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New isotopic evidence for micro and mesothermal valleys camelids from Northwest Argentina

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Introduction: Domestic and wild camelids were the most significant meat resource for pre-Hispanic agropastoral societies in the Argentine Northwest's micro valleys (between 2,500 and 3,400 masl) and mesothermal valleys (2,500 and 1,500 masl), with varying relative importance in comparison to cultivated and collected plants. Examining pastoral movement techniques, as well as the areas available for wild resource gathering, allows us to acquire a better understanding of the nature and scale of social structure among these human communities. Stable isotope analyses of carbon ($^{13}\text{C}/^{12}\text{C}$; $\delta^{13}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$; $\delta^{15}\text{N}$) provide efficient tools for understanding these features.

Methods: The article shows the bone collagen measurements of a sample of camelid bones from archaeofaunas recovered from Soria 2 sites ($n = 7$) and structure 93 of Loma l'Antigo ($n = 5$), all in Catamarca province. The first is a residential unit in the Yocavil valley (2,400 masl), and its chronology corresponds to the beginning of the region's Formative Period. The second is in the Cajón Valley (2,700 masl) and dates to the Regional Developments Period. Bone specimens were previously categorized to genus or species rank employing morphological and osteometric criteria.

Results: Our results suggest that C_4 plants have been important in animal diets since the Formative period. At the same time, access to pastures or wildlife at high altitudinal levels persisted during the Regional Developments, with the possibility of a fodder intensification strategy also based on C_3 plants.

Discussion: Such kind of data allows us to assess whether a livestock intensification plan based on corn provision coincided with social, political, and economic changes in the early second millennium AD.

KEYWORDS

zooarchaeology, agropastoralism, stable isotope analysis, South American camelids, diet

1 Introduction

Zooarchaeological investigations in the Argentine Northwest (ANW) have focused on the numerous uses of the Camelidae resource since the beginning of human occupancy in the area (Yacobaccio, 1994). This family is represented by three species of the Lamini tribe in the ANW: Andean guanaco (*Lama guanicoe cacsilensis*, wild), southern vicuña

(*Vicugna vicugna vicugna*, wild) and llama (*Lama glama*, domestic). Research topics included hunting specialization on guanaco and vicuña during the Holocene and its continued importance among food-producing societies, the domestication of llama, management strategies for llama herds, and the impact of the introduction of European livestock on camelid populations (Olivera, 1997; Yacobaccio et al., 1997, 1998; Yacobaccio, 2001; Izeta, 2008; Arias, 2020; Belotti López de Medina, 2015; Grant and Escola, 2015; Mengoni Goñalons and Yacobaccio, 2006; Olivera and Grant, 2008, 2009; Miyano et al., 2017; among others). Although animal husbandry was well-established in village societies during the last 3000 years, the relevance of the Camelidae resource in the history of the ANW went beyond domestic species, as hunting of wild camelids remained very important (Olivera and Grant, 2008, 2009; Grant, 2010; Belotti López de Medina, 2015; Mercolli, 2016; Moreno and Revuelta, 2010; Ortiz and Urquiza, 2012). These investigations were enhanced in the last 30 years by osteometric techniques applied to taxonomic identification, allowing to distinguish domestic specimens from wild ones, even distinct morphotypes, as is the case of the llamas (Grant, 2010; Yacobaccio, 2010; Gasco et al., 2014). In turn, stable isotope analyses (SIA), particularly of carbon and nitrogen, have emerged as a helpful method for researching camelids. This is because it allows us to go deeper into areas of interest for the discipline, such as the analysis of changes in herd management and its relationship with agro-pastoral intensification (Grant, 2017; Miyano et al., 2017; Dantas and Figueroa, 2018; Grant et al., 2018; Samec et al., 2018, among others). The value of SIA arises from the systematic relationship between the isotopic composition of consumer tissues and the resources they consume, identifying type and spatial location of forage plants as a starting point for comprehending this relationship.

SIA applied to camelids remains has gained importance in the interpretation of sociocultural processes in the ANW's micro and mesothermal valleys over the last decade (Srur et al., 2012; Dantas and Figueroa, 2018; Miyano, 2020; Hernández and Valenzuela, 2021; Moreno et al., 2022; Neveu Collado et al., 2024). These range in elevation from 3,500 to 1,000 masl and link to the highlands and the Yungas jungle. Carbon ($^{13}\text{C}/^{12}\text{C}$; $\delta^{13}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$; $\delta^{15}\text{N}$) isotopic values were measured for at least 125 archaeological camelid specimens from valley sites in the ANW, including llamas, guanacos, vicuñas, and individuals at higher taxonomic ranks (e.g., *Lama* sp.). Mengoni Goñalons (2014) and Izeta et al. (2009) were pioneers in the ANW in illustrating the presence of diets based on maize (*Zea mays*), not as a sporadic supplement, but as a strategy to boost productivity. Applying SIA to the study of camelids in the Ambato Valley (Catamarca), shows that herd management strategies changed around 1500 years ago, coinciding with the beginning of agricultural intensification, and that a maize-based supplement has since been added to the diet of llamas (Dantas et al., 2014). Dantas et al. (2014) understood that there was a mechanism of synergy between agricultural and pastoral activity, which, at least in the Ambato valley, revealed the division between both activities as artificial, as it was very difficult for either of them to cope without the support of the byproducts of the other. In the Conchopata region of Peru, a comparable strategy was hypothesized. The argument's main points were the high nitrogen

values—which were the result of an agricultural intensification strategy based on camelid guano for soil fertilization—and the high carbon values—which were linked to the maize supplement (Finucane et al., 2006). Neveu Collado et al. (2024), Hernández and Valenzuela (2021), and Moreno et al. (2022) also examined the evidence using this premise in ANW valleys. Miyano (2020) goes beyond and analyzes $\delta^{13}\text{C}$ values from different ecozones. He establishes that camelid management tactics vary across Puna and Valley. In valleys, either a fodder supplement is provided, or grazing occurs close to the places of residence.

This research will contribute evidence to the data set by measuring camelid bone collagen from the Soria 2 site ($n = 7$) and structure 93 from the Loma l'Ántigo site ($n = 5$) (Figure 1). The first is a residential unit in the valley of Santa María or Yocavil (Prov. of Catamarca) and dates to the region's Formative Period (100 BC–900 AD). The second is in the Cajón Valley (Catamarca Province) and dates to the Regional Developments Period (ca. 900–1430 AD). The specimens were previously classified to the genus or species ranks based on morphological and osteometric criteria. We will test hypotheses based on the diet's composition, taking into account the predominance of plants with C_3 or C_4 photosynthetic patterns, and other lines of data collected in the research region. First, if there were changes over time in direct access to resources at higher altitudes, such as better-quality pastures in the Puna or the provision of wild animals in the same ecoregion. Second, if there was a fodder intensification plan centered on the provision of maize (*Zea mays*) in tandem with the social, political, and economic changes that are assumed to have occurred at the beginning of the second millennium AD in ANW. Although the number of samples analyzed is relatively low, the data gathered will allow us to take the first steps toward comprehending a difficult subject, such as the shift in the exploitation of resources from pre-Hispanic occupations in the ANW valleys.

2 Study area

The study area is the southern sector of the Calchaquí valleys corresponding to the Cerro Colorado and Santa María river basins. This area covers the Cajón and Santa María valleys, the latter also known as Yocavil, both running parallel to the Andean ranges. The westernmost valley, Cajón, is flanked to the west by the eastern peaks of the Puna (Andean Highland) border, and to the east by Quilmes-Cajón hills. To the east, the Santa María valley lies between the Cajón Hills and the Aconquija snow peaks. The Santa María and Cajón valleys join south of the Cajón Hills at the Campo del Arenal plains.

The Calchaquí valleys are an assemblage of tectonic depressions that originated in the Quechua (Miocene) and Diaguita (Quaternary) orogeny (Salfity, 2004). They are characterized by semi-arid habitats and were included in the High-monte terrestrial ecoregion by Olson et al. (2001), based on the previous "Monte de sierras y Bolsones" ecoregion advanced by Burkart et al. (1999). Recorded yearly precipitation oscillates between 100 and 250 mm with the wet season occurring during the summer, annual mean temperature is 15°C with marked daily thermal amplitude

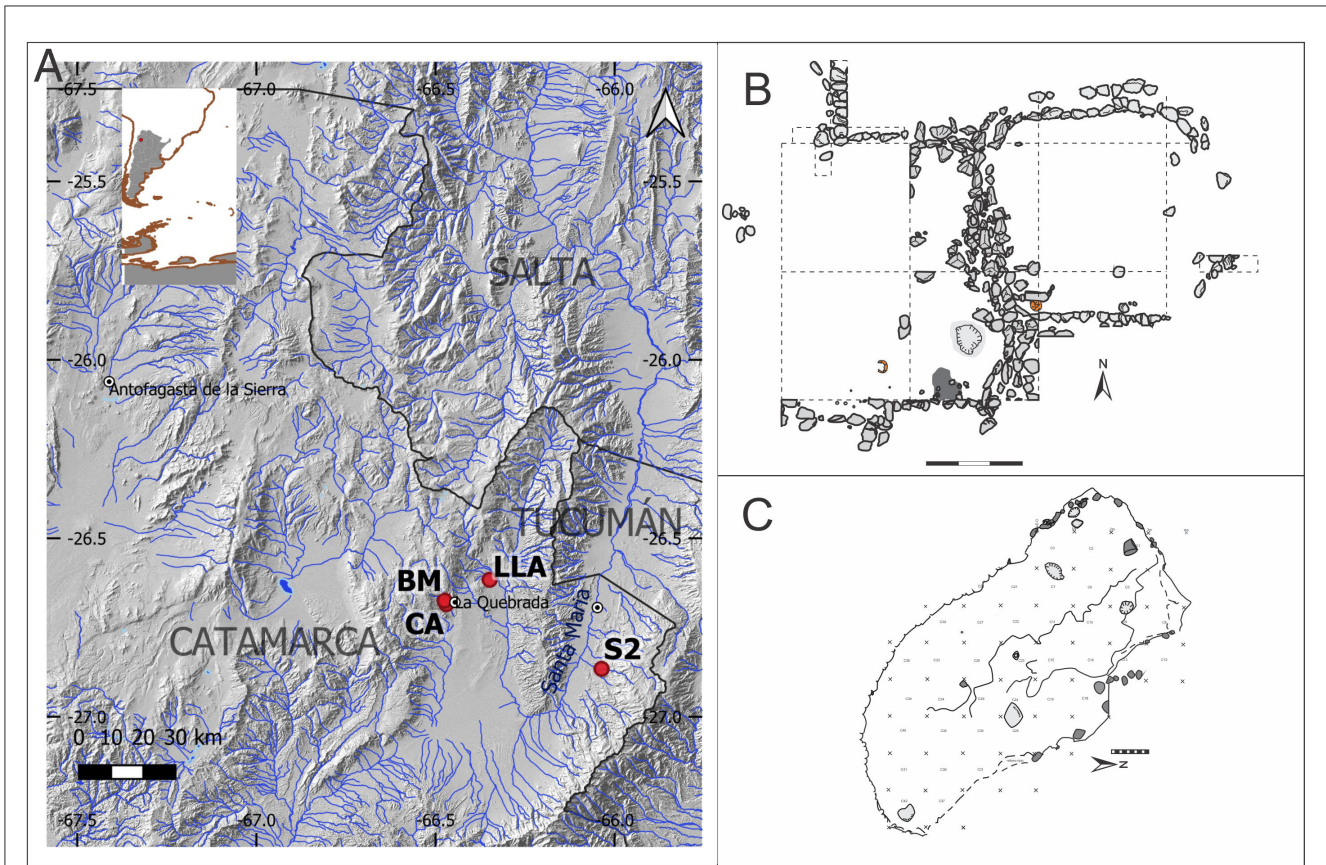


FIGURE 1

Location of the analyzed archaeological sites, Soria 2 (S2) and Loma l'Antigo (LLA), in the southern Calchaquí Valleys (Catamarca, Argentina), along with Bordo Marcial (BM) and Cardonal (CA), sites relevant to this research (A). Floor plans of Soria 2 (B) and Loma l'Antigo (C). Map created in QGIS using vectorial and raster data provided by the National Geographic Institute of the Argentine Republic (IGN).

and high evapotranspiration (Petrucci and Spano, 2020). Shrub-steppe dominates the valley vegetation, punctuated only by small algarroba forests on fluvial terraces and cacti growing on mountain slopes. Climatic conditions result in a chronic hydrological deficit that makes dryland farming impossible. Agriculture is based on irrigation from permanent water courses descending from mountain ice melts and flowing into the Cerro Colorado – Santa María river (González, 1979). It is worth noting that the Calchaquí Valleys limit with two other terrestrial ecoregions, which were also part of their pre-Hispanic interaction sphere: the Andean Salt Puna to the West (Highland desert, designated as Central Andean Dry Puna by Olson et al., 2001) and the Yungas to the East (cloud forests descending over the eastern slopes of the Aconquija Range).

Faunal remains analyzed here were sampled from the archaeofaunas recovered from the following sites: Soria 2 in the Santa María Valley and Loma l'Antigo from the Cajón Valley (Catamarca Province, Argentina). Both archaeofaunas and their archaeological contexts are described in the following section.

2.1 Soria 2

The Soria 2 site is located near the southeast margin of the Mesada de Andalhuala Banda (MAB), a quaternary plateau

at the foothills of the Aconquija range (Santa María valley). The MAB surface has an altitude ranging between 2,100 and 2,300 masl and exhibits succeeding pre-Hispanic occupations since the first century BC at least and up to the fifteenth century AD approximately (Álvarez Larrain, 2016, 2018). First millennium occupations concentrate on the Eastern section of the plateau and their settlement pattern consists of residential units distributed among agricultural fields (Álvarez Larrain, 2016). The first millennium AD of the Calchaquí Valley is included in the Formative Period of Argentine Northwest archaeology (Albeck, 2000; Olivera, 2001; Scattolin, 2006), covering the initial establishment and the ensuing diffusion of agropastoralist village lifeways, whose subsistence was based on a varying combination of both wild and domestic plants and animals.

Soria 2 was dated to 1940 rcybp and is the earliest site of AMB so far (Palamarczuk et al., 2007). Its coordinates are 26° 51' 36,1" S and 66° 02' 08,9" W (altitude 2,234 masl). Fieldwork on this site was carried under the direction of Palamarczuk and Spano. Soria 2 is a residential unit composed of two sub-quadrangular enclosures. The faunal assemblages described here were excavated during fieldwork seasons from 2002 to 2006, covering the southern half of Enclosure 1 structure (32 m²) and the southeast corner of Enclosure 2 structure (4 m²). An archaeological deposit with abundant material evidence and interpreted as an

occupation surface was identified at both enclosures. Ceramic analyses distinguished two pottery sub-assemblages, an *ordinary one* entirely composed of oxidation firing pieces and consisting of closed (pots) and open forms (e.g., bowls or *puco*s), and a fine one mostly fired on oxygen-poor atmospheres and mostly composed of bowls, followed by glasses, bottles and pipes (Baigorria Di Scala, 2009; Spano, 2011). Most of the lithic assemblage consists of debitage, except for an 18% composed of cores, and formal and informal instruments (Carbonelli, 2011). Andesite was the predominant raw material (82% of the assemblage), followed by lesser quantities of metamorphic rocks, quartz and obsidian, the latter originating from Puna. Archaeobotanical evidence includes remains of domestic cultivars such as maize and quinoa, wild plants (algarrobo, chañar) and cacti (Petrucci and Spano, 2019).

Soria 2 analyzed archaeofaunas amount to 3877 specimens from Enclosure 1 and 171 specimens from Enclosure 2. Both assemblages are dominated by artiodactyls and camelids at the order and family ranks respectively (Belotti López de Medina, 2011). Camelidae amounts to 95% of specimens identified to the family rank for the Enclosure 1 assemblage (NISP¹ 426) and 90% of specimens for Enclosure 2 (38 of 42 specimens). Camelid dominance is a recurring pattern exhibited by archaeofaunas from the semi-arid to arid inlands of the South-Central Andes, pointing to a specialized predation on this taxon since Middle Holocene at least (Olivera, 1997; Yacobaccio, 2006; Izeta, 2008; Belotti López de Medina, 2024). Archaeofauna from Enclosure 1 is the largest and most informative on animal exploitation at Soria 2, especially regarding camelids. A sample of camelid bones was further identified to the genus and species ranks using multivariate cluster analyses on osteometric measurements. Both wild (*Lama guanicoe*, *Vicugna vicugna*) and domestic camelid (*Lama glama*) species were identified. Following previous research on agropastoralist contexts, co-occurrence of domestic and wild camelid was interpreted as an indicator of the persistence of big-game hunting alongside animal husbandry, whose function would be to preserve and ensure the reproduction of domestic herds (Göbel, 1994; Yacobaccio et al., 1997; Escola, 2002). Identification of vicuña specimens outside their historical territorial and altitudinal ranges is noteworthy nonetheless, but it should be observed that Pérez Gollán (2000) proposed a broader distribution of this species during the pre-Hispanic times.

The Camelidae sub-assemblage of Enclosure 1 (Figure 2A) exhibits a greater abundance of appendicular elements (NISP 289, 71%) against axial remains (NISP 115). This bias against axial elements markedly departs from observed patterns at modern pastoralist stations and households (Madero and Yacobaccio, 1994; Yacobaccio et al., 1998). This could be due to differences in taphonomic processes affecting accumulation, remotion and destruction of animal remains. Recorded anthropogenic traces on bones are indicative of disarticulation based on their morphology and location. Fragmentation of the sub-assemblage is both extensive (68% of NISP) and intensive (NISP:MNE ratio 2.92 for fragments). Fracture morphology of long bones includes non-green and green surfaces and the later were sometimes associated with percussion traces such as flake-scars. The diversity of fracture

patterns indicates the convergence of several taphonomic agents, including human purposive fragmentation for grease and marrow extraction, pot-sizing, etc.

Epiphyseal fusion of long bones and diaphyseal fusion of metapodia indicate the presence of animals under a year old, even perinates, as well as more mature animals (over 24-36 months old). The survivorship profile for the late epiphyseal fusion group (24-36 months) is low (28% of NISP, 35% if vertebrae are tallied). It is almost impossible to carry a taxonomic identification at the species rank for immature bones and mortality/survivorship profiles mix both wild and domestic species therefore, as well as hunting and husbandry patterns. These profiles could result from a mixed herding strategy aimed at both primary and secondary exploitation nonetheless, as well as some degree of premature deaths among domestic animals (corral diseases such as enterotoxemia). Another possibility is the selective culling of young animals to maintain the herds under their ecological sustainability (Olivera, 1997).

2.2 Loma l'Ántigo

It is an agglomerate settlement located on the western flank of the Cajón valley (26° 36' 57" N, 66° 20' 57" O, 2700 masl), south of the Ovejería river, one of the tributaries of Cerro Colorado River. Early research on this area was conducted by Ten Kate (1893). Later, Weiser (1922) carried the first planimetry of the settlement. The current research phase began in 2009 under the direction of Bugliani (2012, 2018). The settlement rests on the flattened peak of a hill rising 60 meters above its surroundings; the hill sides are abrupt and interrupted by retaining or perimeter walls. A new planimetry tallied a total of 111 enclosures over the hilltop and covering an extension of 1.6 hectares (Bugliani, 2018). A total of nine test-pits were dug across the site, seven of them within the enclosures, and area excavations were carried out later at the E66, E25 and E93 enclosures. Large rectangular and polygonal enclosures with a probable agricultural function lie dispersed south of the Loma l'Ántigo foothill (Bugliani, 2018); as many as 28 structures were recorded to date. Further south extends the Pampa Grande del Cajón plain, thus named by Weiser, where some funerary structures were identified. Nine carbon samples from different excavations were dated and the site chronology was estimated between the thirteenth and fifteenth centuries (calibrated dates, Table 1) (Bugliani, 2018), assigning the site to the Regional Developments Period of Argentine Northwest (Tarragó, 2000). Regional Developments were characterized by a deterioration of environmental conditions, and heightened conflict among middle range polities throughout the South-Central Andes (Nielsen, 2007). Spatially hierarchized settlement patterns are common for the study area during this period, these are dominated by fortified central settlements built over plateaus and mountain buttresses (*pukara*) (Tarragó, 1987, 2000, 2011).

The archaeofauna sampled for the present study comes from a deposit identified as the occupation floor of the E93 enclosure, which was completely exposed (45 m²). This deposit contained two excavated hearths; probable postholes, and other features excavated on the base rock. Three carbon samples were dated (Table 1). Lithic and ceramic artifacts are dispersed through the floor. Pottery is

¹ NISP: number of identified specimens.

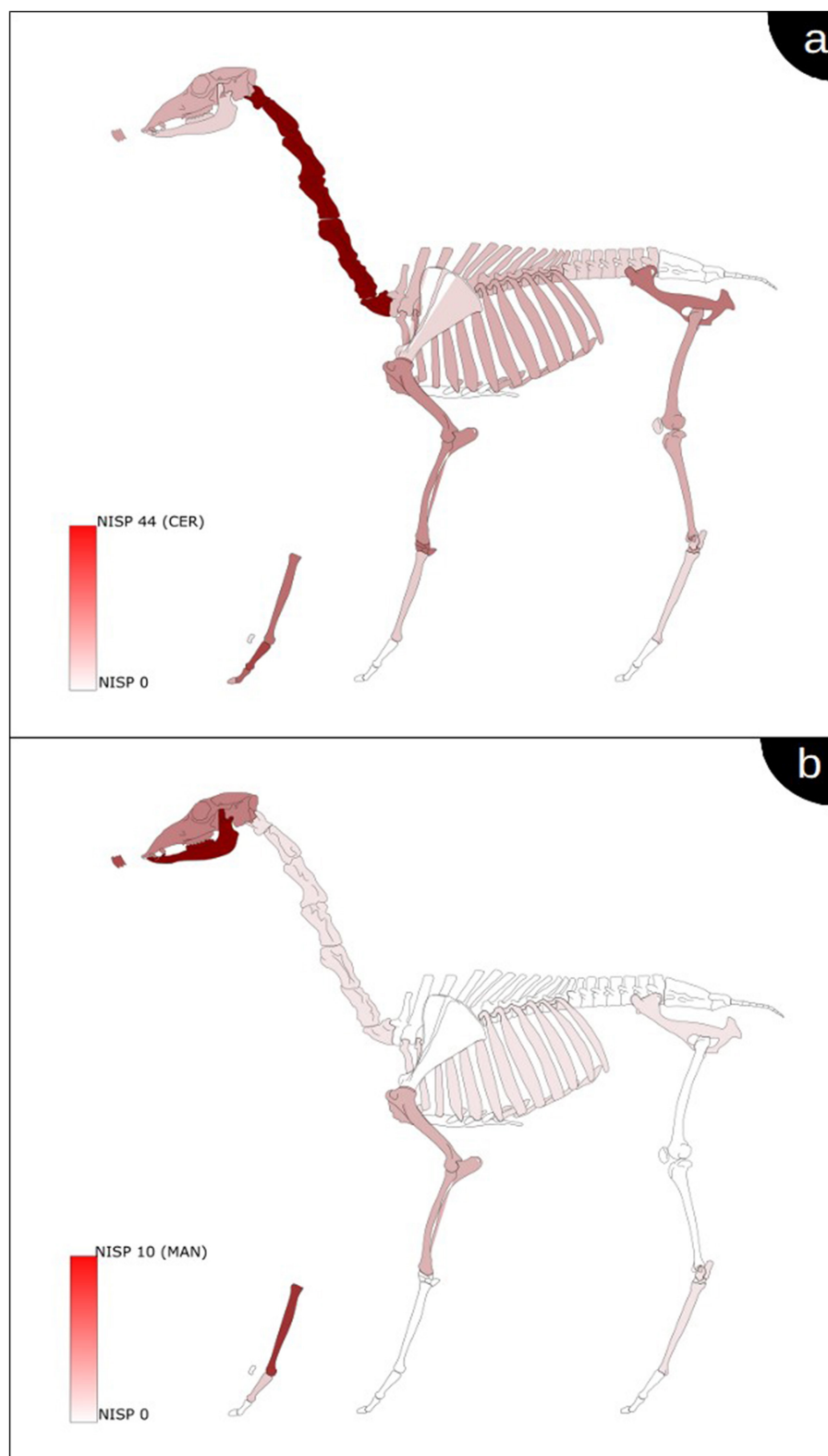


FIGURE 2

(A) Representation of the Camelidae NISP by element at Soria 2–Enclosure 1 standardized as percentage of the most abundant element (cervical vertebrae). (B) Representation of the Camelidae NISP by element at Loma l'Antigo E93 standardized as percentage of the most abundant element (hemimandible).

TABLE 1 Radiocarbon dates obtained on charcoal from the archaeological sites Loma l'Ántigo (Bugliani, 2018, Table 2).

Laboratory code	¹⁴ C date (years BP)	Cal date 1σ	Cal date 2σ	Context	Sample dated
AA89386	680 ± 33 AP	1278–1383	1269–1390 d.C.	Loma l'Ántigo E44, level 4	Charcoal occupation level
AA89385	663 ± 34 AP	1283–1385	1275–1394 d.C.	Loma l'Ántigo AI6, level 2	Charcoal occupation level
AA89382	612 ± 33 AP	1300–1395	1294–1404 d.C.	Loma l'Ántigo E99, level 4	Charcoal occupation level
AA89384	602 ± 34 AP	1306–1398	1296–1408 d.C.	Loma l'Ántigo E93, feature 1	Charcoal hearth remains
AA89380	556 ± 33 AP	1323–1418	1307–1432 d.C.	Loma l'Ántigo E25, level 2	Charcoal occupation level
AA893881	546 ± 33 AP	1326–1424	1312–1436 d.C.	Loma l'Ántigo E103, level 4	Charcoal occupation level
AA97849	516 ± 34 AP	1422–1448	1404–1458 d.C.	Loma l'Ántigo E93, level 3	Charcoal combustion area
AA89383	471 ± 44 AP	1326–1424	1312–1436 d.C.	Loma l'Ántigo E93, level 3	Charcoal hearth remains
AA899379	432 ± 35 AP	1431–1474	[1417–1515] [1598–1617] d.C.	Loma l'Ántigo E8, level 2	Charcoal occupation level

dominated by potsherds from ordinary types and the Santa María bicolor style, and includes open and closed forms, such as bowls and pots (Bugliani and Fernández Sancha, 2023). Fatty acid analyses point to the utilization of pottery containers for cooking and service of animal foods of ruminant origin (pseudo-ruminants such as camelids, more likely) (Fernández Sancha et al., 2021). The lithic assemblage consists of flakes and debitage made of andesite, quartz, rhyolite, and obsidian, plus an obsidian projectile point and four nodules (Moro, 2016). Archaeobotanical studies established the presence of maize and quinoa (Fernández Sancha, 2022); cacti and amaranth were recorded at other enclosures.

Like Soria 2 assemblages, Camelidae is the dominant family of the floor archaeofauna (NISP 48, 75% of specimens identified to the family rank at least) (Belotti López de Medina and Bugliani, 2021). A few specimens were identified as *Lama* sp. and *Vicugna vicugna* by multivariate osteometric cluster analyses and morphological criteria (Miller, 1924; Wheeler, 1982). Appendicular and axial fragments are evenly represented (NISP 24 each, Figure 2B). Cutmarks and fracture flake scars indicative of butchering were recorded. Fragmentation is extensive (94% of NISP) and intensive (NISP: MNE 1.87). Survivorship profiles show 57% of fused vs. unfused specimens for the intermediate range fusion group (12–24 months old). Survivorship is 100% for early and late fusion groups. On the other hand, eruption and wear of dental series permitted identification of two camelid hemimandibles belonging to a six-month-old animal and a third one from a 12–13-year-old animal. This heterogeneous age profile could be explained by a mixed exploitation (primary and secondary resources) of herds (Belotti López de Medina and Bugliani, 2021).

The faunal assemblage from E93 is small compared to those from Soria 2. Based on the potency and area of floor deposits from each site, Soria 2 - Enclosure 1 has a mean density of 403.8 specimens by cubic meter of excavated sediment, while Loma l'Ántigo E93 amounted to 10.7 specimens. This contrast repeats

an emerging pattern of Formative (e.g., Izeta, 2007) vs. Regional Developments (e.g., Álvarez et al., 2021) assemblages from occupation floors of the Southern Calchaquí Valleys; the largest assemblages of later periods (Regional Developments and Inka) often come from contexts such as trash middens (e.g., Pratolongo, 2008). This could be due to differences among accumulation (transport, consumption, and de facto discard) and remotion (floor maintenance, secondary discard areas) anthropogenic processes between the two temporal blocks. The greatest concentration of bone remains from Loma l'Ántigo occurred near walls and combustion features, maybe owing to casual discard in less maintained or walked surfaces (Belotti López de Medina and Bugliani, 2021).

3 Materials and methods

3.1 Archaeofaunal samples

Both assemblages include a small number of camelid specimens identified to the genus or species ranks (NISP 23) (Belotti López de Medina, 2007, 2011; Belotti López de Medina and Bugliani, 2021) by morphological criteria (following Miller, 1924; Wheeler, 1982) or multivariate analyses of osteometric measurements (following Kent, 1982; Izeta, 2004; Izeta et al., 2012; Menegaz et al., 1988). The former criterium was applied to lower incisors of specimens 10, 11 and 13 (Table 2); those of *Lama* sp. are spatulate and exhibit enamel on both labial and lingual faces and the roots are clearly distinct from the crowns, while those of *Vicugna vicugna* have a squarer occlusal surface and enamel would be restricted to the labial face. Every other specimen was identified by multivariate described by Menegaz et al. (1988) and Izeta (2004). This approach consists of a heuristic clustering of archaeological and modern specimens of known species and the classification of clusters across a body-size

gradient purported for Andean camelids. First, a distance matrix (City-Block distance) between pair of specimens is generated for each element based on their measurements, later, hierarchical cluster (UPGMA) and Principal Components Analyses were run on the distance matrices. The results of these analyses were published previously (Belotti López de Medina, 2007; Belotti López de Medina and Bugliani, 2021).

Species assessment is critical to understanding human foraging, domestication and animal husbandry as the three species exhibit different altitudinal/geographical ranges, feeding habits, and degrees of human manipulation of their realized niches. However, this is usually feasible for a small number of bones due to morphological similarities and size distribution overlaps among species and to complex taphonomic histories that identification approaches to analytically isolated bone fragments.

Thirteen specimens (eight from Soria 2 and five from Loma l'Ántigo) were separated for the present study. Selection criteria aimed to include one or more specimens from every Camelid species or genus identified at each site at least. Specimens not included in the present study are currently stored at the Instituto de las Culturas for future analysis.

Except for identical elements (e.g., two distal right humerus). A potential risk from analyzing isolated bone specimens from trash middens or living floors is that two of them came from the same carcass. Attribution of multiple elements to a single carcass could be reached by osteometric pairing of elements (right and left homologous bones with close measurements) and by anatomical refitting of tight articulations such as the humerus-ulna. In the case of Loma l'Ántigo, a common skeletal origin can be discarded for mandibles (NISP 3) as one belongs to *Lama* sp. and the other two are from *Vicugna vicugna*, but overlap anatomically (i.e., both exhibit the same incisors). The remaining bones are two *Lama* sp. right calcaneus. However, there is no way to know if *Lama* sp. calcaneus and mandibles come from a single carcass or not. Soria 2 specimens do not allow for any control on this regard, as only a pair of specimens (right and left calcaneus) would be suitable for osteometric pairing and they showed different measurements leading to their characterization as belonging to different species.

3.2 Stable isotopes measurements

Collagen extraction and isotopic analyses were made after Sealy et al. (2014). The procedure involves the mechanical cleaning of the samples, their weighing to assess collagen yield, and pretreatment with HCl (0.2 M) at ambient temperature—renewed for approximately 10 days—to remove the mineral fraction. To eliminate humic acids, samples were treated with NaOH (0.1 M) for 24 h. Pretreatment and isotopic analyses were performed at the Instituto de Geocronología y Geología Isotópica (INGEIS, Universidad de Buenos Aires-CONICET), with a Carlo Erba EA1108 elemental analyzer connected to a Thermo Scientific Delta V Advantage continuous flow mass spectrometer through a Thermo Scientific ConFlo IV interphase. Measurement precision is in the order of $\pm 0.2\%$. In INGEIS stable carbon isotopic composition was calibrated relative to the VPDB standard using L-SVEC, NBS-19, and NBS-22. Stable nitrogen isotopic composition

was calibrated relative to AIR with IAEA N1 and IAEA N2. The measurement uncertainty was monitored using three internal standards: caffeine ($\delta^{13}\text{C}$: -39.3% , $\delta^{15}\text{N}$: $+7.0\%$), sugar ($\delta^{13}\text{C}$: $+11.4\%$), and collagen TRACE ($\delta^{13}\text{C}$: -18.2% , $\delta^{15}\text{N}$: $+6.1\%$). The total analytical uncertainty was reported to be $\pm 0.2\%$ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. The parameters used to validate the data were acceptable carbon-nitrogen atomic relationships (2.9 to 3.6 C/N, after DeNiro, 1985), carbon and nitrogen concentrations, and bone collagen yield (Ambrose, 1990, 1993).

We estimated the consumption rate of pastures with different metabolic pathways by the camelids studied based on two alternative scenarios, considering average C_3 and C_4 values for plants as published by Fernández and Panarello (1999–2001) for Puna and Ojeda et al. (2022) for a near valley (Amaicha del Valle, Tucumán province), and applying the equation by Balesdent and Mariotti (1996). We considered a 5‰ isotopic fractionation between isotopic values in plants and their assimilation in animal bone collagen (Pate, 1994). In the first scenario 100% C_3 diets, $\delta^{13}\text{C} = -22\%$ is to be expected, while in diets totally C_4 , $\delta^{13}\text{C} = -7.5\%$ is to be expected. In the second scenario 100% C_3 diets, $\delta^{13}\text{C} = -21.5\%$ is to be expected, while in diets totally C_4 , $\delta^{13}\text{C} = -11.2\%$ is to be expected. This second scenario should be considered cautiously since the study of fodder plants is still developing and there is still no representative number of isotopic measurements on C_4 plants. In fact, for this photosynthetic pattern, it was only possible to obtain a value for a plant classified at the genus level (*Paspalum* sp. $\delta^{13}\text{C} = -16.2\%$) much lower than expected. These values were calibrated by considering a $+1.5\%$ ^{13}C -Suess effect over plant resources (Fry, 2006).

4 Results

Collagen was well preserved in all camelid's skeletal elements, and the C/N relationship was satisfactory in all samples.² The results for camelids are presented in Table 3 (mean $\delta^{13}\text{C} = -13.4\%$, SD = 1.8; mean $\delta^{15}\text{N} = +6.0\%$, SD = 0.8 for Soria 2; and mean $\delta^{13}\text{C} = -14.5\%$, SD = 3.0; mean $\delta^{15}\text{N} = +4.8\%$, SD = 1.4 for Loma l'Ántigo). The two sets show a comparable range of nitrogen and carbon values (Figure 3). They correspond linearly in Loma l'Ántigo, though ($R^2 = 0.953$). At the same time, considering the specimens' taxonomic classification, no differences have been discovered in either of the two isotopic systems.

5 Discussion

Pre-Hispanic agropastoral societies in the southern Calchaquí valleys saw significant transformations in two distinct periods. On the one hand, there were organizations structured in villages that date back to the first millennium AD (Formative Period, *sensu* Scattolin, 2007) that lack any evidence of supradomestic political hierarchies. Village societies began extensive and intensive transformation of agriculturally productive environments by the fifth century AD approximately, as evidenced by field clearings

² The vicuña specimen from Soria 2 was excluded due to thermoalteration.

TABLE 2 Analyzed camelid bone specimens from Soria 2 and Loma l'Ántigo archaeological sites.

N	Site	UP or CAT	Level or feature	Element	Development trace	Taxon	Identification method
1	Soria 2, Enclosure 1	125	6	Phalanx 1	Epiphyseal fusion	<i>Lama</i> sp.	Osteometric
2	Soria 2, Enclosure 1	125	6	Right calcaneus	-	<i>Lama glama</i>	Osteometric
3	Soria 2, Enclosure 1	44	Feature 3	Right humerus	Epiphyseal fusion	<i>Lama glama</i>	Osteometric
4	Soria 2, Enclosure 1	124	6	Left calcaneus	Epiphyseal fusion	<i>Lama guanicoe</i>	Osteometric
5	Soria 2, Enclosure 1	97	5	Phalanx 1	Epiphyseal fusion	<i>Vicugna vicugna</i>	Osteometric
6	Soria 2, Enclosure 1	125	6	Left humerus	Epiphyseal fusion	<i>Lama glama</i>	Osteometric
7	Soria 2, Enclosure 1	125	6	Right talus	-	<i>Lama glama</i>	Osteometric
8	Soria 2, Enclosure 1	97	5	Left tibia	Epiphyseal fusion	<i>Lama guanicoe</i>	Osteometric
9	Loma l'Ántigo E93	1,048	1	Right calcaneus	Epiphyseal fusion	<i>Lama</i> sp.	Osteometric
10	Loma l'Ántigo E93	1,091	2	Mandibular symphysis	-	<i>Vicugna vicugna</i>	Morphological
11	Loma l'Ántigo E93	1,118	3	Mandibular symphysis	-	<i>Vicugna vicugna</i>	Morphological
12	Loma l'Ántigo E93	1,123	3	Right calcaneus	Epiphyseal fusion	<i>Lama</i> sp.	Osteometric
13	Loma l'Ántigo E93	1,113	3	LEFT hemimandible	Dentition, <7 months	<i>Lama</i> sp.	Osteometric

and irrigation system building (Scattolin, 2006). Soria 2 is revealed to be a representative site of at least the early phases of the Santa María Formative period, with a low social hierarchy and low-intensification agricultural-pastoral schemes (Álvarez Larrain, 2018). The Andalhuala-Banda Mesada was probably seen as a “fertile oasis” in comparison to the aridity of its surrounding habitats; agriculture could have been carried with minimum technological investment, in material terms, due to the agronomic conditions (e.g. soil quality, solar exposure, water access) presented by this plateau (Álvarez Larrain, 2018). Although there are clear relationships with productive areas further away, as indicated by access to ceramics from the Tebenquiche style (Antofagasta de la Sierra -ANS- microregion, Puna of Catamarca) or the identification of cotton (Valle de Catamarca) and cebil (Valle de Ambato) (Petrucci and Spano, 2020), the site and their inhabitants are thought to have been mainly self-sufficient in terms of subsistence production, as well as regarding the use of resources from the immediate environment, such as andesite as lithic raw material. This does not preclude the reciprocal provision of workforce between similar units linked by kinship for intensive agricultural activities or communal tasks, nor direct or mediated access to resources from other productive zones and ecoregions. It is worth

noting that the archaeofauna from Soria 2 follows a pattern different from those in Puna village and pastoral communities. Olivera (1997), for example, proposed a dynamic sedentary lifestyle model for the Antofagasta de la Sierra microregion, in which all steps of production and consumption would take place in the same location. As a result, axial and appendicular skeletal elements would be present at sites. Soria 2 shows a marked predominance of appendicular specimens instead; however, it is difficult to determine the taphonomic causes. The Yocavil valley belongs to a phytogeographic region distinct from the Puna and subsistence activities and their archaeological correlates could have differed.

During the agro-pottery stage, the Camelidae family dominates the zooarchaeological record in the south of the Calchaquí valleys (Izeta, 2007; Belotti López de Medina, 2015). This trend is found across the semi-arid and arid interior of the South-Central Andes, from the intermediate and high sierra ecozones of the Pacific slope and the Andean highland to the valleys of the ANW, and dates to the middle Holocene *at least*. The domestication of llamas may be traced back to the specialized hunting of vicuñas and guanacos. Livestock raising, or the combination of hunting and herding of camelids throughout the late Holocene, shows a continuation of this process. Hunting was never abandoned following the

TABLE 3 Carbon and nitrogen stable isotope values from Soria 2 and Loma l'Ántigo camelid samples.

n	Site	Taxon	ID	ID Lab.	% Coll. yield	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	%N	%C	C/N	Puna		Valley		
						V-PDB \pm 0.2	AIR \pm 0.2				%C ₃	%C ₄	%C ₃	%C ₄	
1	Soria 2, Enclosure 1	<i>Lama sp.</i>	S273	44772	9.9	−15.9	5.7	14.1	39.4	3.3	68.0	32.0	60.1	39.9	
2		<i>Lama glama</i>	S255	44789	9.8	−15.6	5.7	14.3	40.2	3.3	66.0	34.0	57.3	42.7	
3		<i>Lama glama</i>	S238	44792	2.3	−11.9	5.3	14.7	41.4	3.3	40.6	59.4	21.3	78.7	
4		<i>Lama guanicoe</i>	S267	44770	6.3	−12.1	5.4	13.3	38.6	3.4	41.9	58.1	23.2	76.8	
5		<i>Vicugna vicugna</i>	S286	No collagen											
6		<i>Lama glama</i>	S2167	44769	4.6	−12.4	7.3	13.8	40.0	3.4	44.1	55.9	26.3	73.7	
7		<i>Lama glama</i>	S233	44774	10.7	−14.5	5.9	14.3	40.2	3.3	58.4	41.6	46.5	53.5	
8		<i>Lama guanicoe</i>	S213	44771	6.8	−11.7	6.8	13.6	38.9	3.3	39.1	60.9	19.2	80.8	
9	Loma l'Ántigo E93	<i>Lama sp.</i>	LL11	44794	16.1	−14.5	4.8	14.0	38.9	3.2	58.3	41.7	46.4	53.6	
10		<i>Vicugna vicugna</i>	LL205	44773	15.5	−18.6	3.2	12.6	36.4	3.4	86.6	13.4	86.3	13.7	
11		<i>Vicugna vicugna</i>	LL395	44793	18.8	−12.7	5.9	14.0	38.6	3.2	46.0	54.0	29.0	71.0	
12		<i>Lama sp.</i>	LLT1	44791	15.2	−16.1	3.5	14.2	39.6	3.3	69.8	30.2	62.6	37.4	
13		<i>Lama sp.</i>	LL375	44790	17.1	−10.8	6.4	15.0	41.9	3.3	32.8	67.2	10.3	89.7	

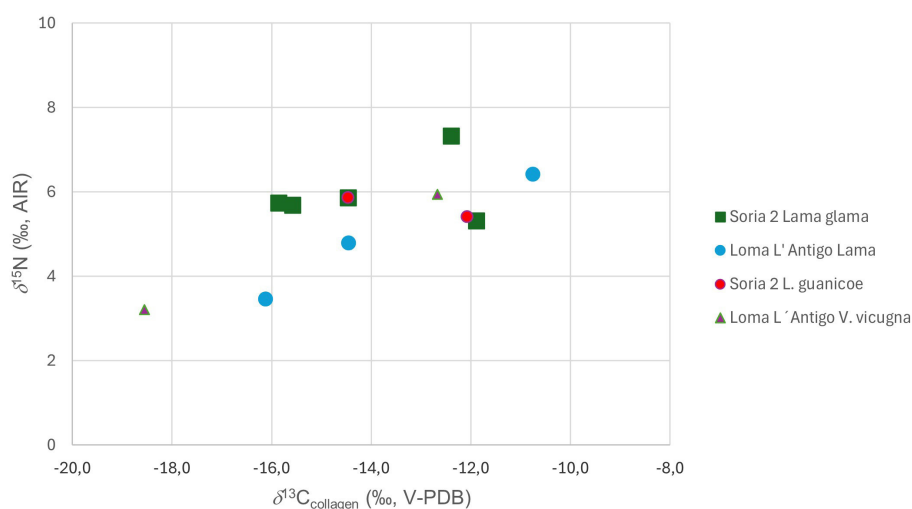


FIGURE 3

Carbon and nitrogen stable isotope values from camelid bone collagen samples from Soria 2 and Loma l'Antigo.

emergence of agropastoral lifestyles, and the ethological and ecological parallels between the three species resulted in shared knowledge applicable to both types of activities. Furthermore, pre-Hispanic livestock husbandry in the ANW was monospecific, with each productive unit's entire farm subject to identical environmental pressures throughout the year, and, in the case of small herds, conservation or killing of individual animals could have impacted on their reproductive sustainability. These circumstances favored hunting as a means of foraging primary products without sacrificing livestock, regardless of the additional economic, political, or symbolic purposes wild animals could have. The combination of wild camelid hunting and llama husbandry could be interpreted as a diversification strategy within the frame of Andean specialization on Camelidae.

Zooarchaeological studies of agropastoral sites in the Calchaquí valleys reveal the presence of the three species throughout the whole timespan of agropastoral societies (from the Formative to the Regional Developments and Inca periods). Izeta (2007) found that wild and domestic camelids were equally represented in the southern Calchaquí valleys record during the first millennium. *Lama* is the most abundant taxon (NISP) in the Santa María Valley throughout the agropastoral stage compared to vicuña at the genus level; in turn, *L. glama* dominates over *L. guanicoe* and *V. vicugna* at the species rank (Belotti López de Medina, 2015). The Regional Developments and Inca periods of Santa María differs from the Formative Period (Belotti López de Medina, 2015), with a relative reduction of wild camelids compared to *L. glama* and a slightly larger accumulation of small to medium sized vertebrates. If there was a drop in large game hunting, it could have been because of a variety of reasons. For example, the reduction in the mobility of domestic groups, related to greater territorial restrictions, and/or a decrease or distancing of the wild camelid population caused by the lower availability of pastures, due to competition with herds or due to the aridization process that occurred in the area, as well as changes in the organization of work linked to the supradomestic

division of labor and the emergence of hierarchies (Belotti López de Medina, 2015).

The societies of the second millennium belong to the later scenario, which might be complemented by a decrease in land available for grazing due to increased maize production (Sruet et al., 2012). Loma l'Antigo can be seen as a typical village of the time, a conglomerate site with a large population. The demand for agropastoral surpluses beyond subsistence (e.g., secondary exploitation of animals for transportation of goods or to meet complex political demands) could also have influenced herd management and husbandry practices during this time.

What has been said so far raises expectations for the feeding of animals at these two archaeological sites. In addition to belonging to different periods and kinds of sociocultural systems, Soria 2 and Loma l'Antigo are located at different altitudes and close to contrasting eco-regions. Although there is no specific research to reconstruct the isotopic ecology of the Calchaquí valleys, we can develop isotopic expectations for the archaeofaunas based on the following premises:

- 1) Camelids from intermontane valleys are likely to have differing isotopic values compared to those from other settings, such as Puna. This is due to variations in vegetation communities, which might feature trees, shrubs, herbs, and succulents. Although South American camelids may browse, especially llamas and guanacos, they prefer herbaceous vegetation with high nutritional value. The prevalence of grasses and a higher relative average temperature may support a higher proportion of C_4 plants, in contrast to their abundance in arid places with lower temperatures, such as Puna.
- 2) Based on what has been said, while there is enough evidence of systematic supplementation with maize-based fodder in the diet of these camelids, according to the presence of this cultigen in the archaeological record of the area, the presence of natural C_4 fodder plants cannot be ignored. They are probably present, to

a greater extent, in the valley floors of the two basins where the analyzed sites are located.

- 3) Archaeofauna isotope composition in Argentina's Puna region correlates with altitude due to temperature and humidity conditions (Grant, 2017; Samec et al., 2017). Extrapolating these connections to the basins under discussion, camelids at higher altitudes (masl) are likely to exhibit lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope values relative to those at lower altitudes.

Regarding diet reconstruction, especially if the first scenario is considered (plant specimens from Puna) more reliable about the isotopic values of the plants, the results indicate six specimens with a diet based mainly on natural pastures under a dominantly C_4 photosynthetic pattern and were present in both sites (Figure 4). The relevance of this photosynthetic pattern amounts to eight specimens under the second scenario. The results gathered in this study suggest that the camelids hunted or protected by the people that inhabited Soria 2 during the Formative period were provided with or had access to pastures with a C_4 photosynthetic pattern or maize. Species of *Trichocereus* may even be consumed in a more systematic manner than imagined. This could have happened more intensely during the dry season when there is a lack of water and high-quality plants. It is worth noting that the study of plant macroremains recovered by flotation in Soria 2 showed remains compatible with *Trichocereus* sp. (Petrucci and Spano, 2020), which could have entered as camelid guano to fuel hearts. Recently, Amuedo (2021) discovered *Trichocereus* carpores in camelid guano in the Guitian archeological site, located in the northern Calchaquí Valley. Soria 2's high $\delta^{13}\text{C}$ values may be attributed to family self-sufficiency and ecological settings, rather than intensive agriculture's maize-based fattening technique.

In Loma l'Ántigo, certain vicuñas and *Lama* sp. specimens exhibit a diet based on plants under C_3 photosynthetic pattern, while one *Lama* sp. specimen had a diet dominated by C_4 plants. If there is a correlation between isotope abundance and altitude in this basin, it is possible that the set was formed as a result of having access to a larger altitudinal gradient than in the previous case. Trends in the Santa María Valley cannot be evaluated chronologically, although those from the Cajon Valley can. When compared to specimens from the Bordo Marcial and Cardonal sites (Srur et al., 2012), which correspond to Formative period occupations (Figure 5A; BM Camelidae, $n = 2$, $\delta^{13}\text{C} -19.2\%$, -17.3% and $\delta^{15}\text{N} +3.6\%$, $+3.8\%$; C. Camelidae, $n = 8$, $\delta^{13}\text{C} -16.4 \pm 2.8\%$ and $\delta^{15}\text{N} +4.5 \pm 0.4\%$), both isotope systems show lower values. In the case of carbon, we can conclude that C_4 plants have a relatively low contribution to the diet. However, like in Loma l'Ántigo case, there is a considerable variety.

The Cajón Valley's agropastoral groups have more access to higher altitudes for grazing or hunting, as seen by comparing valley values to those from Antofagasta de la Sierra (ANS), Catamarca (Grant, 2017). These are from archeological sites located between 3,200 and 4,000 masl, in an extremely arid environment. The camelid archaeofaunistic assemblages are from both the Formative (Figure 5A; *L.glama*, $n = 14$, $\delta^{13}\text{C} -16.8 \pm 2.1\%$ and $\delta^{15}\text{N} +6.4 \pm 1.2\%$; *V. vicugna*, $n = 11$, $\delta^{13}\text{C} -17.6 \pm 0.8\%$ and $\delta^{15}\text{N} +5.5 \pm 0.8\%$) and late occupations (Figure 5B; *L.glama*, $n = 2$, $\delta^{13}\text{C} -17.1\%$, -13.7% and $\delta^{15}\text{N} +6.7\%$, $+5.4\%$; *V. vicugna*, $n = 21$, $\delta^{13}\text{C} -17.8 \pm 1.3\%$ and $\delta^{15}\text{N} +6.0 \pm 1.2\%$) and include wild and

domestic animal remains. When it regards ecozonal origin, there appears to be some segregation; however, the early occupations of the Cajón Valley coincide with Puna values. Similarly, a few Puna values, including three llama specimens, fall within the dispersion range of sites at lower elevations. As the Cajón Valley serves as a corridor to the Puna, the area of resource capture has likely included higher altitudes in early human occupations. At the same time, there could have been a circulation of animals that, having resided largely in valleys other than those we're discussing here, ended up in the highlands of Catamarca because of the trade. The ideas in general are in the opposite direction, as Puna is envisioned as a source of meat resources and other products derived from camelid raising (Raffino, 2007). However, different methods of herd management have been developed in the Andes (Goepfert et al., 2013), suggesting that camelids are not necessarily bred or originate in their current habitat, but that their phenotypic plasticity allows them to adapt to a wide range of conditions.

Beyond these guesses, the residents of Loma l'Ántigo were able to expand the resource-gathering region by utilizing better grazing pastures outside the territory closest to the residential conglomeration. As a result, they were able to develop an agropastoral system that could use the byproducts of intense maize production to feed animal herds on a systematic basis. The latter is more difficult to claim because domestic *Lama* specimens cannot be distinguished from wild ones in this case.

Fernández Sancha's (2022) research in Loma l'Ántigo revealed more than only *Trichocereus* remnants, like the case of Soria 2. There are also remnants of weeds from the Malvaceae and Fabaceae families. We have to take into account that ethnobotanical research has linked these to farming in soils damaged by heavy grazing (Langlie and Capriles, 2021). However, because no dry or burned manure has been identified in the areas surveyed (Fernández Sancha, 2022), it is not yet possible to conclude that the remains of possible fodder plants (e.g., Asteraceae) or the families previously mentioned as indicators of intensive agropastoralism explain animal diet. For the moment, the high isotopic variation found in the Loma l'Ántigo complex suggests extensive access to the territory, rather than a strategy based on the supply of maize as forage for domestic animals, as proposed in other adjacent valleys (Izeta et al., 2009; Svoboda, 2010; Dantas and Figueroa, 2018; Moreno et al., 2022).

6 Conclusions

In this work, we presented unpublished data for the dietary reconstruction of two archaeofaunistic assemblages, belonging to the sites Soria 2 and Loma l'Ántigo, located in intermontane valleys of the ANW, contrasting both geographically and chronologically. Based on the diet composition and the prevalence of plants with C_3 or C_4 photosynthesis, hypotheses based on other lines of evidence in the study area are tested. Specifically, if there were changes over time in direct access to resources at higher altitudes, such as improved quality pastures in the Puna or the provision of wild animals in the same ecoregion. In turn, there was a forage intensification plan focused on the provision of maize in tandem with the social, political, and economic changes

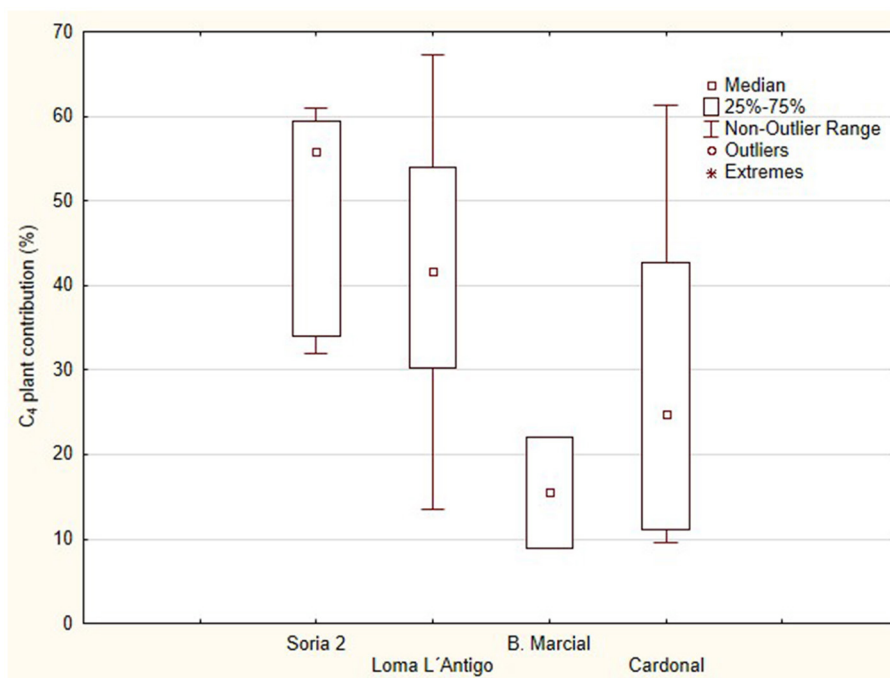


FIGURE 4 Estimates of the average calorie contribution of C_4 plants (%) for camelids from Soria 2, Loma l'Antigo and Valle del Cajón early occupations (Bordo Marcial and Cardonal sites).

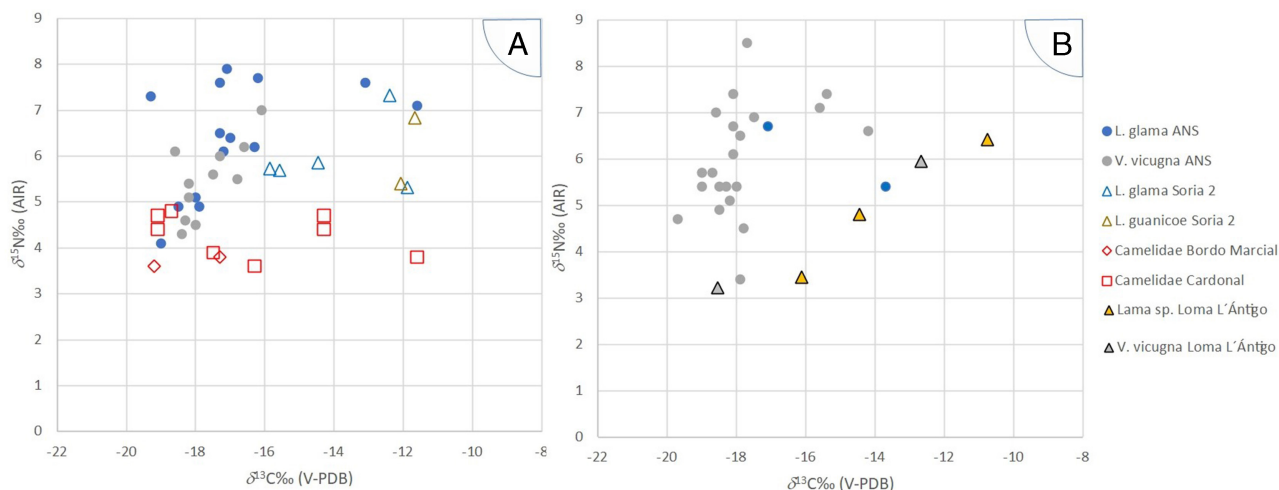


FIGURE 5 $\delta^{13}C$ and $\delta^{15}N$ values of camelid bones from Soria 2, early Antofagasta de la Sierra -ANS-occupations (A) and from Loma l'Antigo and late ANS (B).

that are said to have occurred in the ANW in the early second millennium AD.

The SIA distinguishes ranges of action because the isotopic composition of forage plants is changed by variables such as height, humidity, and temperature. It is feasible to model spatial occupation in this way, particularly if the floristic properties of the vegetation cover are known, such as the incidence of C_4 vs. C_3 plants and the range of variation between them. According to

Moreno et al. (2022), studies on the proportions of photosynthetic pattern coverage in intermontane valleys are still in their early stages, posing a constraint to this subject. Our findings suggest that C_4 plants were important in camelid's diet, even in the Formative period, as part of a local provisioning strategy, and that access to pastures or wildlife at various altitudes may have been available even during times of marked territoriality during Regional Developments.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/supplementary material.

Ethics statement

The requirement of ethical approval was waived by Dirección Provincial de Antropología de Catamarca for the studies involving animals because the skeleton remains are of archaeological origin. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

VK: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Writing – original draft, Writing – review & editing. CB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Writing – original draft, Writing – review & editing. MB: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. RS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

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