



Isotopic analysis as proxy to investigate the presence of domestic camelids (*Lama glama*) in central Argentina during the late period (~1220–330 BP)

Andrea Recalde * , Diego Rivero

Conicet, Instituto de Estudios Históricos/Centro de Estudios Históricos, Facultad de Filosofía y Humanidades, Universidad Nacional de Córdoba, Corro 308, 5000 Córdoba, Argentina

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ABSTRACT

Camelid exploitation has been important throughout the Holocene in central Argentina, emphasizing *Lama guanicoe* hunting. Despite attempts (i.e. osteometry, DNA) no conclusive results have been obtained on the presence or management of *Lama glama* (domestic camelids) in the region. This study represents the first isotopic analysis conducted on archaeofaunal remains of Camelidae from the Sierras del Norte (central Argentina), dating to the Late Period (~1220–330 cal BP), to discuss the possible presence of *Lama glama* in the region. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ obtained in bone collagen showed that camelids from Quebrada Norte 7 (QN7) have high values of $\delta^{13}\text{C}$ (values between -14.98 ‰ and -12.54 ‰) concerning other assemblages dated from the Early and Late Holocene, with isotopic values ranging from -21.6 ‰ and -16.5 ‰ . These results are discussed and compared against published data from another site in the region. In this way, the camelid samples with high $\delta^{13}\text{C}$ from QN 7 could contribute to the discussion and reflection on the introduction of *Lama glama* within a flexible subsistence and mobility pattern.

1. Introduction

South America camelids include two wild species, guanaco (*Lama guanicoe*) and vicuna (*Vicugna vicugna*), and two domestic species, llama (*Lama glama*) and alpaca (*Vicugna pacos*) (Yacobaccio, 2021). Especially *L. guanicoe* and *L. glama*, have been the most important resource for Holocene societies from north-west, center-west and center of Argentina, including the Patagonia for the first (Mengoni Góñalons, 1995; Elkin, 1996; Olivera, 1997; Martínez and Gutiérrez, 2004; de Lamo, 2011; Politis et al., 2011; Yacobaccio, 2021). The guanaco (*Lama guanicoe*) was the major faunal resource exploited by past people in Sierras Centrales (Argentina), dominating bone assemblages since the Early Holocene and making up peaks of 90 % of the specimens identified from family-to-species level (Rivero, 2009; Medina et al., 2014; Costa, 2016; Medina and Rivero, 2020). However, the presence of domesticated species in the region remains to be established. Furthermore, research about camelid husbandry and its economic benefits during the Late Period (1200–330 cal. BP) has been poorly developed. The presence of *Lama glama* was only suggested in Spanish documents from the early colonial period (XVI–XVII centuries AD), providing some reference to its presence in indigenous sites (Berberián, 1987).

Accordingly, despite no direct evidence of the existence of domestic camelids, indirect archaeological indicators were considered (Fig. 1). Herding scenes in rock art, llama figurines in domestic contexts, and the presence of spindle whorls associated with spinning have led to the assumption of camelid herding in the region (González, 1943; Serrano, 1945; Berberián, 1984; Laguens and Bonnín, 2009). In other cases, the size of camelid bones identified at some sites has been interpreted as evidence of *Lama glama* presence (Pascual, 1954; Berberián, 1984; Gambier, 1998).

Likewise, an attempt was made to use osteometry on camelid bones from different sites spanning the entire Holocene. These analyses were not conclusive given the variability in the size of Holocene camelids in Sierras Centrales (Medina et al., 2014). In addition, other indicators to identify *L. glama*, such as fibers (i.e. Wheeler et al., 1992; Reigadas, 2012), were excluded since they have not been preserved in the local archaeological record. Preliminary studies of ancient DNA carried out on camelid bones from the Late Period were not conclusive, since bones showed haplotypes common to current samples of *L. guanicoe* from Reserva La Payunia (Mendoza, Argentina) and Putaendo-San Felipe (V Region, Chile) (Metcalf et al., 2011).

Considering the problems and challenges exposed before, the main

* Corresponding author.

E-mail address: andrea.recalde@unc.edu.ar (A. Recalde).

goal of this work is to explore the use of the carbon and nitrogen stable isotope composition analyses to propose a line of inquiry about the presence of domestic camelids during the Late Period (~1220–330 cal BP). The results of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis of camelid samples from Quebrada Norte 7 (Sierras del Norte, central Argentina) are discussed and compared with information derived from newly reported analyses and published sources from other regions of Sierras Centrales (central Argentina). The results will be considered within the flexible subsistence framework and mobility patterns proposed for the Late Period, where nuclear families moved around the landscape to take advantage of both agricultural and wild resources as available (Pastor, 2010; González Navarro, 2012; Medina et al., 2016; Recalde and López, 2017). There, small-scale agriculture with scarce or no mechanization characterized by the production of corn (*Zea mays*), squash (*Cucurbita* sp.), beans (*Phaseolus* spp.), tubers (cf. *Solanum* sp. and cf. *Ipomea batata*), and quinoa (*Chenopodium quinoa*) (Medina et al., 2016; López and Recalde, 2016; López, 2017). We expect the results to contribute to the discussion and reflection on the introduction of *Lama glama* within a flexible subsistence and mobility pattern, in which Cerro Colorado inhabitants utilized both agricultural and wild resources as available.

2. Characteristics of QN7 in late Holocene Occupation, Sierras Centrales region

The landscape of Cerro Colorado (north of the Sierras Centrales, Argentina), encompasses a great diversity of environments in a limited region of about 900 km². The Chaco forest, where the Quebrada Norte 7 is located, is distributed between 500 and 800 m a.s.l., dominated by highland forests (v.gr. *Lithraea molleoides*, *Myrcianthes cisplatensis*, *Neltuma alba*, *Neltuma nigra*, *Celtis ehrenbergiana*, *Aspidosperma quebrachoblanco*) (Sayago, 1963; Cabrera, 1971). The western sector, which exceeds 800 m a.s.l., is composed of shrubland of low shrubs, more or less

open, which is replaced in the higher areas by grasslands (*Festuca hieronymii*, *Poa ligulais*, *Nasella* spp., and, in smaller quantities, *Eustachis retusa*, *Pappopharon maci* and *Digitaria californica*) (Sayago, 1963). Finally, to the east, between 500 and 350 m a.s.l., it is developed the Chaco plains, semi-deciduous at medium to high altitudes, where the presence of *Stetsonia coryne* (cardón) and *Cereus validus* (ule) stands out (Sayago, 1963; Cabrera, 1971).

Quebrada Norte 7 (QN7) is an open-air site at 617 m a.s.l. (Fig. 2), covering 1.5 ha. It is surrounded by slope organic-rich soil suitable for precipitation-dependent farming. Excavations were carried out over 15 m² to a maximum depth of 70 cm, where a dense concentration of

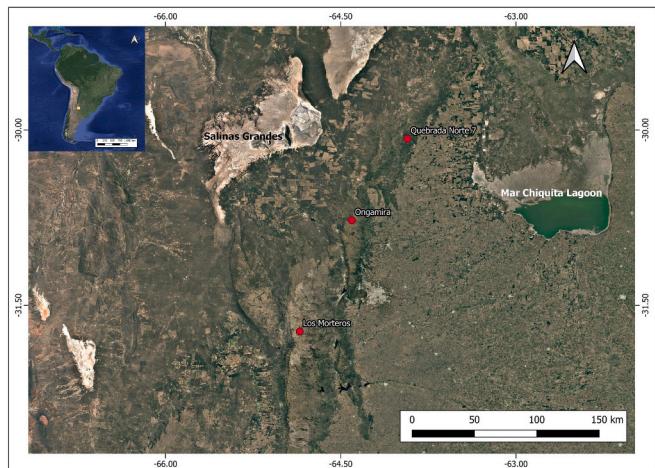


Fig. 2. Sierras of Córdoba region, center of Argentina, with the sites mentioned in the text.

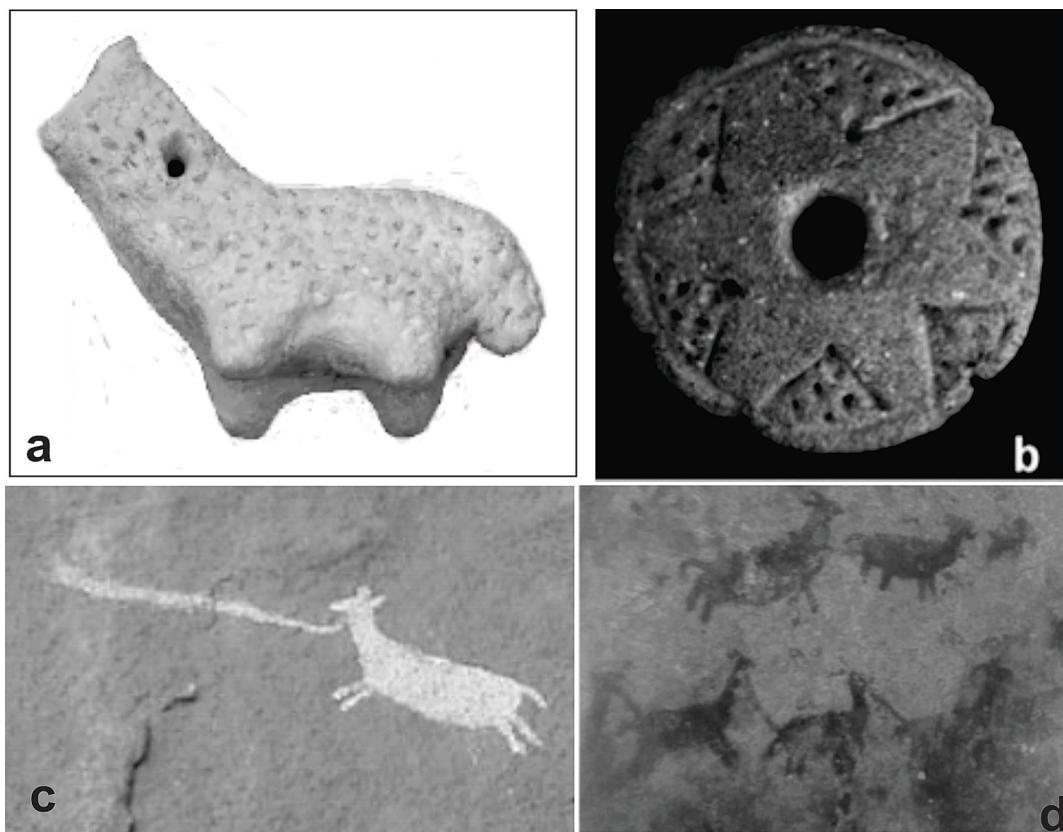


Fig. 1. Indirect archaeological indicators of camelid husbandry. A, ceramic figurine of llamas, photo by Bixio et al., 2010. B, textile artifacts, Estancia de Jesús María – Museo Jesuitico Nacional collection). C, camelid on a rope. D, caravan motifs.

pottery fragments, cultivated plants, wood charcoal, faunal remains, and bone, lithic, and grinding tools, were recorded across the strata (Recalde and López, 2017). The QN7 archaeological record suggests an open-air, multi-purpose residential site composed of a few dwellings associated with small-scale agricultural fields with low technological input levels. Radiocarbon dates indicate Late Period occupations between 1250 ± 80 BP (LP – 3212) and 405 ± 21 BP (AA 107245) (Recalde, 2015; López and Recalde, 2016).

The zooarchaeological evidence indicates that inhabitants of QN7 had access to prey species from Bosque Serrano, such as *Cavia* sp., *Chaetophractus villosus* and *Subulo* sp., but also from open vegetation environment, such as camelids and deers (*Ozotocerus bezoarticus*). In addition, the macro-botanical remains recovered in QN7 include domesticated and wild plants (i.e. piquillín –*Condalia* spp., mistol-*Ziziphus* mistol). The presence of maize, quinoa, ajara (*C. quinoa* cf. var. *melanospermum*) and beans, the absence of pumpkin (*Cucurbita* sp.), and evidence of tubers indicate a method of agricultural management related to a broad agricultural calendar that articulated winter and spring species in the Sierras of Norte (López y Recalde 2016; Recalde and López, 2017). Five grinding areas and six rock art sites surround QN7.

3. Materials and methods

Eight fused first phalanges of *Lama* sp. from QN7 that presented good condition (i.e. not burned, weathered, or with chemical deposition) were selected for the isotopic analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. The studies were performed at Laboratorio de Isótopos Estables en Ciencias Ambientales (LIECA-CONICET), and the collagen was obtained following the protocol defined in Gil et al. (2024). The values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are expressed in parts per thousand (‰) relative to international measurement VPDB and AIR scales, respectively. The instruments used were Flash 2000 Elemental Analyzer coupled to Thermo Delta Advantage IRMS. The integrity of the obtained isotopic signals was evaluated by considering the atomic C: N ratio. All samples show values within the accepted range for collagen (2.9–3.6) indicating a good state of preservation (De Niro, 1985). The only exception is sample No. 5 (2.85), which was discarded.

The analysis of the Cerro Colorado isotopic ecology is already in

progress. Thus, the results of QN7 were compared with stable isotope values from archaeological and modern camelid samples. In this regard, dates were compared with the isotopic values, also presented here, of two fused first phalanges of *Lama guanicoe* from the Los Morteros site (2190 m a.s.l., Pampa de Achala, Córdoba), an Early Late Holocene forager site located in the upper mountain grassland range and dated at ca. 3000 BP (Rivero et al., 2025). Values of Late Holocene camelid bones from Ongamira (between 1905 ± 20 and 4654 ± 22 BP) (Weihmüller et al., 2024) were also considered during the analysis (Fig. 1: Table 1). Isotopic analyses performed on specimens of the present-day native population from Northwest Córdoba were also used for comparison (Weihmüller et al., 2024). In these modern samples, the authors considered the Suess effect, and the $\delta^{13}\text{C}$ values were corrected by adding + 1.5 ‰, as frequently applied (Tessone et al., 2014; Moscardi et al., 2022). On the other hand, the isotopic values of a human sample from Cerro Colorado, dating in 713 ± 25 AP (AA110930), were included. Finally, some complementary data of $\delta^{13}\text{C}$ values carried out in plants of archaeological sites of Sierras de Córdoba were analyzed (Table 2) (Pastor, 2007; Medina, 2008).

A Hierarchical clustering analysis using Euclidean distance based on Ward's method explored whether the $\delta^{13}\text{C}$ values of the analyzed samples clustered together. Cluster analysis was performed using PAST v. 4.03 software (Hammer et al., 2001).

4. Results

Seven of the eight samples from QN7 site show values within the

Table 2

The carbon isotopic values of wild and cultivated plants from Sierras Centrales archaeological sites.

Taxa	^{14}C BP	$\delta^{13}\text{C}$ ($\pm 0.1\text{ ‰}$, 1σ)	References
<i>Zea</i> maiz	878 ± 18	-9.1 ‰	Medina, 2008
<i>Phaseolus</i> sp.	525 ± 39	-24.6 ‰	
<i>Prosopis</i> sp.	866 ± 39	-26.0 ‰	
<i>Phaseolus</i> sp.	1028 ± 40	-22.5 ‰	Pastor, 2007

Table 1
Isotopic composition of bone collagen camelid samples for Late Holocene camelids.

Site	Altitude (m a.s.l.)	Lab. Code	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C:N	References
Los Morteros	2190	1228	-20.53	4.19	3.26	This work
Los Morteros	2190	X32581	-21.6	3.9	3.1	This work
Quebrada Norte 7	617	1478	-16.05	7.35	3.28	This work
Quebrada Norte 7	617	1473	-16.03	9.24	3.30	This work
Quebrada Norte 7	617	1477	-15.35	5.74	3.28	This work
Quebrada Norte 7	617	1225	-14.98	5.46	3.31	This work
Quebrada Norte 7	617	1481	-13.69	4.99	3.28	This work
Quebrada Norte 7	617	1474	-12.85	5.91	3.28	This work
Quebrada Norte 7	617	1226	-12.54	8.83	3.37	This work
Ongamira	1100	MT170631	-17.3	3.5	3.3	Weihmüller et al., 2024
Ongamira	1100	MTC-15148	-17.0	4.3	3.4	Weihmüller et al., 2024
Ongamira	1100	MT170625-1	-15.7	3.8	3.2	Weihmüller et al., 2024
Ongamira	1100	MT170622-1	-17.1	4.7	3.3	Weihmüller et al., 2024
Ongamira	1100	MT170630-1	-18.4	6.4	3.3	Weihmüller et al., 2024
Ongamira	1100	ADR-09	-18.4	4.0	3.2	Weihmüller et al., 2024
Ongamira	1100	MT170623	-16.7	4.7	3.2	Weihmüller et al., 2024
Ongamira	1100	ADR-07	-16.6	4.8	3.2	Weihmüller et al., 2024
Ongamira	1100	PN-04	-17.2	5.3	3.2	Weihmüller et al., 2024
Ongamira	1100	PN-03	-15.0	4.7	3.3	Weihmüller et al., 2024
Ongamira	1100	PN-05	17.3	5.9	3.3	Weihmüller et al., 2024
Ongamira	1100	PN-010	-15.2	3.9	3.2	Weihmüller et al., 2024
Ongamira	1100	PN-011	-16.0	5.8	3.2	Weihmüller et al., 2024
Ongamira	1100	PN-012	18.3	6.1	3.2	Weihmüller et al., 2024
Ongamira	1100	MT170620	-14.3	3.3	3.2	Weihmüller et al., 2024
Ongamira	1100	MT170621	-17.2	5.3	3.2	Weihmüller et al., 2024
Ongamira	1100	MT170624	-17.9	6.4	3.3	Weihmüller et al., 2024
Ongamira	1100	MT170623	-17.5	6.5	3.2	Weihmüller et al., 2024
Ongamira	1100	YU-14911	-19.4	6.0	3.3	Weihmüller et al., 2024

accepted range for collagen (2.9–3.6) indicating a good state of preservation (De Niro, 1985). The only exception is sample No. 5 (2.85), which was discarded. The samples show $\delta^{13}\text{C}$ values that were grouped into three clusters (Fig. 3), one of the LM and the other two of the QN7. The LM samples (Cluster 3) possess the lowest $\delta^{13}\text{C}$ values, ranging from -21.6 ‰ to -16.5 ‰ (Code X32581 and 1228, Table 1, Fig. 3). While one of QN7 Cluster with medium and high $\delta^{13}\text{C}$ values (Cluster 1), ranged from -16.3 ‰ to -14.98 ‰ (Code 1478, 1473, 1477, and 1225; Table 1, Fig. 3), and the other (group 2) includes three specimens exhibiting particularly high $\delta^{13}\text{C}$ values, ranging from -12.54 ‰ to -13.69 ‰ . (Code 1481, 1474, and 1226) (Table 1, Fig. 3).

While the values of $\delta^{15}\text{N}$ show a wide range from 3.9 ‰ to 9.24 ‰ , the lowest compositions correspond to the Los Morteros site, while in QN7 the values range from 4.99 ‰ to 9.24 ‰ (Table 1).

5. Discussion

QN7 samples of $\delta^{13}\text{C}$ were separated into two groups (Fig. 3). On the one hand, values lower than -14 ‰ (Cluster 1), are consistent with mixed diets of guanacos that inhabit the lowland foothills. On the other hand, the values higher than -14 ‰ (Cluster 2), may be linked to mixed diets that include higher proportions of C_4 plants. It may be captive animals subjected to different diets (Politis and Pedrotta, 2006).

Some authors warn that the high values of $\delta^{13}\text{C}$ may be influenced by the access of camelids to ecological environments with high proportions of C_4 plants (Thornton et al., 2011; Grant et al., 2018). Studies on the composition of the vegetation in the study area indicate that since 3,870 (± 210) years before present relative abundance of C_3 plants increased 32 % in average (Silva et al., 2011: 265). In addition, recent research on Chaco Arido camelid diets (i.e., Salinas Grandes) also reports that the average proportion of C_4 plants in camelid diets does not exceed 30 % to

35 %, highlighting a dietary emphasis on C_3 plants (Giesa et al., 2018). The analysis of the $\delta^{13}\text{C}$ of camelids (*Lama guanicoe*) from Ongamira and those currently inhabiting the circumsaline area suggests a mixed diet consisting of approximately 65 % C_3 plants and 35 % C_4 plants (Weihmüller et al., 2024). In this way, the isotopic data of modern *Lama guanicoe* samples present $\delta^{13}\text{C}$ values ranging from -20.0 ‰ to -15.7 ‰ (Weihmüller et al., 2024: 7) (Fig. 4).

Complementarily, Weihmüller et al. (2024) indicate that the isotopic signature of C_4 plants could increase, as suggested by Llano and Ugan (2014), due to the consumption of CAM plants (e.g., cactus) in arid environments. However, they argue that this consumption would account for less than 5 % of the potential dietary contribution of these artiodactyls (Weihmüller et al., 2024). A key finding of this proposal is that census data show guanacos, even under markedly arid conditions, selected C_3 plants (e.g., *Neltuma* sp.) over CAM plants (e.g., cactus), which are abundant in the Chaco landscape (Giesa et al., 2018).

The Cluster 2 of QN7 samples, with high values from -12.54 ‰ to -13.69 ‰ $\delta^{13}\text{C}$, are most proximal and similar to the presence of captive camelids fed on high proportions of C_4 plants, as has been proposed for other contexts from Perú (Finucane et al., 2006; Dufour et al., 2014; Szpak et al., 2014), Argentine Puna (Grant and Olivera, 2016) and Ambato Valley, in Northwestern Argentine (Dantas et al., 2014, 2015). In this sense, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the *Lama glama* samples from the Ambato Valley (AV) (Dantas et al., 2015), fed wild and a controlled diet based on corn, are consistent with those of Cluster 2 of QN7 (Fig. 4). Thus, the isotopic values of the human remains recovered at the area near the site ($-12.6\text{ ‰ } \delta^{13}\text{C}/8.9\text{ ‰ } \delta^{15}\text{N}$) (Díaz and Recalde, 2019), contemporaneous with the occupation of QN7, support a mixed diet, where wild and cultivated plants like *Zea mays* were consumed (López and Recalde, 2016). This archaeological site provides macro-botanical remains associated with the processing and consumption of cultivated plants (e.g., *Cucurbita* sp., *Phaseolus vulgaris*, and *Chenopodium quinoa*), and phytoliths recovered from hand-stones offered direct evidence of maize processing (López and Recalde, 2016).

The lowest $\delta^{15}\text{N}$ compositions, from 3.9 ‰ to 4.19 ‰ (Table 1), correspond to the Los Morteros site and are consistent with a diet of wild camelids inhabiting the upper mountain grassland range. While the values of $\delta^{15}\text{N}$ from the QN7 sample range from 4.99 ‰ to 9.24 ‰ . Since high values of $\delta^{15}\text{N}$ are found in saline environments (Yacobaccio et al., 2010; Thornton et al., 2011), it is possible that some of the wild specimens were hunted near the area of Salinas Grandes (northwest of the province of Córdoba; Fig. 2) or Mar Chiquita lagoon, both saline environments, 60–80 km away from the site. However, as proposed by Panarello and Mondini (2015) claim that multiple factors can influence the nitrogen concentration in the species; therefore, these should be corroborated in future studies.

6. Conclusion

The isotopic analysis of the QN7 samples presented here represents an exploratory approach regarding the possible presence of domesticated camelids in the Sierras Centrales, where various approaches (indirect evidence, osteometry, DNA analysis) have been employed without success. Archaeological data from QN7 suggest a mixed foraging and farming economy, characteristic of Late Period (~1220–330 cal BP) (Medina et al., 2016). Similarly, this archaeological site provides macro-micro botanical remains including taxa beyond maize (López and Recalde, 2016).

Researchers have suggested for neighboring regions (e.g., Panarello et al., 2006–2009; Izeta et al., 2009; Yacobaccio et al., 2010; Dantas et al., 2014), that the values higher in $\delta^{13}\text{C}$, may be associated with mixed diets incorporating greater proportions of C_4 plants. In this way, the maize contribution to camelid diets may have occurred directly or indirectly (e.g., via crop residues) (Gheggi et al., 2024). Consequently, in QN7 we cannot rule out the possibility of human intervention in the feeding practices of some of the isotopic analyzed camelids.

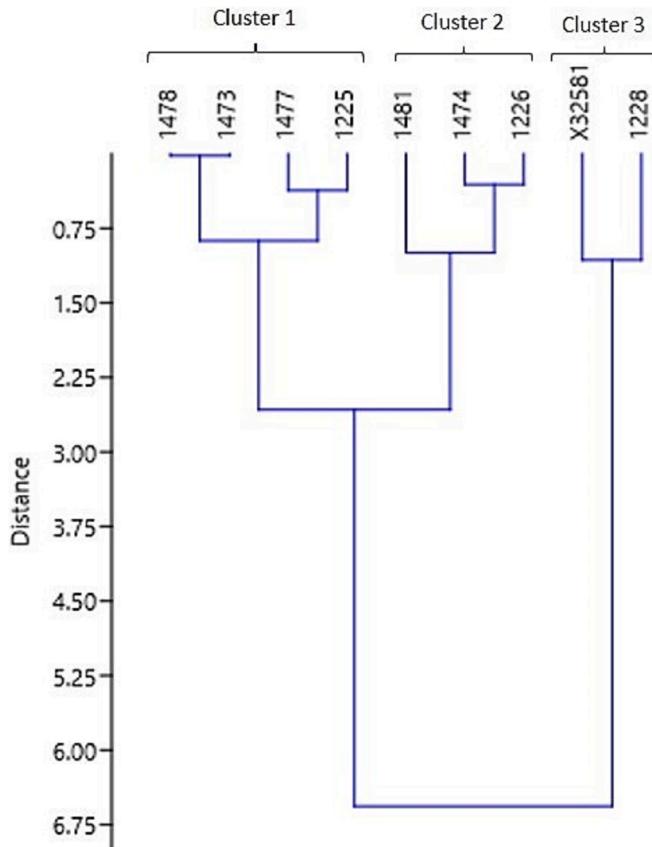


Fig. 3. Clustering analysis (Ward's method) from $\delta^{13}\text{C}$ values from camelids samples from QN7 and LM sites.

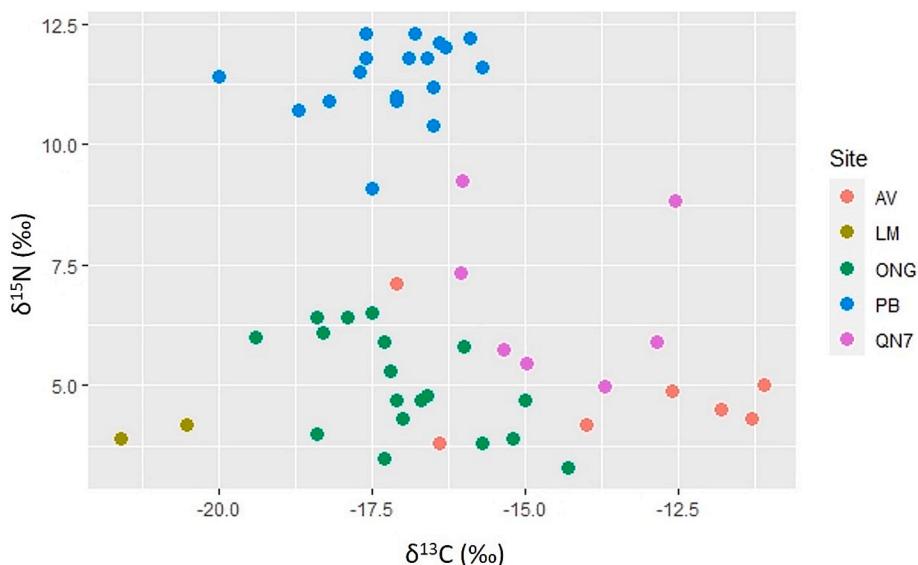


Fig. 4. Values of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of samples from Los Morteros (LM), Ambato Valley (AV), (data from Dantas et al., 2015), Ongamira (ONG), (data from Weihmüller et al., 2024), and QN7 archaeological sites and current Northwestern Córdoba (NC) camelids (data from Weihmüller et al., 2024).

Various lines of inquiry emerge to investigate a possible camelid management strategy within the subsistence strategies developed by the past inhabitants of Cerro Colorado. For example, no corrals or pens for keeping herds have been found near QN7, suggesting a smaller-scale variety of camelid husbandry, with camelids being kept by families or other small social units, as proposed for other Andean regions, (i.e. Szpak et al., 2014; Szpak and Valenzuela, 2020).

In sum, quantifying dietary (isotopic) variation has excellent potential to provide insights into the nature of human-animal interaction in prehistoric contexts. Therefore, by extending the QN7 sample size of camelid isotopic and adding different environments and sites we could better understand the role of domestic camelids for the groups that inhabited Sierras Centrales during the Late Holocene.

CRediT authorship contribution statement

Andrea Recalde: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Diego Rivero:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

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

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Data availability

Data will be made available on request.

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