and the Balqa highland.

2.3. Dental microwear analysis

The occlusal surface of all the available teeth (58 extant goats and 16 archaeological samples) was carefully cleaned using acetone followed by 96% ethanol to remove any remaining sediment and dust. This was done using cotton to prevent the surface becoming damaged. The occlusal surface was then moulded using high-precision polyvinylsiloxane (President Light Body, Coltene Waledent). A first impression was made to remove any remaining dust embedded in the occlusal surface, and the second impression was analysed.

The moulds were analysed using a Sensofar Plu Neox white-light scanning confocal microscope housed at the Institutió Milà i Fontanals-CSIC (Barcelona, Spain) and employing the SensoSCAN® acquisition software package. For each facet, an area of $150 \times 150 \mu\text{m}$ was selected from images of $255 \times 191 \mu\text{m}$ taken using a 50x (0.80 NA) objective lens (Fig. 2). The selected areas ($150 \times 150 \mu\text{m}$) were treated and measured using MountainsMap 7® (Digital Surf). Firstly, the samples were inverted along the z-axis, since negative moulds were analysed. The least-square (LS) plan method was used to correct the lack of horizontality of the sample. The occlusal surface of the tooth generally presents a curved morphology. Consequently, the curvature was

eliminated using a polynomial function (power 8; Francisco et al., 2018). Finally, the extreme points were eliminated (upper and lower 0.5%) to remove outliers.

For the archaeological samples, any teeth whose surface was altered by post-depositional agents were discarded from this analysis. The identification of non-dietary traces was based on several experimental works (i.e., King et al., 1999; El-Zaatari, 2010; Dauphin et al., 2018; Weber et al., 2020; Uzunidis et al., 2021).

2.4. Statistical analysis

Dental microwear texture analysis was quantified using two methods in MountainsMap 7®: (1) scale-sensitive fractal analysis (SSFA); and (2) standard roughness (ISO 25178) and flatness (12781) ISO (International Standard Organization; Leach, 2013). On the one hand, three SSFA parameters were measured: anisotropy (EpLsar), complexity (Asfc), and heterogeneity of complexity (HASfc9) (Scott et al., 2005, 2006). On the other hand, 34 ISO parameters relating to the height, volume, direction, peak sharpness, and plateau size were obtained (Table 3). The information gathered was assigned to five datasets according to the hypotheses: (1) sexual feeding variability; (2) seasonal variability; (3) age variability; (4) discrimination between different wild and domestic goat populations; and (5) discrimination according to status (wild versus domestic).

The variability between males and females was analysed for the *Capra pyrenaica* population from the southern Iberian Peninsula and *Capra ibex* from the Alps. The analysis of seasonal variability was possible in individuals from the southern Iberian Peninsula wild goat population that had died in the spring ($n = 5$) and summer ($n = 7$). Age variability was analysed in ibexes from the southern Iberian Peninsula: 12 adults (2–6 years), and six older specimens (6–10 years). The non-parametric Mann-Whitney test was performed on the ISO and SSFA parameters to explore the null hypothesis that dental microwear does not vary according to season or sex. SSFA and ISO parameters that differed between the groups were explored using univariate plots indicating the mean and the standard error.

The set used to test the hypothesis that dental microwear differs between distinct wild and domestic goat populations comprised four groups: the wild goat populations from the southern Iberian Peninsula, Alps, and Near East; and domestic goats reared in woodland areas. The three populations of wild goats were subsequently combined into a single category to test the hypothesis that DMTA differs according to status (i.e. domestic versus wild).

In both cases, the following procedure was used. SSFA parameters (epLsar, Asfc, and Hasfc9) were explored through univariate plots. The non-parametric Mann-Whitney test was used to analyse the presence of significant differences in the SSFA. The statistical procedure applied to the ISO parameters was adapted from previous works (e.g., Adams et al., 2020; Francisco et al., 2021; McLennan and Purnell, 2021). The ISO parameters were log-transformed to increase the normality and homoscedasticity. According to a Shapiro-Wilks test, the data were normally distributed, so parametric tests were used. An analysis of variance (ANOVA) was constructed. When the homogeneity of variance test (Levene test) showed significant differences, Welch's ANOVA was used. A linear discriminant analysis (LDA), based on the ISO texture parameters that presented significant differences, was constructed. When Box's M test was violated ($p \leq 0.05$), a quadratic discriminant analysis (QDA) was performed. The significance of the QDA and LDA was assessed using Wilks' lambda. All the statistical analyses were carried out using the IBM SPSS 26® statistics software package.

3. Results

3.1. Sexual variability

The results obtained from the SSFA and ISO parameters show no

Table 3
Description and functional groups of the ISO and SSFA parameters.

Abbreviation	Description	Functional group
epLsar (SSFA)	Anisotropy	Direction
Asfc (SSFA)	Area-scale complexity	Complexity
Hasfc9 (SSFA)	Heterogeneity	Heterogeneity of complexity
Sq (ISO parameter)	Root mean square height	Height
Sku (ISO parameter)	Kurtosis of the height distribution	Height
Sp (ISO parameter)	Maximum peak height	Height
Sv (ISO parameter)	Depth between the mean plane and the deepest valley	Height
Sz (ISO parameter)	Height between the highest peak and the deepest valley	Height
Sa (ISO parameter)	Arithmetic mean height	Height
Smr (ISO parameter)	Peak material proportion	Functional
Smc (ISO parameter)	Inverse areal material ratio	Plateau size
Sal (ISO parameter)	Auto-correlation height	Density
Str (ISO parameter)	Texture aspect ratio	Spatial
Std (ISO parameter)	Texture direction	Spatial
Vm (ISO parameter)	Material volume at a given material ratio	Volume
Vv (ISO parameter)	Void volume of the core	Volume
Vmp (ISO parameter)	Material volume of the core at given material ratio	Volume
Vmc (ISO parameter)	Material volume of the core at given material ratio	Volume
Vvc (ISO parameter)	Void volume of the core	Volume
Vvv (ISO parameter)	Dale void volume	Volume
Spd (ISO parameter)	Density of peaks	Feature
Spc (ISO parameter)	Arithmetic mean peak curvature	Feature
s10z (ISO parameter)	Ten-point height	Height
s5p (ISO parameter)	Five-point height	Height
s5v (ISO parameter)	Five-point pit height	Height
Sda (ISO parameter)	Closed dale area	Area
Sha (ISO parameter)	Closed hill area	Area
Sdv (ISO parameter)	Mean dale volume	Feature
Shv (ISO parameter)	Mean hill volume	Feature
Sk (ISO parameter)	Core height	Functional
Spk (ISO parameter)	Peak reduced height	Functional
Svk (ISO parameter)	Reduced dale height, Reduced valley depth	Functional
Smr1 (ISO parameter)	Low peak material portion	Functional
Smr2 (ISO parameter)	High peak material portion	Functional

significant differences between males and females in the wild goat population from the Alps (*Capra ibex*) (Supplementary material 2). In the population from the southern Iberian Peninsula (*Capra pyrenaica*), significant differences were found in Smr2 and Svk (Fig. 3 and Supplementary material 2). Svk and Smr2 are two functional parameters that reflect surface roughness (Table 1), more specifically, the depth of the

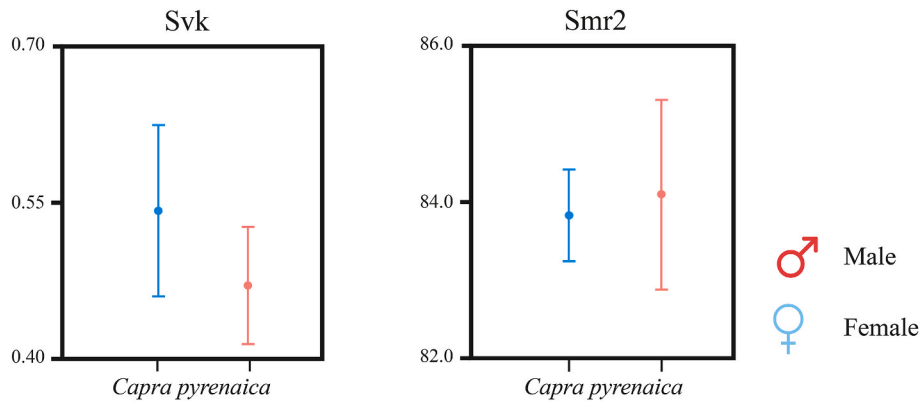


Fig. 3. The mean and standard error (SE) of Svk and Smr2 parameters by sex *Capra pyrenaica*.

valleys. From Fig. 3, it can be seen that the dental texture wear of the male goats involves deeper valleys than recorded for females (Svk parameter).

3.2. Seasonal variability

The seasonal variability between spring and summer in the *Capra pyrenaica* wild goat population shows no significant differences in ISO parameters (Supplementary material 3). For SSFA parameters, even though no significant differences were found, the surface tooth texture of wild goats which died in the spring months was characterised by a higher degree of complexity (Asfc) than that of goats which died in the summer, but these differences are not significant.

3.3. Age variability

No significant differences in either the ISO or SSFA parameters were found between adult (2–6 years) and older specimens (<6 years) in the *Capra pyrenaica* wild goat population (Supplementary material 4).

3.4. Inter-group variability

The results obtained for the set of SSFA parameters show that domestic goats present significantly lower complexity values (Asfc) than wild goats (Fig. 4). In terms of anisotropy (epLsar), domestic goats present slightly higher values than wild goats, even though these trends are not significantly different (Supplementary material 4).

The analysis of variance (ANOVA), carried out on the ISO parameters, indicated significant differences between goat populations in 24 parameters (Supplementary material 4). Subsequently, a Quadratic Discriminant Analysis (Box’s M test = 40.156; gl = 18; $p > 0.007$) was performed on the basis of these parameters. The QDA removed seven parameters (s5p, Vmp, Spk, Vvv, Vvc, Vv, and Sdv). The Wilks’ lambda test indicated that there were significant differences between the four goat groups (WL = 0.116; Khi2 = 100.101; gl = 51; $p < 0.001$). The QDA classification was correct for 82.8% of the entire sample. Wild goats from the Near East (91.7%) and the southern Iberian Peninsula (100%) were the most accurately classified, followed by the domestic animals (80%). The wild goat population from the Alps (73.7%) was

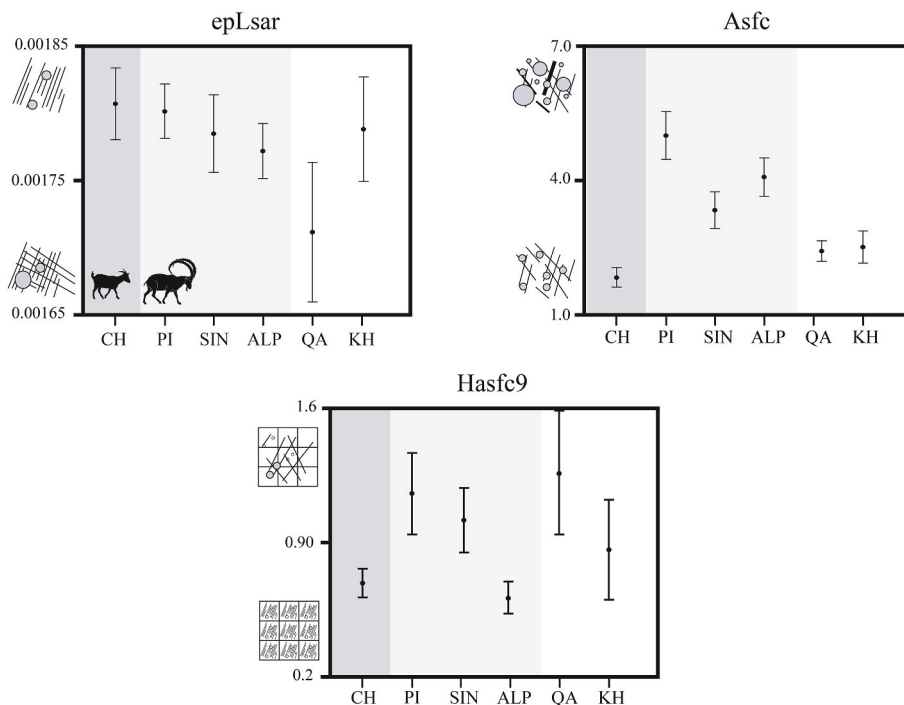


Fig. 4. Mean and standard error (SE) of SSFA parameters by goat population and archaeological site (CH = domestic goat reared in an extensive system; CP= *Capra pyrenaica*; CI= *Capra ibex*; CN= *Capra nubiana*; Kh = Kharaysin; Qa = Tell Qarassa).

more poorly classified (Table 4 and Supplementary material 6).

Domestic and wild goat populations occupy different areas of the QDA texture-diet plot (discriminant function1, DF1 = 52.4%; discriminant function 2, DF2 = 32.4%) (Fig. 5A). The domestic goats have significantly more negative DF1 values than the wild goat populations ($t = 13.512, p < 0.001$). According to the discriminant coefficients (Supplementary material 7), negative DF1 values represent reduced peaks and valleys, and not a very rough surface (Sq, Sz, and Vmc parameters). The three wild goat populations occupy different areas along the DF2 axis (38.4%). According to the discriminant coefficients, parameters related to height (Sq and Sa), peak sharpness (Spc), and function (Svk) can be discriminated between distinct wild goat populations living in different ecological niches.

3.5. Status variability

The results show the presence of significant differences between domestic and wild goats in terms of complexity (Asfc) (Fig. 6). This data indicates that domestic goats present a lower degree of complexity than wild ones. There were no significant anisotropy (epLsar) or heterogeneity (Hasfc9) differences between these two groups (Supplementary material 8).

The Analysis of Variance (ANOVA) showed the presence of significant differences in 23 ISO parameters (Supplementary material 8). The LDA (Box's M test = 2.286; $g1 = 1; p = 0.136$), constructed on the basis of these parameters, removed four parameters (Vmp, Vv, Vvv, and Vvc). Wilks' lambda indicated that there were significant differences between the two groups (WL = 0.412; $Khi2 = 41.194; g1 = 19; p = 0.002$). The classification was correct for 89.7% of the samples. In more detail, 80% of the domestic goats were classified correctly, as were 93% of the wild goats (Table 5 and Supplementary material 9). According to the discriminant coefficients (Supplementary material 10), the tooth surface texture of domestic goats presented small height ranges (Sp and Sv parameters) and a low degree of roughness (Smc), suggesting that the surfaces were more polished than those of wild goat teeth (Fig. 7).

3.6. Archaeological samples

The results obtained through the SSFA parameters show that the goats from Tell Qarassa ($n = 3$) and Kharaysin ($n = 13$) have intermediate anisotropy (epLsar), heterogeneity (Hasfc9) and complexity (Asfc) values (Figs. 4 and 6).

The archaeological samples from Tell Qarassa and Kharaysin were added to the Quadratic Discriminant Analysis (Fig. 5B). Two goats from Qarassa presented negative values for DF1, and one individual had values close to '0'. The samples from Kharaysin presented a high degree of variability. Four individuals had negative values for DF1, six individuals plotted close to '0', and three other specimens presented positive values. The variability of the specimens from Kharaysin is higher than for any of the extant wild or domestic goat populations

Table 4
Classification of each extant wild and domestic goat group using the classification rule obtained from Quadratic Discriminant Analysis (QDA).

Extant wild and domestic goat groups	<i>Capra hircus</i> (Extensive system)	<i>Capra ibex</i>	<i>Capra nubiana</i>	<i>Capra pyrenaica</i>
<i>Capra hircus</i> (extensive system)	12 (80%)	2 (13.3%)	1 (6.8%)	–
<i>Capra ibex</i>	–	11 (91.7%)	–	1 (8.3%)
<i>Capra nubiana</i>	–	1 (8.4%)	11 (91.7%)	–
<i>Capra ibex</i>	–	2 (10.5%)	3 (15.8%)	14 (73.7%)

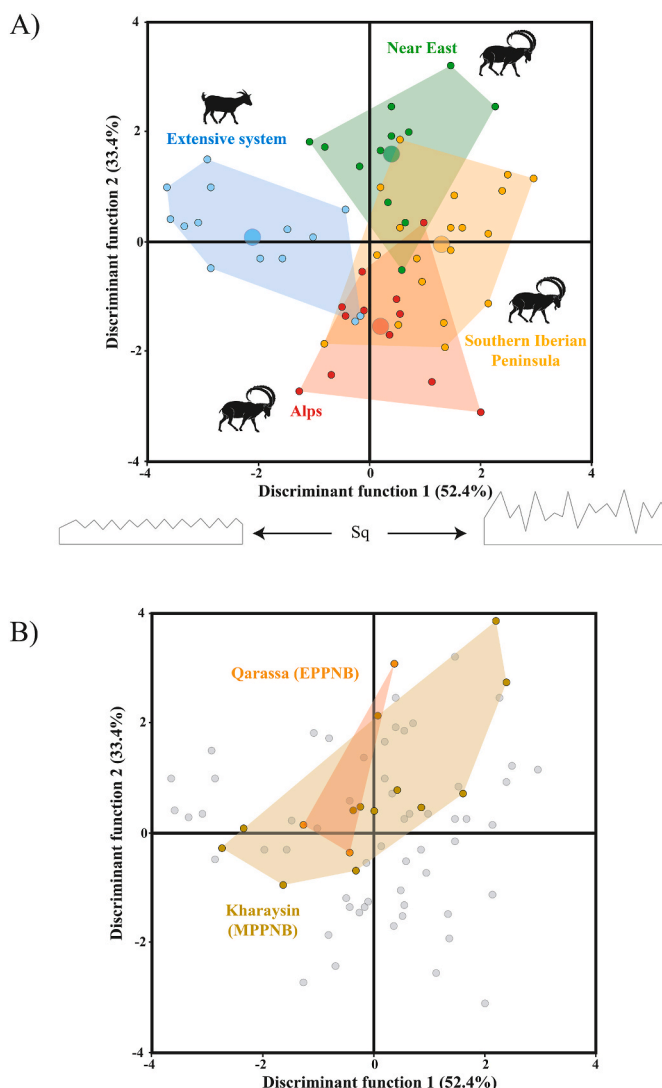


Fig. 5. (A) Quadratic discriminant analysis (QDA) of ISO parameters that exhibit significant differences between different wild and domestic goat populations. The circle shows the centroid for each group. (B) Plot of archaeological specimens of Tell Qarassa and Kharaysin according to the QDA conducted on extant specimens.

(Fig. 8).

The predictive model obtained for domestic and wild goats using the LDA was used to classify the archaeological specimens (Table 6). One of the three goats from Tell Qarassa was classified as being “domestic”. Three individuals from the Kharaysin site (23.1%) were classified as being “domestic” and the rest (76.9%) as “wild”.

4. Discussion

4.1. DMTA can discriminate between extant wild and domestic goats

In this work, we analysed three extant wild goat populations (*Capra pyrenaica*, *Capra ibex* and *Capra nubiana*) from three different regions (the southern Iberian Peninsula, northwestern Italy, and the Near East, respectively), and a domestic goat population (*Capra hircus*) reared in an extensive system, in wooded areas, in the northeastern Iberian Peninsula. We explored whether, and how, DMTA differs between these four goat groups.

DMTA conducted on the dental occlusal surface enabled the domestic goats analysed and the three groups of wild goats combined

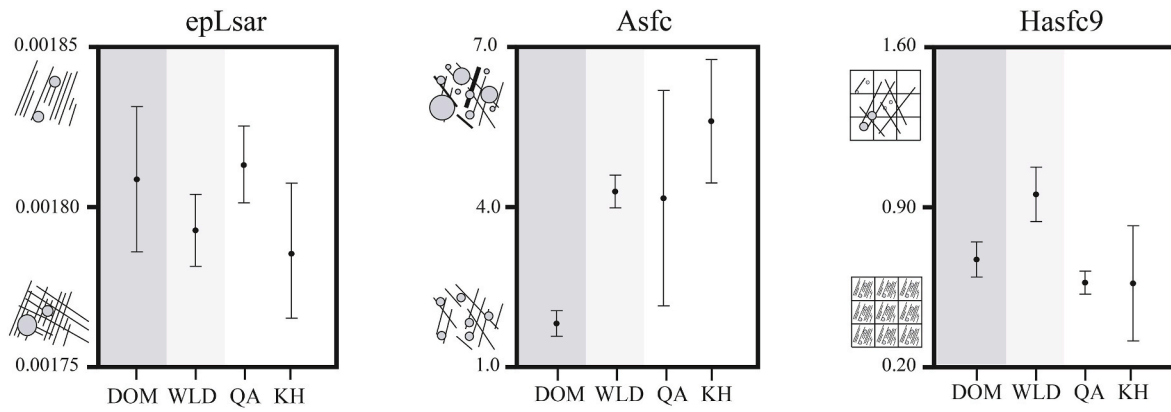


Fig. 6. Mean and standard error (SE) of SSFA parameters by goat status and archaeological site (DOM = domestic; WLD = wild; Kh = Kharaysin; Qa = Tell Qarassa).

Table 5

Classification of extant domestic and wild specimens (combined in a single group) using the classificatory rule obtained from Linear Discriminant Analysis (LDA).

Goat status	Domestic goats	Wild goats
Domestic goats	12 (80%)	3 (20%)
Wild goats	3 (7%)	40 (93%)

together to be distinguished. The dental microwear surfaces in the domestic goats are less rough and less complex than those of the combined wild goat populations, which have rougher and more complex tooth surfaces. The analysis conducted using the four groups individually showed the same trends. The domestic goats exhibit less complex and

more abraded surfaces than the three wild goat populations, which lived in diverse ecological niches. Overall, the tooth surface texture in the domestic goats and the three wild goat populations present different degrees of abrasion.

In this study, a single herd management strategy was studied. The domestic goats analysed were fed in an overgrazed and human-modified environment, as the shepherd herds the goats through similar pastures throughout the year. Given the low availability of woody plants, the ingestion of herbaceous plants close to the ground by the domestic goats was representative (see 2.1.2). The high degree of abrasion on the dental surface of domestic goats could be explained by mechanical factors related to the intake of grasses and dust (Scott et al., 2006; Merceron et al., 2016). However, there are other factors that could contribute to these differences.

Physiological factors, such as the muscle force used during the

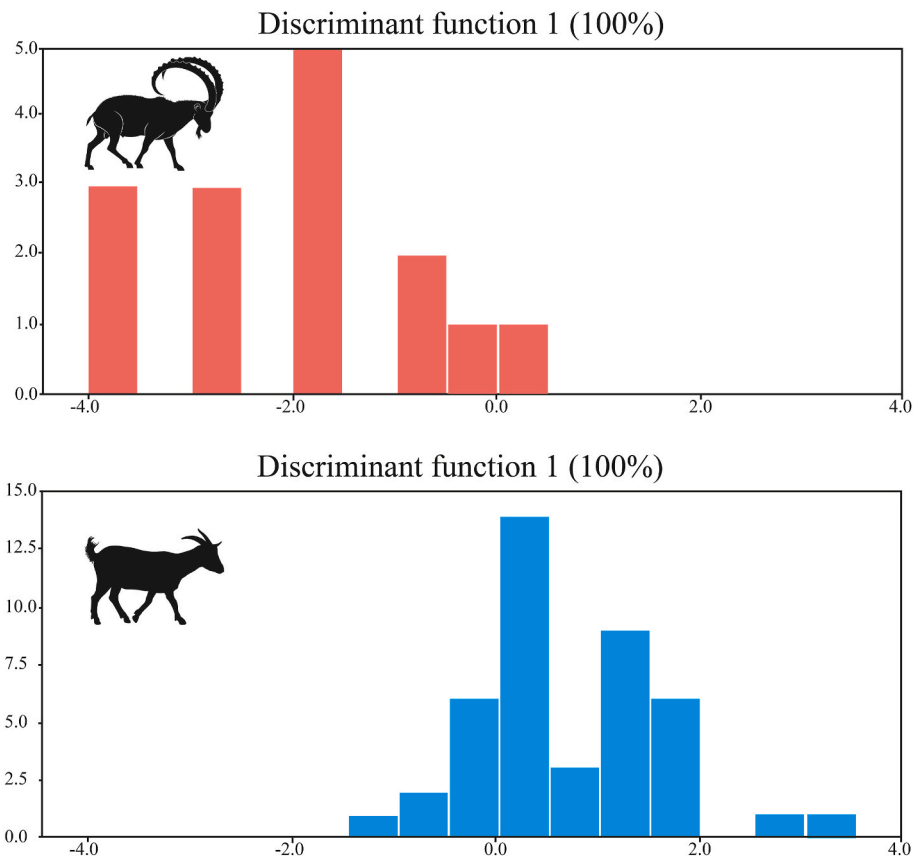


Fig. 7. Linear Discriminant Analysis (LDA) of ISO that exhibit significant differences between domestic and wild goats (combined in a single group).

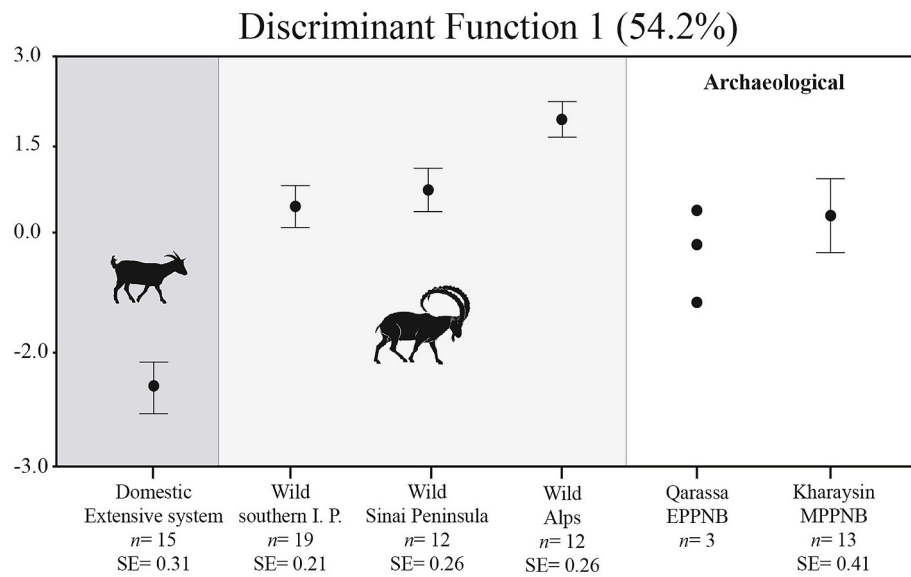


Fig. 8. QDA scores (Discriminant Function 1 = 54.2%) by extant population of goats and archaeological specimens, showing mean and standard error (SE).

Table 6

Classification of each archaeological specimen according to the results obtained from Linear Discriminant Analysis (LDA) conducted on extant domestic and wild specimens (combined in a single group).

Site	Number of specimens	Taxon	Domestic	Wild
Kharaysin	2	<i>Capra f. aegagrus</i>	0.44318	0.55682
Kharaysin	3	<i>Capra f. aegagrus</i>	0.00018	0.99982
Kharaysin	6	<i>Capra f. aegagrus</i>	0.38610	0.61390
Kharaysin	8	<i>Capra f. aegagrus</i>	0.00172	0.99828
Kharaysin	10	<i>Capra f. aegagrus</i>	0.00050	0.99950
Kharaysin	13	<i>Capra f. aegagrus</i>	0.98929	0.01071
Kharaysin	18	<i>Capra f. aegagrus</i>	0.05936	0.94064
Kharaysin	19	<i>Capra f. aegagrus</i>	0.06523	0.93477
Kharaysin	22	<i>Capra f. aegagrus</i>	0.44440	0.55560
Kharaysin	25	<i>Capra f. aegagrus</i>	0.90070	0.09930
Kharaysin	29	<i>Capra f. aegagrus</i>	0.15523	0.84477
Kharaysin	32	<i>Capra f. aegagrus</i>	0.01996	0.98004
Kharaysin	33	<i>Capra f. aegagrus</i>	0.99805	0.00195
Tell Qarassa	10	<i>Capra f. aegagrus</i>	0.23527	0.76473
Tell Qarassa	17	<i>Capra f. aegagrus</i>	0.99789	0.00211
Tell Qarassa	25	<i>Capra f. aegagrus</i>	0.11083	0.88917

chewing process, may also contribute to dental microwear signals. In this sense, Harbers et al. (2020) showed changes in locomotor muscles forces between free-ranging and captive wild boars. Digestive physiology should also be taken into consideration. Ingested dust and grit are washed off by the liquid of the rumen, thus reducing the abrasive load on the teeth (Hatt et al., 2019, 2020). The rumination process varies according to the type of diet, the sex of the animal (e.g., Gross et al., 1995), and between ruminants (e.g., Clauss et al., 2009).

The effect of animal domestication on digestive physiology cannot be ruled out (Clauss et al., 2006). In this sense, some authors have proposed that one effect of the domestication process would have been a relatively high ruminal volume in caprines (García-González, 1987; Cuartas and García-González, 1992). This change in ruminal volume could have led to a change in the rumination process. In addition, domestic goats tend to select more ligneous vegetation in comparison to wild ones (García-González and Cuartas, 1989; Cuartas and García-González, 1992, 1993; Cuartas et al., 1996; Aldezabal et al., 2002), which could have led to different rumination times.

In this work, we focused on one single domestic goat management strategy (extensive system in overgrazed areas). For this reason, these preliminary results must be taken with caution. It highlights the need to analyse further domestic goat populations fed using different

management strategies (e.g., grasses and/or fodder).

The DMTA also allowed the three wild goat species to be distinguished. They inhabit different ecological niches with diverse food availability. The significant differences observed between the three populations probably correspond to this ecological diversity. The ibexes from the southern Iberian Peninsula (*C. pyrenaica*) present the highest values of slope, plateau size and complexity among the wild goats studied. This is probably due to the fact that, of these three goat populations, the diet of this group includes the highest proportion of ligneous plants (e.g., Martínez, 2000). The Nubian and Alpine goats present lower values, likely because the intake of herbaceous plants is higher for these two species (Couturier, 1962; Zingg, 2009; Parrini et al., 2009; Gross et al., 1995; Hackham and Ritte, 1991).

4.2. The effect of seasonality, age and sex on DMTA

Seasonal and sexual variability can affect DMTA, as reported in previous studies on extant ungulate populations (e.g., Merceron et al., 2010; Rivals et al., 2015; Uzunidis, 2020; Merceron et al., 2021). In this work, we explored how these factors can affect DMTA in goats, and how they can be taken into account to characterise archaeological goat palaeodiets.

A portion of the samples from the osteological collections lacked information related to season of death and sex. For this reason, the number of specimens for which seasonal- and sex-related variability could be analysed in this study is limited.

In terms of social behaviour in extant wild goat populations, males and females are segregated according to the season (e.g., Villaret et al., 1997; Granados et al., 2001). Group size (unisex or mixed), and the areas of vegetation that these access vary according to both season and sex. In this paper, the DMTA conducted on extant goat populations showed significant differences between males and females in *C. pyrenaica*, which could be related to their behavioural segregation. Conversely, no significant differences were found related to seasonal variability. However, the low number of specimens analysed must also be taken into account. In future work, the use of techniques that distinguish the seasonality of the last food intakes, such as dental cementum analysis (Monks, 1981; Naji et al., 2015, 2022; Jiménez-Manchón et al., forthcoming), should be included.

The results presented in this study show no significant differences between adults and older individuals. These results are consistent with studies on extant Iberian ibexes, where differences have only been found

between adults and the youngest specimens (<2 years; [Granados et al., 2001](#)). In future work, other factors that may affect variability in the DMTA, such as the use of different facets and teeth, will be analysed.

4.3. Reconstruction of goat diets in the early and middle PPNB sites of Tell Qarassa and Kharaysin

We analysed the surface enamel texture of goats (*Capra f. aegagrus*) from two PPNB sites in the southern Levant: Tell Qarassa and Kharaysin. In these contexts, the goat is the most-common taxon, as is the case in the majority of the Neolithic sites from this region dated to the same period ([Horwitz et al., 1999](#); [Martin and Edwards, 2013](#); [Munro et al., 2018](#); [Gourichon and Kolska-Horwitz, 2021](#)). However, the status of *Capra f. aegagrus* is very difficult to determine. This paper, represents the first attempt to explore the use of DMTA to characterise and infer the status of PPNB goats.

For the Early PPNB site of Tell Qarassa, the ISO parameters reveal surface textures characterised by intermediate height and volume values. The SSFA parameters show intermediate isotropy and complexity, suggesting that both grasses and woody plants were consumed. The palaeoenvironmental data from Tell Qarassa evidences the presence of open Savannah-type landscapes with grasslands and trees suitable for agropastoral activities ([Arranz-Oategui et al., 2017](#)). The results obtained from the DMTA fit this scenario. However, caution must be exercised due to the low number of specimens analysed.

At Kharaysin, the specimens tend to present a surface enamel texture with values that are compatible with the intake of ligneous plants. According to preliminary carpological studies, eudicotyledonous plants were predominant ([Ibáñez et al., 2019](#)).

The large variability seen in the Kharaysin goats is noteworthy. This variability is greater than in any of the extant goat populations analysed in this work. This cannot be due to the presence of different species of *Capra* because no *Capra nubiana* remains have been identified at this site so far. However, the osteological discrimination between *C. nubiana* and *C. aegagrus* has to be taken into account. Indeed, based on mitochondrial DNA analysis, a few bones of *Capra nubiana* has been identified in Pre-Pottery Neolithic levels at the southern-levantine site of Abu Ghosh ([Bar-Gal et al., 2002](#)).

Ecological and environmental factors can be rejected. On the one hand, it does not seem likely that the inhabitants of Kharaysin could have regularly hunted beyond a 20 km radius from the settlement. On the other hand, the preliminary palaeoenvironmental data suggest that there were no significant changes during the 9th and 8th millennia BC. In this sense, the further study gazelle diets, a wild ungulate that was not domesticated, could provide more information for comparison.

The specimens of the extant goat populations we analysed died in different seasons and correspond to both males and females ([Supplementary material 1](#)). These factors could have affected the DMTA (see Section 4.2), resulting in increased intra-group variability. Even so, the variability observed in the PPNB goats from the Kharaysin site is higher still. For this reason, we think that the greater variability is not related to either sex or season of death.

The tooth microwear diversity in the Kharaysin goats could be an indicator of human-controlled feeding behaviours. The concomitant occurrence of wild goat hunting and experimental management systems could explain this high degree of variability. Managed goats would have grazed in areas close to the site, possibly in a human-modified landscape, in croplands and/or livestock pens. In this sense, at Tell Qarassa, coprophilous fungi have been identified in the surroundings of the site ([Arranz-Oategui et al., 2017](#)). New experimental programmes assessing extant domestic populations are needed to improve our understanding of the diet of early managed goats.

Stable carbon and nitrogen isotope analyses conducted on *Capra* specimens from the MPPNB site of Abu Ghosh and Late PPNB site of Basta have shown a wide variability in goat diet, higher than in gazelles, which has been related to the presence of early managed animals

([Makarewicz and Tuross, 2012](#)). Reduction in goat body size in Middle PPNB sites, such as Tell Aswad, Kfar Hahores and Yiftah'el sites, suggests the presence of early managed animals at more or less the same period of the MPPNB levels of Kharaysin ([Helmer and Gourichon, 2008, 2017](#); [Munro et al., 2018](#); [Sapir-Hen et al., 2016](#)). The classification of three of the 12 archaeological specimens of Kharaysin as "domestic" supports this explanation. Regarding Tell Qarassa, whose occupations date back to the EPPNB, the status of the exploited goats is still uncertain, although one the three teeth analysed was classified as closer to the present-day domestic goats than to the comparative wild populations.

5. Conclusions

In this paper, we explored the use of DMTA to discriminate dietary behaviour between wild and domestic goats. The DMTA applied to extant populations demonstrates that this method facilitates the correct differentiation of wild and domestic goats. In general, domestic goats present a more abraded tooth texture surface than wild ones. This greater degree of abrasion may be due to mechanical factors, related to the intake of a high amount of dust/grit and grasses in a human-modified environment, since domestic goats generally browse in similar areas throughout the year, very probably in overgrazed pastures. Physiological agents, such as digestive physiology and muscle force differences between wild and domestic goats, cannot be ruled out, possibly in addition to the first factor mentioned above. The intragroup variability results obtained show that, despite the existence of a certain level of variability related to sex and the season of death, the intragroup values of extant wild and domestic goats are homogeneous. However, caution must be exercised as the sample sizes studied were quite small and because only one goat management strategy was taken into account.

The DMTA conducted on *Capra f. aegagrus* from two key Pre-Pottery Neolithic B sites from the southern Levant (Tell Qarassa and Kharaysin) showed great variability in the dental microwear texture, suggesting the presence of diversified diets. The variability of specimens from these sites is greater than for any of the extant wild or domestic goat populations studied and could reflect the occurrence of both hunted and controlled goats in the faunal assemblages. These preliminary results could support the hypothesis that humans manipulated certain goats and, therefore, evidence the initial experimentation with goat management strategies in the southern Levant during the 9th and 8th millennia BC.

The aim of this paper was to explore and provide a new line of evidence to identify the behavioural changes in early human-controlled goats that may have occurred prior to the appearance of clear morphometric changes. Our results show that DMTA can be a relevant proxy to investigate goat domestication and early husbandry practices. Future works will need to consider a broader spectrum of livestock management strategies and a larger archaeological corpus.

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.

Acknowledgements

This work was funded by a Fyssen Foundation research fellowship (Paris, France) and Grant FJC 2021-046527-I funded by MCIN/AEI/10.13039/501100011033 and "European Union NextGenerationEU/PRTR". It has also been funded by the Spanish Ministry of Science (PID 2019-105767 GB-I00) and is part of the project PDC 2021-121613-I00, funded by MCIN/AEI/10.13039/501100011033 and the "European Union NextGeneration EU"/PRTR. The authors thank to Xavier Pons, Eco Bosc de Miralles, Zoological Museum of Strasbourg (Strasbourg, France; special thanks are given to Dr. Marie Meister and Dr. Rose-Marie

Arbogast), Estación Biológica de Doñana-CSIC (Sevilla, Spain; special thanks are given to Carlos Urdiales), Estación Experimental de Zonas Áridas-CSIC (Almería, Spain; Special thanks are given to Ángel Belmonte and Dr. Jorge Cassinello), Parque Nacional de Sierra Nevada (special thanks are given to José Enrique Granados) and IPHES - Institut de Paleoeologia Humana i Evolució Social (Tarragona, Spain; special thanks are given to Dr. Isabel Cáceres).

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jas.2023.105779>.

References

- Adams, N.F., Gray, T., Purnell, M.A., 2020. Dietary signals in dental microwear of predatory small mammals appear unaffected by extremes in environmental abrasive load. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 558, 109929.
- Aldezabal, A., García-González, R., Gómez, D., Fillat, F., 2002. El papel de los herbívoros en la conservación de los pastos. *Ecosistemas* 11 (3). www.aet.org/ecosistemas/investigacion6.htm.
- Arbuckle, B.S., Atici, L., 2013. Initial diversity in sheep and goat management in Neolithic Southwestern Asia. *Levant* 45, 219–235.
- Arbuckle, B.S., 2014. Pace and process in the emergence of animal husbandry in Neolithic Southwest Asia. *Bioarchaeol. Near East* 8, 1–29.
- Arranz-Oategui, A., López-Sáez, J.A., Araus, J.L., Portillo, M., Balbo, A., Iriarte, E., Gourichon, L., Braemer, F., Zapata, L., Ibáñez, J.J., 2017. Landscape transformations at the dawn of agriculture in southern Syria (10.7–9.9 ka cal. BP): plant-specific responses to the impact of human activities and climate change. *Quat. Sci. Rev.* 158, 145–163.
- Asouti, E., Kabukcu, C., White, C.E., Kuijt, I., Finlayson, B., Makarewicz, C., 2015. Early Holocene woodland vegetation and human impacts in the arid zone of the southern Levant. *PLoS One* 10, 1565–1580.
- Bar-Gal, G.K., Khalaily, H., Mader, O., Ducos, P., Horwitz, L.K., 2002. Ancient DNA evidence for the transition from wild to domestic status in neolithic goats: a case study from the site of Abu gosh, Israel. *Anc. Biomol.* 4 (1), 9–17.
- Berlioz, E., Azorit, C., Blondel, T., Tellado Ruiz, M.S., Merceron, G., 2017. Deer in arid habitat: dental microwear texture track feeding adaptability. *The Italian Journal of Mammalogy* 28 (2), 222–230.
- Clauss, M., Hummel, J., Streich, W.J., 2006. The dissociation of the fluid and particle phase in the forestomach as a physiological characteristic of large grazing ruminants: an evaluation of available, comparable ruminant passage data. *Eur. J. Wildl. Res.* 52, 88–98.
- Clauss, M., Hofmann, R.R., Fickel, J., Streich, W.J., Hummel, J., 2009. The intraruminal papillum gradient in wild ruminants of different feeding types: implications for rumen physiology. *J. Morphol.* 270, 929–942.
- Couturier, M.A.J., 1962. Le bouquetin des Alpes *Capra aegagrus ibex ibex* L. M.A.J. Couturier, Grenoble.
- Cuartas, P., García-González, R., 1992. *Quercus ilex* browse utilization by caprini in Sierra de Cazorla and segura (Spain). *Vegetatio* 99–100, 317–330.
- Cuartas, P., García-González, R., 1993. Comparación de la dieta de rumiantes domésticos y salvajes en la Sierra de Cazorla. In: Aguilera-Sánchez, J. (Ed.), *Nutrición de rumiantes en zonas áridas y de montaña y su relación con la conservación del medio natural*. Junta de Andalucía, Sevilla, pp. 101–108.
- Cuartas, P., García-González, R., Alados, C.L., Escós, J., 1996. Selección de la dieta y comportamiento alimentario. In: Alados, C.L., Quilez, J.E. (Eds.), *Ecología y comportamiento de la cabra montés. Consideraciones para su gestión*. Monografías del Museo Nacional de Ciencias Naturales, Madrid, pp. 151–198.
- Dauphin, Y., Castillo-Michel, H., Denys, C., El Hajraoui, M.A., Nespoulet, R., Stoetzel, E., 2018. Diagenetic alterations of *Meriones* incisors (rodentia) of el harhoura 2 cave, Morocco (late pleistocene–middle Holocene). *Paläontol. Z.* 92, 163–177.
- Deckers, K., Riehl, S., Jenkins, E., Rosen, A., Dodonov, A., Simakova, A.N., Conard, N.J., 2009. Vegetation development and human occupation in the Damascus region of southwestern Syria from the Late Pleistocene to Holocene. *Veg. Hist. Archaeobotany* 18, 329–340.
- Ducos, P., Horwitz, L.K., 2003. The pre-pottery neolithic B fauna from the lechevalier excavations at Abu Ghosh. In: Khalaily, H., Marder, O. (Eds.), *The Neolithic Site of Abu Ghosh. The 1995 Excavations*. Israel Antiquity Authority, Jerusalem, pp. 103–119.
- Edwards, P.C., 2016. The chronology and dispersal of the Pre-Pottery Neolithic B cultural complex in the Levant. *Paleorient* 42 (2), 53–72.
- El-Zaatari, S., 2010. Occlusal microwear texture analysis and the diets of historical/prehistoric hunter-gatherers. *Int. J. Osteoarchaeol.* 20, 67–87.
- Finlayson, B., Makarewicz, C.A., 2020. Beyond the Jordan: multiforities of the pre-pottery neolithic. *Documenta Praehistorica* 47, 54–75.
- Francisco, A., Blondel, C., Brunetière, N., Ramdarshan, A., Merceron, G., 2018. Enamel surface topography analysis for diet discrimination. A methodology to enhance and select discriminative parameters. *Surf. Topogr. Metrol. Prop.* 6 (1), 015002.
- Francisco, A., Blondel, C., Brunetière, N., Ramdarshan, A., Merceron, G., 2021. Enamel surface topography analysis for diet discrimination. A methodology to enhance and select discriminative parameters. *Surf. Topogr. Metrol. Prop.* 6, 015002.
- García-González, R., 1987. Estudio del crecimiento postnatal en corderos de raza Rasa Aragonesa. *Monografías del Instituto de Estudios Altoaragoneses* 13. CSIC, Diputación Provincial de Huesca, Huesca.
- García-González, R., Cuartas, P., 1989. A comparison of the diets of the wild goat (*Capra pyrenaica*), domestic goat (*Capra hircus*), mouflon (*Ovis musimon*) and domestic sheep (*Ovis aries*) in the Cazorla mountain range. *Acta biologica Montana* 9, 123–132.
- García-González, R., Herrero, J., Nores, C., 2021. The names of southwestern European goats: is Iberian ibex the best common name for *Capra pyrenaica*? *Anim. Biodivers. Conserv.* 44 (1), 1–16.
- Gordon, K.D., 1984. Hominoid dental microwear: complications in the use of microwear analysis to detect diet. *J. Dent. Res.* 63, 195–215.
- Gourichon, L., Kolska-Horwitz, L., 2021. An inter-regional comparison of animal domestication in the northern and southern Levant. In: Vieugé, J., Mazzucchi, N. (Eds.), *Dietary Practices of the First Mediterranean Farmers Producing, Storing, Preparing and Consuming Foodstuffs in the Neolithic Period*. Brepols Publishers, Turnhout, pp. 33–68.
- Granados, J.E., Pérez, J.M., Márquez, F.J., Serrano, E., Soriguer, R.C., Fandos, P., 2001. La cabra montés (*Capra pyrenaica*, schinz 1838). *GALEMYS* 13 (1), 3–37.
- Gross, J.E., Demment, M.W., Alkon, P.U., Kotzman, M., 1995. Feeding and chewing behaviours of nubian ibex: compensation for sex-related differences in body size. *British Ecological Society* 9 (3), 385–393.
- Grupe, G., 1995. Preservation of collagen in bone from dry, sandy soil. *J. Archaeol. Sci.* 22 (2), 193–199.
- Grupe, G., Peters, J., 2008. Feeding humans and animals at Pre-Pottery Neolithic Nevali Çori (SE-Anatolia) as evidenced by stable isotope analysis. In: Vila, E., Gourichon, L., Choyke, A.M., Buitenhuis, H. (Eds.), *Archaeozoology of the Near East 8. Publications de la Maison de l'Orient et de la Méditerranée*, Lyon, pp. 119–151.
- Hackham, E., Ritte, U., 1991. Foraging pressure of the Nubian ibex *Capra ibex nubiana* and its effect on the indigenous vegetation of the En Gedi Nature Reserve, Israel. *Biol. Conserv.* 63, 9–21.
- Harbers, H., Zanolli, C., Cazenave, M., Theil, J.-C., Ortiz, K., Blanc, B., Locatelli, Y., Schafberg, R., Lecomte, F., Baly, I., Laurens, F., Callou, C., Herrel, A., Puymail, L., Cucchi, T., 2020. Investigating the impact of captivity and domestication on limb bone cortical morphology: an experimental approach using a wild boar model. *Nature Scientific Reports* 10, 19070.
- Hatt, J.-M., Codron, D., Müller, D.W.H., Ackermans, N.L., Martin, L.F., Kircher, P.R., Hummel, J., Clauss, M., 2019. The rumen washes off abrasives before heavy-duty chewing in ruminants. *Mamm. Biol.* 97, 104–111.
- Hatt, J.-M., Codron, D., Ackermans, N.L., Martin, L.F., Richter, H., Kircher, P.R., Gerspach, C., Hummel, J., Clauss, M., 2020. Differences in the rumen washing mechanism in sheep fed diets with abrasives of various concentrations and sizes. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 550, 109728.
- Helmer, D., Gourichon, L., 2008. Premières données sur les modalités de subsistance à Tell Aswad (Syrie, PPNB moyen et récent, Néolithique céramique ancien) - fouilles 2001-2005. In: Vila, E., Gourichon, L., Choyke, A.M., Buitenhuis, H. (Eds.), *Archaeozoology of the Near East 8. Publications de la Maison de l'Orient et de la Méditerranée*, Lyon, pp. 119–151.
- Helmer, D., Gourichon, L., 2017. The fauna of Tell Aswad (Damascus, Syria), early Neolithic levels. Comparison with northern and southern Levant sites. In: Mashkour, M., Beech, M. (Eds.), *Archaeozoology of the Near East 9. Oxbow Books, Oxford & Philadelphia*, pp. 23–40.
- Horwitz, L.K., Ducos, P., 1998. An investigation into the origins of domestic sheep in the southern Levant. In: Buitenhuis, H., Bartosiewicz, L., Choyke, A. (Eds.), *Archaeozoology of the Near East 3. ARC-Publications* 18, Groningen, pp. 80–95.
- Horwitz, L.K., Tchernov, E., Ducos, P., Becker, C., von den Driesch, A., Martin, L., Garrard, A., 1999. Animal domestication in the southern Levant. *Paleorient* 25 (2), 63–80.
- Ibáñez, J.J., Balbo, A., Braemer, F., Gourichon, F., Gourichon, L., Iriarte, E., Santana, J., Zapata, L., 2010. The early PPNB levels of Tell Qarassa North (sweida, southern Syria). *Antiquity* 84, 325.
- Ibáñez, J.J., Muñoz, J., Iriarte, E., Monik, M., Santana, J., Teira, L., Corrada, M., Lagüera, M.A., Lendakova, Z., Regalado, E., Rosillo, R., 2015. Kharaysin: a PPNB site by the Zarqa river 2014 and 2015 field seasons. *Neo-Lithics* 2/15, 11–19.
- Ibáñez, J.J., Muñoz, J.R., Huet, T., Santana, J., Teira, L.C., Borrell, F., Rosillo, R., Iriarte, E., 2020. Flint 'figurines' from the early neolithic site of Kharaysin, Jordan. *Antiquity* 94, 376.
- Ibáñez, J.J., González-Urquijo, J., Teira-Mayolini, L.C., Lazuén, T., 2018. The emergence of the Neolithic in the Near East: a protracted and multi-regional model. *Quat. Int.* 470, 226–252.
- Ibáñez, J.J., Muñoz, J., Iriarte, E., Teira, L., Santana, J., Monik, M., Lendakova, Z., Lagüera, M.A., Regalado, E., Corrada, M., González, M., Moreno, M.A., Rosillo, R., Gourichon, L., Borrell, F., Tapia, J., Arranz-Oategui, A., 2019. Los primeros agricultores y ganaderos. Excavaciones en el yacimiento del Neolítico Precerámico A y B de Kharaysin (Zarqa, Jordania). *Campañas de 2016 y 2016*. In: *Informes Y Trabajos* 17. Ministerio de Cultura y Deporte, Madrid, pp. 103–123.
- Jiménez-Manchón, S., Rivals, F., Gourichon, L., De Prado, G., Codina, F., Castanyer, P., Tremoleda, J., Santos, M., Gardeisen, A., Forthcoming. A Combined Approach to Reconstruct Livestock Management in Iron Age North-Eastern Iberia: Estimating the Season of Death and Palaeodiet Using Cementochronology and Dental Micro- and Mesowear Analyses. *Archaeofauna*.
- King, T., Andrews, P., Boz, B., Boz, B., 1999. Effect of taphonomic processes on dental microwear. *Am. J. Phys. Anthropol.* 108 (3), 359–373.
- Kuijt, I., Goring-Morris, N., 2002. Foraging, farming, and social complexity in the pre-pottery neolithic of the southern Levant: a review and synthesis. *J. World PreHistory* 16, 361–440.
- Leach, R.K., 2013. *Characterisation of Areal Surface Texture*. Springer, Berlin.

- Louail, M., Caner, L., Neaux, D., Ortiz, K., Locatelli, Y., Cucchi, T., 2022. Identifying the impact of soil ingestion on dental microwear textures using a wild boar experimental model. *Journal of Archaeological Method and Theory*. <https://doi.org/10.1007/s10816-022-09574-6>.
- Makarewicz, C., Tuross, N., 2009. Changes in Goat-Management Strategies through the Later Pre-pottery Neolithic B. *Transitions in Prehistory: Essays in Honor of Bar-Yosef Oxbow*, Oxford, pp. 285–303.
- Makarewicz, C., Tuross, N., 2012. Finding fodder and tracking transhumance: isotopic detection of goat domestication processes in the Near East. *Curr. Anthropol.* 53 (4), 495–505.
- Makarewicz, C., Horwitz, L.K., Goring-Morris, A.N., 2016. Local adoption of animal husbandry in the southern Levant: an isotopic perspective from the Pre-Pottery Neolithic B funerary site of Kfar HaHoresh. *Environ. Archaeol.* 21 (3), 199–213.
- Martin, L., Edwards, Y., 2013. Diverse strategies: evaluating the appearance and spread of domestic caprines in the southern Levant. In: Colledge, S., Conolly, J., Dobney, K., Manning, K., Shennan, S. (Eds.), *Domestic Animals in Southwest Asia and Europe*. Left Coast Press, Walnut Creek, California, pp. 49–82.
- Martinez, T., Martínez, E., Fandos, P., 1985. Composition of the food of the Spanish wild goat in sierras de Cazorla and segura, Spain. *Acta Theorologica* 30 (29), 461–494.
- Martínez, T., 2000. Diet selection by Spanish ibex in early summer in Sierra Nevada. *Acta Theorologica* 45 (3), 335–346.
- McLennan, L., Purnell, M.A., 2021. Dental microwear texture analysis as a tool for dietary discrimination in elasmobranchs. *Nature Scientific Reports* 11, 2444.
- Merceron, G., Escarguel, G., Angibault, J.-M., Verheyden-Tixier, H., 2010. Can dental microwear textures record inter-individual dietary variations? *PLoS One* 5 (3), 1–9.
- Merceron, G., Ramdarshan, A., Blondel, C., Boisserie, J.-R., Brunetiere, N., Francisco, A., Gautier, D., Milhet, X., Novello, A., Pret, D., 2016. Untangling the Environmental from the dietary: Dust Does Not Matter, vol. 283. The Rosal Society Publishing, 20161032.
- Merceron, G., Berlioz, É., Vonhof, H., Green, D., Garel, M., Tütken, T., 2021. Tooth tales told by dental diet proxies: an alpine community of sympatric ruminants as a model to decipher the ecology of fossil fauna. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* <https://doi.org/10.1016/j.palaeo.2020.110077>.
- Miller, H., Baird, D., Pearson, J., Lamb, A.L., Grove, M., Martin, M., Garrard, A., 2019. The origins of nomadic pastoralism in the eastern Jordanian steppe: a combined stable isotope and chipped stone assessment. *Levant* 50 (3), 281–304.
- Monks, G.G., 1981. Seasonality studies. In: Schiffer, M.B. (Ed.), *Advances in Archaeological Method and Theory*, vol. 4. Academic Press, New York, pp. 177–240.
- Munro, N., Bar-Oz, G., Meier, J., Sapir-Hen, L., Stiner, M.C., Yeshurun, R., 2018. The emergence of animal management in the southern Levant. *Nature Scientific Reports* 8, 9279.
- Naji, S., Gourichon, L., Rendu, W., 2015. La cémento-chronologie. In: Balasse, M., Brugal, J.P., Dauphin, Y., Geigl, E.M., Oberlin, C., Reiche, I. (Eds.), *Messages d'os: Archéométrie du squelette animale et humain*. Éditions des archives contemporaines, Paris, pp. 217–240.
- Naji, S., Rendu, W., Gourichon, L., 2022. Dental Cementum in Anthropology. Cambridge University Press, Cambridge.
- Parrini, F., Cain, J.W., Krausman, P.R., 2009. *Capra ibex* (artiodactyla: bovidae). *Mamm. Species* 830, 1–12.
- Pearson, J.A., Buitenhuis, H., Hedges, R.E.M., Martin, L., Russell, N., Twiss, K.C., 2007. New light on early caprine herding strategies from isotope analysis: a case study from Neolithic Anatolia. *J. Archaeol. Sci.* 34, 2170–2179.
- Peters, J., von den Driesch, A., Helmer, D., 2005. The upper Euphrates-Tiguis basin: cradle of agro-pastoralism? In: Vigne, J.-D., Peters, J., Helmer, D. (Eds.), *First Steps of Animal Domestication. New Archaeozoological Approaches. Proceedings of the 9th ICAZ Conference*. Oxbow Books, Oxford, pp. 96–124.
- Pöllath, N., Schafberg, R., Peters, J., 2019. Astragalar morphology: approaching the cultural trajectories of wild and domestic sheep applying Geometric Morphometrics. *J. Archaeol. Sci.: Report* 23, 810–821.
- Rivals, F., Prignano, L., Semprebon, G., Lozano, S., 2015. A tool for determining duration of mortality events in archaeological assemblages using extant ungulate microwear. *Nature Scientific Reports* 5, 17330.
- Ramdarshan, A., Blondel, C., Surault, J., Merceron, G., 2017. Overcoming sampling issues in dental tribology: insights from an experimentation on sheep. *Palaeontologia electronica* 30 (3), 1–19.
- Rivals, F., Álvarez-Lao, D.J., 2018. Ungulate dietary traits and plasticity in zones of ecological transition inferred from late Pleistocene assemblages at Jou Puerta and Rexidora in the Cantabrian Region of northern Spain. *Palaeogeography. Palaeoclimatology Palaeoecology* 499, 123–130.
- Sapir-Hen, L., Dayan, T., Khalaily, H., Munro, N.D., 2016. Human hunting and nascent animal management at middle pre-pottery neolithic yiftah'el, Israel. *PLoS One* 11 (7), e0156964.
- Scott, R.S., Ungar, P.S., Bergstrom, T.S., Brown, C.A., Grine, F.E., Teaford, M.F., Walker, A., 2005. Dental microwear texture analysis reflects diets of living primates and fossil hominins. *Nature* 436, 693e695.
- Scott, R.S., Ungar, P.S., Bergstrom, T.S., Brown, C.A., Childs, B.E., Teaford, M.F., Walker, A., 2006. Dental microwear texture analysis: technical considerations. *J. Hum. Evol.* 51, 339–349.
- Stiner, M.C., Özbaşaran, M., Duru, G., 2022. Aşıklı höyük: the generative evolution of a central anatolian PPN settlement in regional context. *J. Archaeol. Res.* <https://doi.org/10.1007/s10814-021-09167-z>.
- Teaford, M.F., Walker, A., 1984. Quantitative differences in dental microwear between primate species with different diets and a comment on the presumed diet of *sivapithecus*. *Am. J. Phys. Anthropol.* 64 (2), 191–200.
- Tornero, C., Saña, M., 2011. In: Turbanti-Memmi, I. (Ed.), *Integrating Stable Isotopes to the Study of the Origin of Management Strategies for Domestic Animals: $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ Results from Bioapatite Enamel of Cattle from the Tell Halula Site, Syria (7800–7000 BC)*. Proceedings of the 37th International Symposium on Archaeometry, 13th - 16th May 2008, Siena, Italy, pp. 435–440. Springer.
- Uzunidis, A., 2020. Dental wear analyses of Middle Pleistocene site of Lunel-Viel (Hérault, France): did *Equus* and *Bos* live in a wetland? *Quat. Int.* 557, 39–46.
- Uzunidis, A., Pineda, A., Jiménez-Manchón, S., Xafis, A., Ollivier, V., Rivals, F., 2021. The impact of sediment abrasion on tooth microwear analysis: an experimental study. *Archaeological and Anthropological Sciences* 13, 134.
- Vigne, J.D., Carrère, I., Briois, F., Guilaine, J., 2011. The early process of mammal domestication in the Near East new evidence from the pre-neolithic and pre-pottery neolithic in Cyprus. *Curr. Anthropol.* 52, s255–s271.
- Villaret, J.C., Bon, R., Rivet, A., 1997. Sexual segregation of habitat by the Alpine ibex in the French Alps. *J. Mammal.* 78, 1273–1281.
- Walker, A., Hoeck, H.N., Perez, L., 1978. Microwear of mammalian teeth as an indicator of diet. *Science* 201, 908–910.
- Weber, K., Winkler, D.E., Kaiser, T.M., Žigaitė, Ž., Tütken, T., 2020. Dental microwear texture analysis on extant and extinct sharks: ante- or post-mortem tooth wear? *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, 110147
- Weiner, S., Bar-Yosef, O., 1990. States of preservation of bones from prehistoric sites in the Near East: a survey. *J. Archaeol. Sci.* 17, 187–196.
- Zeder, M., Hesse, B., 2000. The initial domestication of goats (*Capra hircus*) in the Zagros mountains 10,000 years ago. *Science* 287 (5461), 2254–2257.
- Zeder, M., 2006. Central question in the domestication of plants and animals. *Evol. Anthropol.* 15, 105–117.
- Zeder, M., 2008. Domestication and early agriculture in the Mediterranean Basin: origins, diffusion, and impact. *Proc. Natl. Acad. Sci. USA* 105 (33), 11597–11604.
- Zeder, M., 2012. The domestication of animals. *J. Anthropol. Res.* 68 (2), 161–190.
- Zimmermann, M.L., Pöllath, N., Özbaşaran, M., Peters, J., 2018. Joint health in free-ranging and confined small bovids - implications for early stage caprine management. *J. Archaeol. Sci.* 92, 13–27.
- Zingg, A., 2009. Seasonal Variability in the Diet Composition of Alpine Ibex (*Capra ibex* L.) in the Swiss National Park. Master Thesis in Ecology at University of Zurich.