

**Pastures and fodder for feeding equids 3000 years ago. The Can Roqueta site (Barcelona, Spain) as a model of equine herd management**

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4 **(Barcelona, Spain) as a model of equine herd management**  
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30 **Conflicts of interest<sup>1</sup>**  
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51 **<sup>1</sup> Conflicts of Interest**

52 The authors certify that they have no affiliations with or involvement in any organization  
53 or entity with any financial interest (such as honoraria; membership, employment,  
54 consultancies, stock ownership, or patent-licensing arrangements) in the subject matter  
55 or materials discussed in this manuscript  
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## Abstract

Can Roqueta has provided a large number of equid and dog assemblages from the Late Bronze Age to the Early Iron Age.

An analysis of the stable isotopes  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  in 42 bone samples has made it possible to reconstruct the diet of domestic equids. The results and carpological remains show that the territory was managed for agricultural and pasture use. They indicate the cultivation of two types of highly nutritious and digestible millet, used in combination with other cereals to prepare fodder, as well as the use of natural pastures.

**Keywords:** stable isotope analysis, equids alimentation, feeding management, Iberian Peninsula, Late Bronze Age and Early Iron Age

## Introduction

Very few studies have been conducted on the diet of European horses from the time of their introduction as domestic animals (Fenner et al., 2014; Nuviola et al., 2014; Hamilton et al., 2019), and until only a few years ago, our information came from Roman and Greek agronomists. Their explanations of how to improve pasture quality and animal health by cultivating forage crops are important for understanding the development of livestock farming through agriculture in the past (Kron, 2008, 2014). In classical Greece, the equine diet described in the *Hippologia Hethitica* included staples such as wheat and barley and some form of oats or emmer, fresh grass, hay, straw and other unidentified ingredients rigorously prepared (Gangutia, 2003). The treatises of Roman agronomists show a wide ranging knowledge tailored to different needs. Forage legumes —alfalfa and clover— were widely used, especially for horses and sick or breeding animals. Columela (ca. 42 AD) advises certain mixtures such as barley and bitter vetch (*Vicia ervilla*), to strengthen pregnant mares (Alvarez de Soto Mayor, 1824). Nowadays, the amount and proportion of forage crops given in the diet will depend on the animal's physical condition and level of activity.

Analyses of seeds at archaeological sites and of stable  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotopes in animal bones have greatly expanded our information on animal feed crops in the past. For example, forage crops including cereals with and without gluten, such as millet, have

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3 been documented at Can Roqueta in relation to cattle, goats and dogs (Albizuri et al.,  
4 2021; Albizuri et al., in press).  
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### 8 **Can Roqueta site**

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11 The site in the pre-coastal zone of Barcelona (Vallès Occidental) (Figure 1), has provided  
12 a broad chronological sequence. The Late Bronze Age -LBA- (1300-750 cal BCE) and  
13 the Early Iron Age -EIA- (750-550 cal BCE) are the best represented chronological  
14 periods (Carlús et al., 2007).  
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17 The archaeobotanical and archaeozoological studies of LBA and EIA indicate an  
18 economy based on cultivating cereals and legumes complemented by raising livestock for  
19 meat, milk and traction (Albizuri et al., 2011; Albizuri et al., in press).  
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25 According to carpological remains, the main crop was barley (*Hordeum vulgare*),  
26 followed by wheat (*Triticum aestivum/durum* and *Triticum dicoccum*) and legumes,  
27 lentils (*Lens culinaris*) and peas (*Pisum sativum*). A considerable increase in the  
28 production of wheat over barley and the appearance of foreign group C4 plants that do  
29 not contain gluten, such as millets (*Panicum miliaceum* and *Setaria italica*), is visible  
30 from the LBA but in NE Iberia it is recorded from EBA at Punta Farisa (Alonso, 2000).  
31 These two millet species increased until they became staple in the EIA.  
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39 Faunal remains reveal a livestock farming model based on the rearing of three species for  
40 meat and milk: sheep, goats (*Ovis/Capra*) and pigs (*Sus domesticus*). Cattle (*Bos taurus*),  
41 was basically used for agricultural work, but were also slaughtered for meat at the end of  
42 their working life (Albizuri et al. in press). The first records of horse bones (*Equus*  
43 *caballus*) appear in the LBA. 18 horses have been identified according to the MNI,  
44 represented by 37 remains. These were probably only destined for human consumption  
45 at the end of their working life. In the EIA, there is a very significant increase. 46  
46 individuals (MNI) represented by 381 remains have been identified (not including the  
47 complete specimens CR6 and CRII811), and for the first time, there also is evidence of  
48 the occasional presence of other equids such as the ass (*Equus asinus*) and hybrids or  
49 mules. From this moment on, they were clearly used for riding and pulling loads and  
50 probably also for consumption at specific times and at the end of their lives (Albizuri et  
51 al., 2019). As with the equids, the dogs were also probably used exclusively for work,  
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3 and from the EIA onwards they are generally associated with special deposits. Their  
4 remains are usually recorded inside silos, sometimes accompanying inhumations or in  
5 adjoining structures, and sometimes in isolated pits (Figure 2). Certain patterns in the  
6 disposition of the bones and their morphometric characteristics suggest the intentionality  
7 of the deposits and the presence of more than one specimen in some structures (López  
8 Cachero et al., in press).  
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15 A recent study determined non-local strontium values in some EIA equids that may have  
16 been reared elsewhere. Given the estimated adult ages (around 5-10 years old), the  
17 animals may have come from other places specialising in equine husbandry (Albizuri et  
18 al., 2019).  
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22 The presence of exogenous species such as millets, the cockerel, the donkey, and of  
23 Phoenician ceramics and metallic materials associated with south-eastern France, suggest  
24 regular trade with other populations (Albizuri et al., 2021).  
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## 29 **Materials and methods**

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32 We analysed 42 bone samples from domestic equids (*Equus caballus*, *Equus asinus* and  
33 hybrids), taken from 35 structures (Table 1), most of which are dated to the EIA (24  
34 structures, 30 samples). We also sampled 6 LBA structures (7 samples) and included 2  
35 samples from the Early-Middle Iron Age/Iberian period and 3 from the Late Roman  
36 period, to obtain a diachronic view.  
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41 Given the difficulties entailed in associating remains found in the same structure with one  
42 or more equids, we took several samples in four structures (CRTR163, CRCRV16-15,  
43 CRCRV16-31 and CRCRV09-285) (Table 1).  
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50 5 wild horses (*Equus ferus*) from the north-east of the Iberian Peninsula and classified as  
51 undomesticated were used as a reference for a natural, grass-based diet. Four individuals  
52 came from the Chaves cave (Huesca), dated to the Early Neolithic (Villalba-Mouco et al.  
53 2018) and one from the La Guineu cave (Barcelona), dated to the Late Neolithic (Villalba-  
54 Mouco et al., 2019). We also included a group of cows and a rabbit from Can Roqueta as  
55 reference herbivores (Albizuri et al., in press).  
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60 The isotopic study was performed on bone collagen extracted from bone powder  
following Longin (1971), with the modifications proposed by Bocherens et al. (1997) and

described in detail in Grandal-d'Anglade et al. (2019) and Grandal-d'Anglade et al (2021a). The determination of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  was made in the Instrumental Analysis Techniques Unit (UTIA) of the Research Support Services of the University of A Coruña. It was carried out in a FlashEA1112 elemental analyzer (ThermoFinnigan) linked via a ConFloIII interface to a MAT253 isotope ratio mass spectrometer (ThermoFinnigan). Because of the small sample size in some of the groups analysed, non-parametric tests (Mann-Whitney U) were used to compare isotopic values, and cluster analysis (Ward's method) was performed to group samples by affinity according to their isotopic values. All statistical tests were performed using PAST 3.12 software (Hammer et al., 2001).

## Results

In general, the preservation of the bone collagen analysed was good in all cases and can be seen in detail in Grandal-d'Anglade et al (2021a). All samples show acceptable collagen yields (above 1.5%, according Van Klinken, 1999), a C:N atomic ratio between 3.0 and 3.3 (De Niro, 1985) and the percentages of C and N in the collagen are above 13% and 5% respectively. These percentages exceed 10% for N and 30% for C in 27 cases, 65% of the samples (Ambrose, 1990). The detailed results of the isotopic analysis are available in Grandal-d'Anglade et al (2021b) and summarized in Table 2.

In three of the cases where several samples were taken from the same structure, similar isotopic values were not obtained. The differences found between samples can reach up to 2.3‰ for  $\delta^{15}\text{N}$  and up to 3.8‰ in  $\delta^{13}\text{C}$ . This suggests that there is more than one animal per structure. In other cases, they are lower than the measurement error of the spectrometer (0.15‰ for both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ ).

In general, the isotopic signals obtained for these equids show a wide dispersion (Table 2, Figure 3). The observed variability renders it difficult to interpret the isotopic signals by period or even for the total equid assemblage. Thus, we performed a cluster analysis (Ward's method) of the equids in order to detect groupings based on the similarity of their isotopic signals (Figure 4). The analysis revealed two main groups with highly significant differences in  $\delta^{13}\text{C}$  ( $t$ -test,  $p < 0.0001$ ) and significant differences in  $\delta^{15}\text{N}$  ( $p = 0.0021$ ), which we have termed *Groups 1* and *2*. In turn, each of these groups contains two new sub-groups: *1a* and *1b*, mainly differentiated by their  $\delta^{15}\text{N}$  values (Mann-Whitney U,  $p < 0.0001$ ), and *2a* and *2b*, which differ significantly in both  $\delta^{13}\text{C}$  ( $p = 0.0005$ ) and  $\delta^{15}\text{N}$

( $p < 0.0001$ ). Given the possibility that isotopes vary over time, the cluster analysis was run as a separate test on the EIA equids to see if they cluster in the same way. As a result, cluster 1a, consisting almost exclusively of Neolithic and Bronze Age horses, disappeared. The only EIA horse from this group became part of Group 1b. In Groups 2a and 2b, only two horses changed their classification from 2a to 2b. The differences between these two groups remained statistically significant for  $\delta^{13}\text{C}$  between Group 1 and 2 ( $p = 0.0001$ ) and for  $\delta^{15}\text{N}$  ( $p = 0.0004$ ) between Groups 2a and 2b.

## Discussion

Significant variations in isotopic values indicate differences in the type of food received in chronologically contemporaneous structures, even in animals sharing the same structure and stratigraphic level (Table 1, Figure 3).

The isotopic values of several samples from the same structure and from the same stratigraphic level raise the possibility of having different animals. In some cases, both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  showed very little difference (up to 0.2‰), allowing the identification of a single specimen, as in the case of metacarpal CRTR163(1) and phalanx CRTR163(2) (Figure 3). However, the difference in isotopic signatures in three structures is larger. The rate of collagen remodelling in anatomical segments may produce different isotopic signatures if there were changes in diet (Fahy et al., 2017). Under normal conditions and without dietary changes, different bones or even different parts of the same bone can differ by up to about 1‰, as has been shown for small carnivores (mink) and herbivores (rabbit) (Schoeninger and De Niro, 1983), or more recently for red deer, which seems a better equine analogue (Sykut et al., 2020). To this must be added the spectrometer error, which can vary the isotopic signature by  $\pm 0.15\%$ .

In structure CRCRV16-15, the articulated bones of two forefeet and two hind feet were recovered with osteometric differences evidencing two different horses (Figure 2). In addition, 7 cervical vertebrae and an entire skull without jaws was deposited separately from the neck vertebrae.  $\delta^{13}\text{C}$  values for one of the phalanges, CRCRV16-15(1) are close to those for the skull CRCRV16-15(nd) (-21.2 and -20.8 respectively) (Figure 3). However, the phalanx CRCRV16-15(2), from a second animal, show a difference in  $\delta^{13}\text{C}$  from the two previous samples of 2.8 and 2.2 ‰, respectively. The  $\delta^{15}\text{N}$  values vary only between 5.3 and 5.8‰ in the three bones.

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3 In structure CRCRV16-31, disarticulated bones apparently belonged to the same animal  
4 (Figure 2); however, the isotopic results suggest at least two animals (Figure 3). The skull  
5 CRCRV16-31(nd) and a sesamoid CRCRV16-31(1) present very similar values (-20.3  
6 and -20.0 for  $\delta^{13}\text{C}$ , 6.9 and 6.6 for  $\delta^{15}\text{N}$ ) but the pelvis CRCRV16-31(2) does not, with a  
7 difference in carbon from the two previous samples of 3.5 and 3.8‰ respectively, while  
8 its  $\delta^{15}\text{N}$  value (6.4‰) is intermediate.  
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13 CRCRV09-285 contained a horse skull and two hip bones (left and right) at the same  
14 inhumation level of an adult male (Figure 2). The morphometric coherence of the two  
15 horse hip bones suggests a single pelvic girdle. However, the values of the left hip bone  
16 CRCRV09-285(1) are close to the values of the skull CRCRV09-285(nd), while the right  
17 hip bone CRCRV09-285(2) shows a difference in  $\delta^{15}\text{N}$  of 1.6‰ with respect to the left  
18 hip bone and 2.3‰ with respect to the skull (Figure 3). This suggests the presence of two  
19 different animals. Another possibility is that the same animal suffered different  
20 mechanical stress in each half of the pelvis. Mechanical stress, as well as some bone  
21 pathologies or fractures (Katzenberg and Lovell, 1999), produce higher rates of bone  
22 turnover that can record the diet in the short term (Fahy et al., 2017). But both hip bones  
23 show no signs of stress-related pathology or thickening. Considering that the osteometric  
24 data showed the presence of more than one animal in some structures and that the  
25 difference in isotopic signatures exceeds what is described in the literature for the same  
26 individual (Sykut et al., 2020), we propose that these samples belong to different animals  
27 as the most parsimonious hypothesis.  
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41 The variability in the equids diet may possibly indicate the provision of a greater or lesser  
42 proportion of grain in the forage according to the use made of the animal, whereby  
43 animals used exclusively for riding may have been fed differently from those used as  
44 draught and pack animals, perhaps receiving higher energy forage. A cluster analysis  
45 based on  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values distinguished four diet-based groups of equids (Figures 4,  
46 5, Table 3) characterised by their particular combination of isotopic values. However, we  
47 cannot confirm that members of the same group received a very similar diet, because  
48 several factors influence the isotopic signal from the bottom of the trophic chain upwards.  
49 These factors can sometimes act on isotopic values in the same direction, but also in the  
50 opposite direction, as we shall see below.  
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### 59 *Contribution of millet*

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3 The isotopic values of bone collagen are derived from ingested proteins, which in  
4 herbivores are of plant origin. Thus, theoretically, the isotopic signal of a herbivore's  
5 collagen enables us to deduce the types of plant in its food. In practice, however, this is  
6 not a straightforward deduction because various factors related to the environment or to  
7 crop management influence the isotopic signals in the plants themselves.  
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12 In the case of carbon, the bone collagen of herbivores records  $\delta^{13}\text{C}$  values that are  
13 approximately 5‰ more positive than those of the plants on which they feed (De Niro &  
14 Epstein, 1978). The carbon isotopic signature of plants depends primarily on a plant's  
15 carbon fixation pathway. C3 plants, which comprise trees and most temperate herbaceous  
16 plants, including almost all cereals, preferentially fix the light isotope and consequently  
17 have very negative  $\delta^{13}\text{C}$  values of between -12.4‰ and -37.0‰. In contrast, C4 plants,  
18 which are tropical herbaceous plants, do not show this preference and reach markedly  
19 more positive values of between -2.0‰ and -14.0‰ (Farquhar et al., 1989). This  
20 conspicuous difference makes it possible to identify the contribution of C4 plants, such  
21 as millets, to an animal's diet. At Can Roqueta, millets had been grown since at least the  
22 LBA (Albizuri et al., in press), although the use of millet for animal feed can be traced  
23 back to the Early-Middle Bronze Age in some juvenile canids (Grandal-d'Anglade et al.,  
24 2019). Several *Group 2b* equids, mainly from the EIA but also two from the LBA,  
25 received a significant input of millet (Table 3, Figure 5), whereas in *Group 2a*, the  
26 proportion of millet was low and in *Groups 1a and 1b*, it was entirely absent from the  
27 diet. Similar signals to those of the equids in *Groups 2a and 2b* were obtained for the EIA  
28 cattle (Figure 5), albeit with slightly higher  $\delta^{15}\text{N}$  values (see Table 2). Interestingly, this  
29 has not been observed in any of the EIA humans analysed (Albizuri et al., in press) but it  
30 has been observed in northern Italy (Laffranchi et al. 2016).  
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#### 46 *Agricultural techniques*

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49 The  $\delta^{15}\text{N}$  value of herbivores increases by approximately 3 to 5‰ over that of the plants  
50 on which they feed (Bocherens & Drucker, 2003). The source of nitrogen is atmospheric  
51  $\text{N}_2$  and decomposing organic matter in soils. Nitrogen is made available to plants by  
52 nitrifying bacteria in the soil, whose activity involves significant isotopic fractionation.  
53 Because of this, plants are enriched in the heavy isotope relative to atmospheric  $\text{N}_2$ . One  
54 exception to this rule are the legumes (e.g. alfalfa, vetch, beans and peas), which are  
55 capable of fixing atmospheric nitrogen thanks to the activity of symbiont bacteria and  
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3 mycorrhizae, which provide the plant with low  $\delta^{15}\text{N}$  values close to or even lower than  
4 those in the air (Dawson et al., 2002).

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6 In agro-pastoral systems, the effects of crop management techniques (e.g. irrigation,  
7 fertilisation, crop rotation, slash and burn) are superimposed on the above processes and  
8 vary the isotopic signatures of cultivated plants (Szpak, 2014). Manuring and slash-and-  
9 burn cultivation produce a significant input of  $^{15}\text{N}$  into the soil, yielding a marked increase  
10 in the N isotopic signature value of the plants (Bogaard et al., 2007).

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12 Meanwhile, the effect of irrigation or rainfall on the nitrogen isotopic signal is more  
13 variable and depends on various factors, but it has been shown that conditions of higher  
14 humidity are associated with lower  $\delta^{15}\text{N}$  values. The same is true for shallower rooted  
15 herbaceous plants, as the  $^{15}\text{N}$  pool increases with soil depth.

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17 More is known about the effect of irrigation on the carbon signal. In C3 cereals, a negative  
18 correlation has been found between  $\delta^{13}\text{C}$  and water availability, which allows plants to be  
19 more selective and preferentially fix the light isotope  $^{12}\text{C}$ . Thus, in well irrigated crops or  
20 in cooler and wetter areas,  $\delta^{13}\text{C}$  values are more negative (Ferrio et al., 2005).  
21 Furthermore, areas with denser tree cover show more negative  $\delta^{13}\text{C}$  values due to the  
22 canopy effect (Drucker et al., 2008).

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24 This suggests the interpretation that the equids in *Group 1a* (Figure 5), which includes  
25 most of the Neolithic and LBA horses, were fed in cooler, wetter areas, such as natural  
26 pasture, perhaps with more tree cover and little agricultural management. Low  $\delta^{13}\text{C}$  and  
27  $\delta^{15}\text{N}$  values are often associated with natural grassland environments. For example,  
28 horses from the Early Neolithic Chaves cave (Figure 5), which are thought to have been  
29 undomesticated, show low isotopic values similar to those of wild ungulates such as  
30 cervids (Villalba-Mouco et al., 2018). The higher  $\delta^{15}\text{N}$  values of *Group 1b* equids (Mean  
31  $\delta^{15}\text{N}=5.5\text{‰}$ ) compared to those in group 1a (Mean  $\delta^{15}\text{N}=3.5\text{‰}$ ) are unrelated to higher  
32 aridity of the environment because  $\delta^{13}\text{C}$  values remain very negative (Figure 5, Table 3).  
33 This could be interpreted as a result of the use of manure to fertilise the fields.

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35 The rabbit found near the *Group 1b* equids (Figure 3, Figure 5) would have foraged in  
36 these more agriculturally managed fields. It should be noted that the EIA cows did not  
37 show isotopic values coincident with those of the horses in *Groups 1a* and *1b*, except in  
38 a single case.  
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3 However, in millet the correlation between isotopic signals and water availability is not  
4 apparent. Millet's C4-type physiology allows its cultivation in more arid environments  
5 and it is therefore less likely that they were cultivated in areas of water availability  
6 (Lightfoot et al., 2020). The difference between the millet-fed equids in *Group 2b* and the  
7 cows with high  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  isotopic values could again be due to increased fertilisation  
8 of crops grown for cattle feed (Figure 5).  
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15 The Late Roman equids fall into *Groups 2a* and *1a*, with intermediate  $\delta^{13}\text{C}$  and generally  
16 low  $\delta^{15}\text{N}$  values that may reflect significant legume consumption, as described in the  
17 Classical sources (Figure 5).  
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### 21 *Grain vs straw*

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23 In cereals, there is a difference between the isotopic value of the grain and the rest of the  
24 plant, whereby the grain is enriched in both  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  relative to the vegetative part.  
25 Wallace et al. (2013) have calculated a  $\delta^{13}\text{C}$  offset of +1.9‰ for wheat and +1.7‰ for  
26 barley. In millet *Setaria italica*, Lightfoot et al. (2020) found similar differences of up to  
27 +2‰. Regarding nitrogen signature, Fraser et al. (2011) have calculated a mean value for  
28 the grain-rachis difference of +2.4‰ in cereal crops in a range of zones and under varying  
29 conditions of irrigation and fertilisation intensity. Consequently, animals fed a higher  
30 proportion of grain would be expected to present more positive values for both  $\delta^{13}\text{C}$  and  
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### 42 *Geographical origin*

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44 The variety of the EIA equid diet indicates different equid management practices that  
45 does not seem to be related to the different geographical origin of some animals (Figure  
46 5). The previous strontium study (Albizuri et al., 2019) was conducted on enamel from  
47 molars forming at around 3 years of age but the age of death of these individuals was  
48 higher. Consequently, the results may be influenced by the turnover of collagen in bone,  
49 which, unlike enamel, occurs throughout the life of the animal. This could have blurred  
50 or even erased the isotopic signal acquired in the region from which the foreign animals  
51 came. Note that at Danebury a combined analysis of  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$  and  $\delta^{34}\text{S}$  determined  
52 differential feeding which has been attributed to the high mobility of the animals, partially  
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3 evidenced by  $\delta^{34}\text{S}$  values indicating the presence of non-local individuals (Hamilton et  
4 al., 2019).  
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### 7 8 *Plant record* 9

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11 The plants grown in the LBA and EIA indicate a majority presence of barley with an  
12 increase in millet and emmer (*Triticum dicoccum*), which may reflect the cultivation of  
13 crops mainly intended for use as forage. There is no proof of the existence of feeding  
14 troughs, but the appearance of cereal remains in most of the silos at the site suggests that  
15 cereals and straw were stored and therefore distributed in places where they could be used  
16 to feed the animals. According to the isotopic results, the animals fed with millet are  
17 mostly cows (Albizuri et al., in press) and horses and this shows that these animals must  
18 not have been consumed regularly by humans.  
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21 From the EIA, the increase in agricultural activity, millet and emmer cultivation and the  
22 use of animals for work may have been related to the cultivation of fodder crops and the  
23 creation of suitable pastures for livestock. Furthermore, the isotopic values of equids  
24 indicate the consumption of highly nutritious and digestible millet and emmer. For  
25 example, emmer, a low-yielding species, is currently used as fodder for livestock,  
26 especially for horses in the Iberian Peninsula (Peña-Chocarro & Zapata, 1997).  
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29 Columela wrote how to feed horses with varieties of wheat and barley mixed with  
30 legumes such as alfalfa, fodder pea and bitter vetch (Álvarez de Soto Mayor, 1824).  
31 Interestingly, in Can Roqueta we have observed a significant contribution of leguminous  
32 plants in the Late Roman specimens and in the A4 stable of Sant Jaume Mas d'en Serra,  
33 dated in the EIA, a high concentration of remains of plants traditionally used for animal  
34 feed, such as fodder pea (*Lathyrus sativus*), bitter vetch and emmer (López et al., 2011),  
35 have been recovered.  
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### 38 39 *Uses of the equids* 40 41

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43 The variability in the diet of the Can Roqueta equids may possibly indicate the provision  
44 of a greater or lesser proportion of grain in the forage according to the use made of the  
45 animal, whereby animals used exclusively for riding may have been fed differently from  
46 those used as draught and pack animals, perhaps receiving higher energy forage.  
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49 The bone pathologies observed in the hybrid mare CRII811 indicate its use for draught  
50 and pack purposes (Albizuri et al., 2019). Isotopic results show that their diet regularly  
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3 consisted of grain forage. In contrast, other animals may have been used more specifically  
4 for riding as they present isotopic values associated with natural feeding in pastures.  
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8 The unusual total number of animals identified suggests the possibility that these are the  
9 remains of ceremonial activities that brought together a large number of people, perhaps  
10 from elsewhere. Of interest in this respect are the ritual practices documented in Mongolia  
11 during the Late Bronze Age. Isotopic analysis shows that the horses and other animals  
12 sacrificed in Mongolia for funerary celebrations were selected by groups of herders who  
13 came together from different places (Makarewicz et al., 2018). Based on this example,  
14 we suggest the possibility that the numerous horse deposits from the EIA at Can Roqueta  
15 were the result of communal celebrations. Horse remains were deposited in silo-like  
16 structures next to human burials and in other cases inside pits located in areas of domestic  
17 activity. The presence of the remains of more than one equid, some with non-local  
18 strontium isotopic signals and accompanied by recovered materials of foreign origin  
19 (Phoenician and from south-eastern France), suggests the possibility that the equids were  
20 slaughtered in mass events where their meat could have been consumed. We have found  
21 no markings on the bones indicating that they were stripped or fractured, but ethnographic  
22 and archaeological evidence from Eurasian sites suggests that similar deposits were the  
23 product of ceremonial sacrifices and the subsequent deposition of skeletal parts with high  
24 symbolic significance (Piggott, 1962; Birtalan, 2003).  
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## 40 **Conclusions**

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43 Isotopic results show evidence of management for agricultural and pasture use. The crops  
44 were intended to feed humans, who consumed cereals with gluten from the C3 group and  
45 legumes, and for animal feed, for which purpose the millets and perhaps emmer may have  
46 been grown. Manuring of the fields is evidenced by the isotopic signal of the herbivores,  
47 mainly cattle, and this may indicate differential use of the land. The equids were fed on  
48 natural pasture, although a large group of them were also fed cereals, in some cases from  
49 the C4 group or millets, which are highly nutritious and digestible because they do not  
50 contain gluten. From the LBA onwards, two types of millet were grown in ever increasing  
51 amounts on the site, coinciding with the new presence of the domestic horse in the  
52 livestock herd.  
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5 The observed feeding variability may be related to a differential use made of the animals,  
6 for agricultural work, carrying loads or light riding. The animals that were primarily  
7 grass-fed may have been used for light riding and transport, or perhaps for herding. Some  
8 individuals would have spent more time stabled because they were used exclusively for  
9 agricultural work and heavy transport while the isotopic results show that its diet regularly  
10 consisted of grain forage.  
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17 In sum, the animals were fed on pastures cultivated with legumes and cereals and with  
18 forage crops most likely provided in troughs, or the two methods may have been  
19 alternated depending on the time of year and the availability of fresh grass and their use  
20 for agricultural work.  
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Structure/Sample	Bone	Taxon	Age (sex)/ Sr	Period	Chronology	14C Lab Code	14C Uncalibrated Age (BP)	14C SD ( $\pm\sigma$ )	14C 2 $\sigma$ Calibrated Date - Lower Limit	14C 2 $\sigma$ Calibrated Date - Upper Limit	Bibliographical Reference
CR60	pelvic	EC	AD	LBA	1000-750 BC	KIA-55380	2727	17	-909	-821	Grandal-d'Anglade et al., 2021
CR134	metatarsal	EC	AD	LBA	1000-750 BC						
CR11345	mandible	EC	10 y (male)	LBA	1000-750 BC	KIA-55377	2677	17	-897	-802	Albizuri et al., 2019
CRTR163(1)	metacarpal	EC	AD	LBA	1000-750 BC						
CRTR163(2)	phalange	EC	AD	LBA	1000-750 BC						
CRTR167	metatarsal	EC	AD	LBA	1000-750 BC						
CRTR249	tibia	EC	AD	LBA	1000-750 BC						
CR6	carpal	EA	10-13 y (male)/ <b>Local</b>	EIA	750-550 BC	Beta 449094	2470	30	-766	-422	Albizuri et al., 2019
CR11-223(2)	metapodial	EC	10 y (male)	EIA	750-550 BC	Beta 423331	2540	30	-796	-547	Albizuri et al., 2019
CR11374	phalange	EC	AD	EIA	750-550 BC						
CR11708	carpal	EC	AD	EIA	750-550 BC	Beta 476163	2500	30	-778	-520	Albizuri et al., 2019
CR11811	carpal	H	9 y (female)	EIA	750-550 BC	KIA-55376	2422	17	-725	-407	Grandal-d'Anglade et al., 2021
CRTR203	mandible	EC	AD	EIA	750-550 BC	Beta 449097	2410	30	-743	-399	Grandal-d'Anglade et al., 2021
CRTR243	mandible	EC	10 y (male)	EIA	750-550 BC	Beta 449099	2470	30	-766	-422	Grandal-d'Anglade et al., 2021
CRTR227	metatarsal	EC	AD	EIA	750-550 BC						
CRTR229	cranium	EC	old	EIA	750-550 BC	Beta 449096	2430	30	-750	-404	Grandal-d'Anglade et al., 2021
CRCRV16-5	mandible	EC	9 y (female)	EIA	750-550 BC						
CRCRV16-15(nd)	cranium	EC	9 y (female)	EIA	750-550 BC	Beta 463863	2430	30	-750	-404	Albizuri et al., 2019
CRCRV16-15(1)	phalange	EC	AD	EIA	750-550 BC						
CRCRV16-15(2)	phalange	EC	AD	EIA	750-550 BC						
CRCRV16-18	cranium	EC	8-9 y (male)	EIA	750-550 BC	Beta 463866	2410	30	-743	-399	Albizuri et al., 2019
CRCRV16-26	mandible	EC	5-7 y	EIA	750-550 BC	Beta 476169	2500	30	-778	-520	Grandal-d'Anglade et al., 2021
CRCRV16-29	tibia	EC	adult	EIA	750-550 BC	Beta 476170	2480	30	-772	-476	Albizuri et al., 2019
CRCRV16-30	mandible	EC	5-7 y	EIA	750-550 BC	Beta 463867	2450	30	-754	-412	Albizuri et al., 2019
CRCRV16-31(nd)	cranium	EC	8-9 y	EIA	750-550 BC	Beta 476168	2530	30	-794	-544	Albizuri et al., 2019
CRCRV16-31(1)	sesamoid	EC	adult	EIA	750-550 BC						
CRCRV16-31(2)	pelvic	EC	adult	EIA	750-550 BC						
CRCRV05-79(2)	cranium	EC	10 y (male)/ <b>No local</b>	EIA	750-550 BC						
CRCRV05-103	cranium	H?	7 y (male)/ <b>No local</b>	EIA	750-550 BC	Beta 423329	2460	30	-758	-416	Albizuri et al., 2019
CRCRV05-110	radius	EC	adult	EIA	750-550 BC	Beta 463860	2400	30	-733	-397	Grandal-d'Anglade et al., 2021
CRCRV05-198	pelvic	EC	adult	EIA	750-550 BC	Beta 463864	2440	30	-751	-408	Grandal-d'Anglade et al., 2021
CRCRV05-217	radius	EC	adult	EIA	750-550 BC						
CRCRV05-277	tibia	H?	>5 y	EIA	750-550 BC						
CRCRV09-285(nd)	cranium	EC	7-8 y (male)/ <b>Local</b>	EIA	750-550 BC						
CRCRV09-285(1)	pelvic (right)	EC	adult	EIA	750-550 BC						
CRCRV09-285(2)	pelvic (left)	EC	adult	EIA	750-550 BC	Beta 463865	2510	30	-786	-541	Albizuri et al., 2019
CRCRV09-294	mandible	EC	>5 y/ <b>No local</b>	EIA	750-550 BC	Beta 423328	2480	30	-772	-476	Albizuri et al., 2019
CRTR171	humerus	EC	>5 y (male)	E-MIA	550-400 BC	Beta 449095	2330	30	-512	-233	Grandal-d'Anglade et al., 2021
CRTR175	phalange	EC	>5 y	E-MIA	550-400 BC	Beta 449098	2390	30	-725	-394	Albizuri et al., 2019
CRTR40	femur	EA	old	LR	400-600 AD						
CRTR240	cranium	EC	adult	LR	400-600 AD						
CRTR279	cranium	EC	old	LR	400-600 AD						

Period	n	$\delta^{13}\text{C}$ mean $\pm$ sd (min to max)	$\delta^{15}\text{N}$ mean $\pm$ sd (min to max)
LBA equids	6	-19.2 $\pm$ 1.5 (-20.7 to -17.3)	4.9 $\pm$ 1.2 (3.3 to 6.3)
LBA cattle	5	-18.8 $\pm$ 1.4 (-19.7 to -16.3)	6.4 $\pm$ 0.7 (5.7 to 7.4)
EIA equids	30	-19.3 $\pm$ 1.4 (-21.3 to -16.5)	5.8 $\pm$ 0.9 (3.7 to 7.3)
EIA cattle	9	-18.1 $\pm$ 1.3 (-20.1 to -16.6)	7.2 $\pm$ 1.3 (5.4 to 8.7)
E-MIA/IP equids	2	-20.4 to -19.1	4.5 to 5.4
LR equids	3	-20.0 $\pm$ 0.5 (-20.6 to -19.6)	4.4 $\pm$ 0.9 (3.4 to 5.0)
LN: equid	1	-20.8	2.6
EN equids	4	-20.7 $\pm$ 0.5 (-21.0 to -20.1)	4.3 $\pm$ 0.9 (3.4 to 5.1)

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Table 3. Isotopic mean values,  $\pm$  standard deviation and range of values on equines according to the groups obtained in the cluster analysis (see Figure 4)

<b>Period</b>	<b>n</b>	<b><math>\delta^{13}\text{C}</math> mean <math>\pm</math> sd (min to max)</b>	<b><math>\delta^{15}\text{N}</math> mean <math>\pm</math> sd (min to max)</b>
Group 1a	6	-20.3 $\pm$ 0.4 (-20.8 to -19.8)	3.5 $\pm$ 0.5 (2.6 to 4.1)
Group 1b	14	-20.7.8 $\pm$ 0.4 (-21.3 to -20.0)	5.5 $\pm$ 0.7 (4.1 to 6.9)
Group 2a	10	-18.9 $\pm$ 0.6 (-19.9 to -18.2)	5.3 $\pm$ 0.5 (4.5 to 6.2)
Group 2b	12	-17.8 $\pm$ 0.7 (-18.9 to -16.6)	6.4 $\pm$ 0.5 (5.8 to 7.3)

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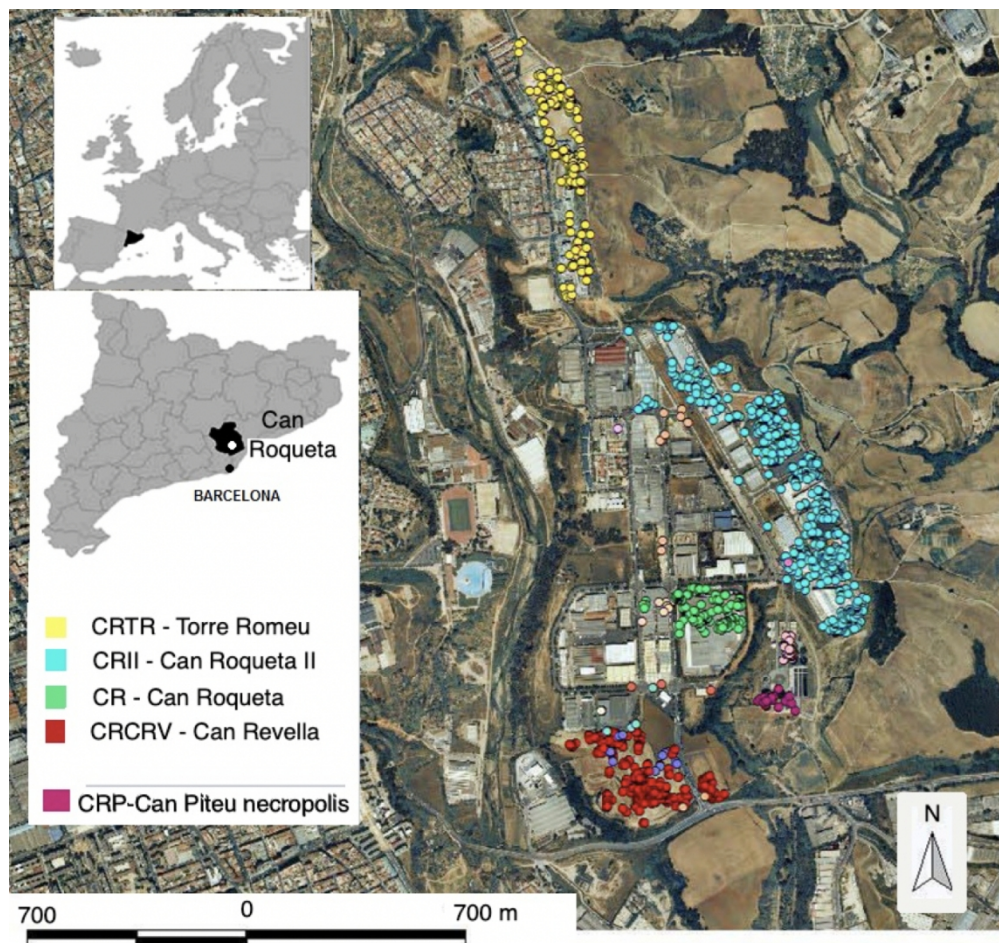


Figure 1. Location of the Can Roqueta site and distribution of the structures in the archaeological sectors

27x26mm (1270 x 1270 DPI)

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CRCRV16-15



CRCRV16-31



CRCRV09-285

Figure 2. Silo deposit CRCRV16-15: horse skull and articulated limbs and neck. Silo deposit CRCRV16-31: horse skull and postcranial remains. Inhumation CRCRV09-285: adult male accompanied by a horse skull and two hip bones, left and right

29x24mm (1270 x 1270 DPI)

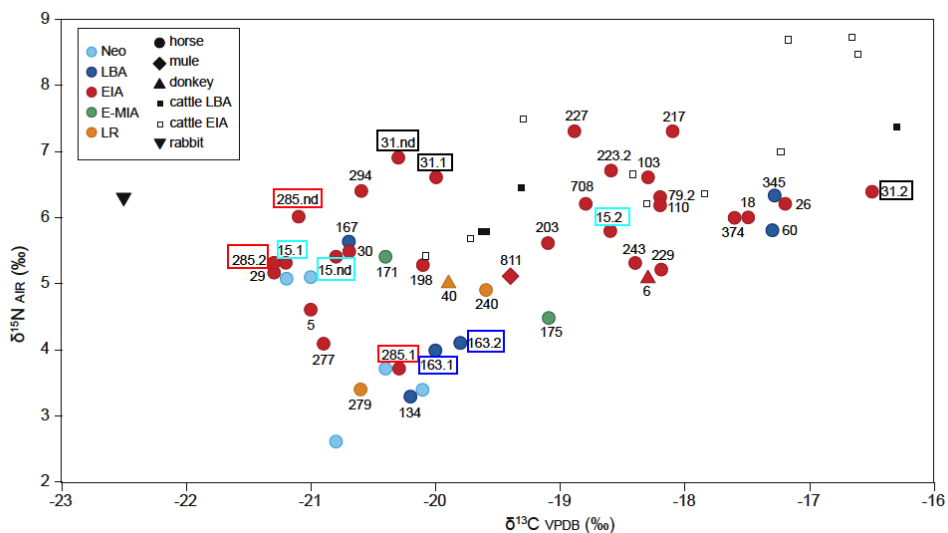


Figure 3. Isotopic values ( $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ) of equids and other herbivores for comparison. The numbers in colored rectangles identify animals from the same structure. Note that the horizontal scale is exaggerated x1.5 for clarity of the graph

20x11mm (1270 x 1270 DPI)

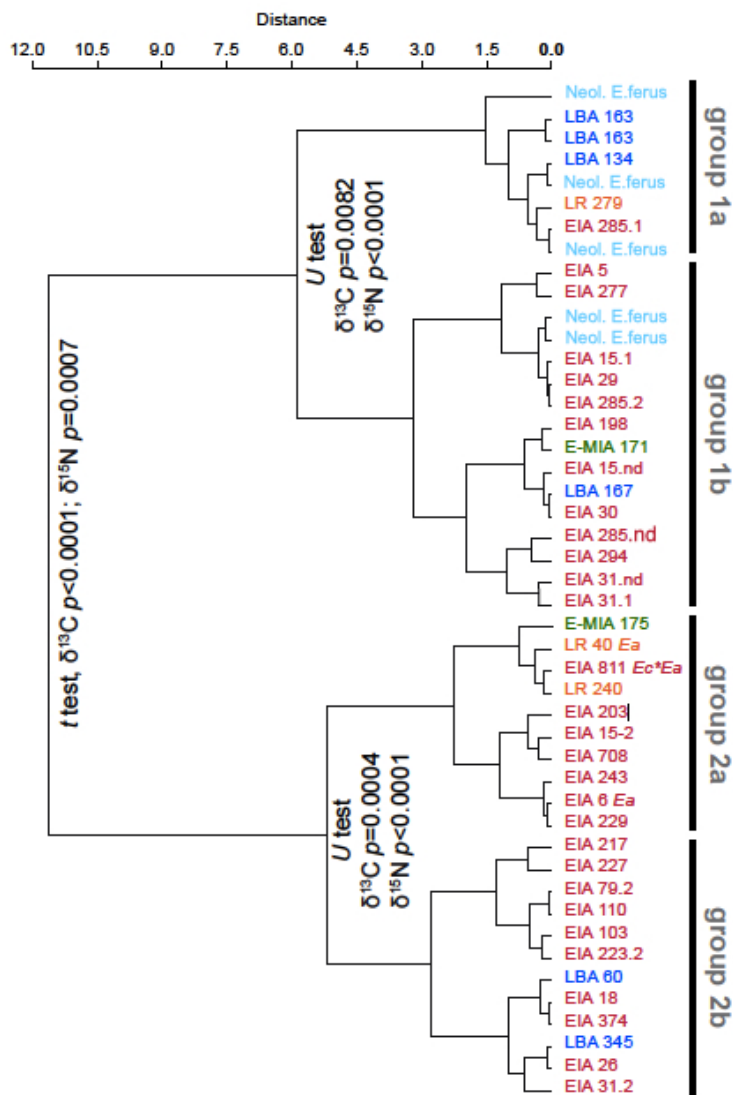


Figure 4. Cluster analysis (Ward's method) of equids, based in their isotopic signatures. Four groupings are observed whose combined isotopic values show statistically significant differences

10x13mm (1270 x 1270 DPI)

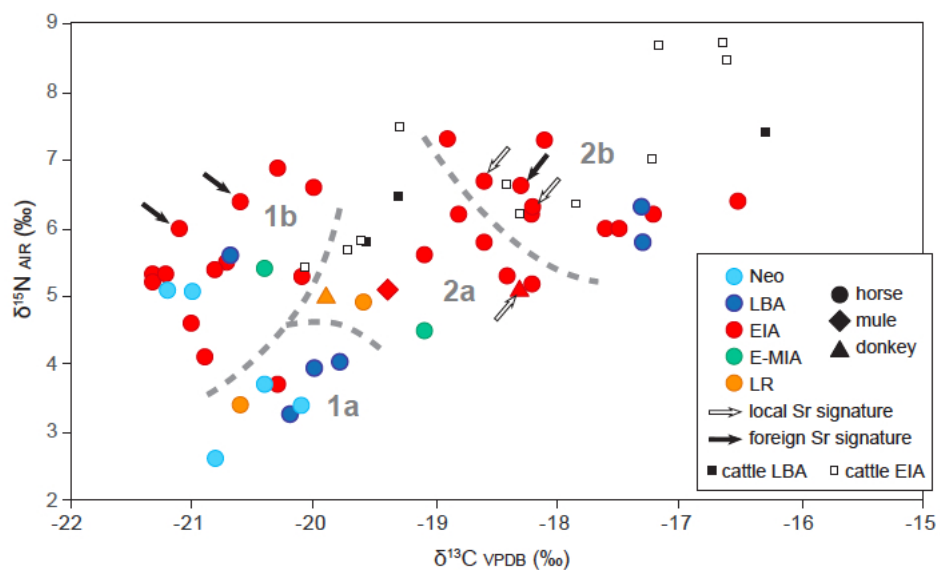


Figure 5. Isotopic signatures of the four equid groups obtained by Cluster analysis. Cases where the  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic signal indicates local or foreign origin are indicated (Albizuri et al., 2019). Note that the horizontal scale is exaggerated x1.5 for clarity of the graph

14x9mm (1270 x 1270 DPI)