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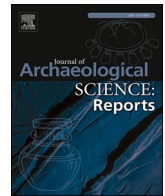
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## To the field of stars: Stable isotope analysis of medieval pilgrims and populations along the *Camino de Santiago* in Navarre and Aragon, Spain

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### A B S T R A C T

The *Camino de Santiago* emerged in the first half of the 9th century CE following the reported discovery of the remains of the Apostle St James by the bishop of Iria-Flavia, Teodomiro. Since then, hundreds of thousands of pilgrims have walked from different parts of the Iberian Peninsula, Europe, and further afield to Santiago de Compostela's Cathedral. This route was particularly important to the populations of Navarre and Aragon, two kingdoms in northern Spain that rose to prominence with the resurgence of Christianity from the 11th century onwards. Here, we present multidisciplinary analysis of medieval individuals buried in Navarre and Aragon at a time when the *Camino de Santiago* was reaching its peak of popularity (11th-15th centuries CE). We use stable isotope analysis ( $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$ , and  $\delta^{13}\text{C}_{\text{ap}}$ ) and radiocarbon dating to investigate a total of 82 human individuals together with 42 fauna samples from 8 different archaeological sites located in the northeast of the Iberian Peninsula. Twenty of these individuals were buried with a scallop shell, a symbol of a pilgrim who had completed the *Camino de Santiago*. Our data corroborate the use of the pilgrim's shell since at least the 11th century CE. Moreover, our results suggest that the pilgrimage was mainly an urban phenomenon for populations from the northern Iberian Peninsula, conducted equally by women and men, although with indications that female pilgrims may have had greater access to animal protein than their male counterparts. Our results represent the largest isotopic dataset of medieval individuals linked to the *Camino de Santiago*, allowing us to further investigate the origins and diets of potential pilgrims and, more generally, other sampled portions of northeastern Iberian society.

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## 1. Introduction

Pilgrimage is a major feature of organised religions (Collins-Kreiner, 2010) that promotes the periodic influx of people to sites of particular sacred importance (Vijayanand, 2012). In a Christian context, two of the three most important centres of pilgrimage emerged during Late Antiquity in Rome and Jerusalem (Freeman, 2011). However, during the early medieval periods, sacred sites and relics began to emerge as key attractions in various parts of Europe (Freeman, 2011). In the early 9th century CE, the claimed discovery of the tomb of the Apostle Santiago (Saint James the Greater) (López Alsina, 2015), one of the most prominent apostles of Jesus of Nazareth (Freeman, 2011; Sulai Capponi, 2006), created a major Christian pilgrimage core (López Alsina, 2015). The tomb of St James promoted the arrival of thousands of votaries together with the creation of a variety of routes across the Iberian Peninsula, known as the *Camino de Santiago* (The St James Way), to the new city that emerged surrounding the sacred tomb, Santiago de Compostela (Galicia, Spain) (Martínez García, 2004) (Fig. 1). Today, Santiago de Compostela is still a core of Christian pilgrimage, receiving more than 300,000 pilgrims every year and remaining an important place for practitioners of Catholicism (González Vázquez, 2008; Millán Vázquez de la Torre et al., 2010). The *Camino de Santiago* spans over 80,000 km along 286 routes, which are present in 28 countries (see Instituto Geológico Nacional de España, <https://www.ign.es>). These intangible aspects, together with significant construction works made since the 9th century CE that were associated with the *Camino* (e.g., churches, shelters, monasteries, or bridges), have led to international recognition of the *Camino de Santiago*, and the city of Santiago de Compostela, as World Heritage sites by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and as the first European Cultural Route by the Council of Europe (CoE) (Álvarez-Sousa, 2015; González, 2018; Millán Vázquez de la Torre et al., 2010).

The kingdoms of Pamplona (from 1162 CE the Kingdom of Navarre) and Aragon in northern Spain were territories with a close history during the medieval period, with times of union under the same monarch and times of division and territorial dispute (Salcedo Izu, 2003). From the end of the 9th century, the Pilgrim's Way to Santiago created a link between the small principality of Aragon and the Kingdom of Pamplona and the rest of the European continent (Laliena Corbera, 1993). After the death of King Sancho III of Pamplona (1004–1035 CE), the kingdom was divided between two of his sons, raising the principality of Aragon to the status of a kingdom. From the mid-11th century in Pamplona (later renamed Navarre) and the 12th century in Aragon, the *Camino de Santiago* had a significant impact on settlements and infrastructure in the region, with historical records documenting immigration into the two kingdoms from around Europe (Laliena Corbera, 1993). The Pilgrim's Way to Santiago led to the creation of new population centres and the expansion of existing urban networks (Martín Duque, 1993). During the heyday of pilgrimages to Santiago, the monarchies of Navarre and Aragon sought to consolidate populations in urban centres, granting privileges to people moving there from rural areas (Laliena Corbera, 1993; Martín Duque, 1993). At the same time, Navarre expanded the territory of its kingdom (Martín Duque, 1993). The emergence of the *Camino de Santiago* (Fig. 1) has thus been seen as contributing to an expansion of urbanism across the northern Iberian Peninsula, as well as a series of major economic and social changes (Franco Aliaga, 1979; Martínez García, 2004). However, despite the relevance of the *Camino de Santiago* to the history of the Iberian Peninsula, medieval Europe, and, more widely, Christianity, the study of its impacts on the lives of local populations from northern Iberia has remained somewhat limited.

The majority of research in this regard has focused on historical sources, with a smaller, although growing, implementation of archaeological research (Candy, 2009; Herrasti Erlogorri and Etxeberria, 2011; Jusú Simonena et al., 2010). Historical sources are limited in their

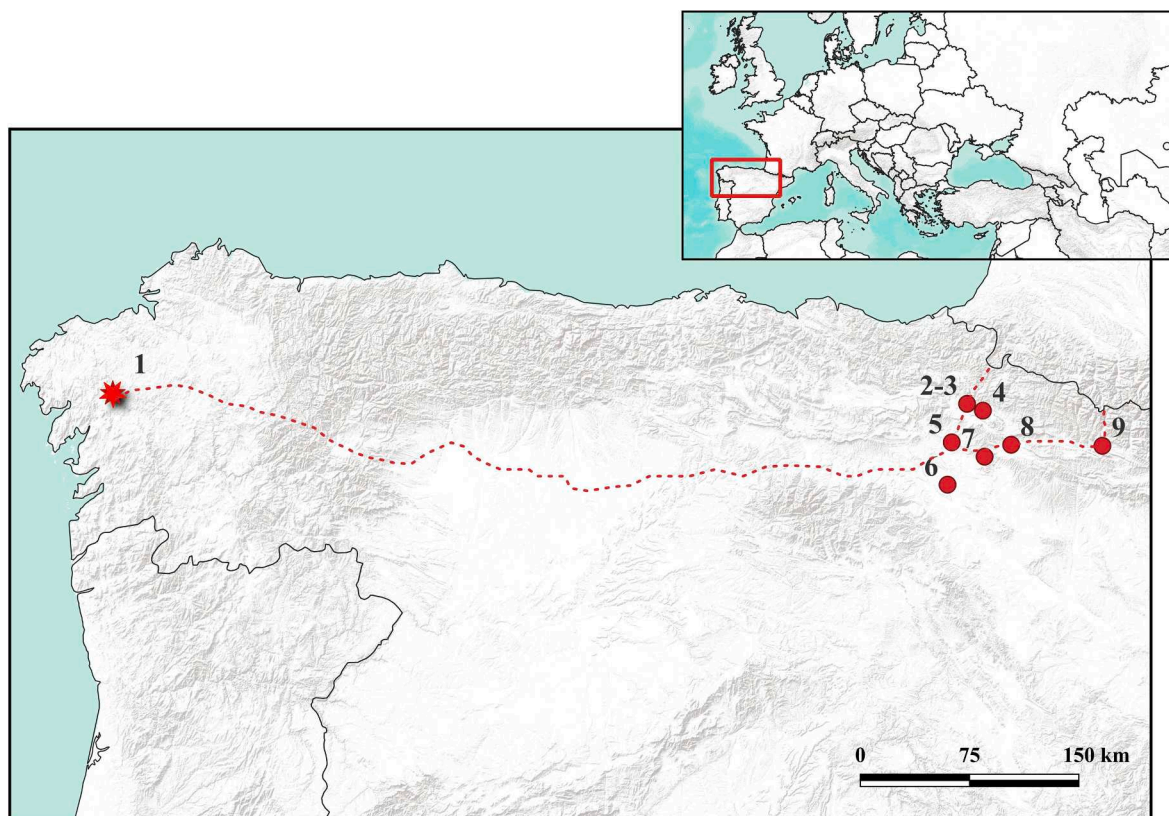


Fig. 1. Map of the Iberian Peninsula showing the French Way of the *Camino de Santiago*, and the sites mentioned in this study: 1. Santiago de Compostela; 2. Plaza de San José, Pamplona; 3. Plaza del Castillo, Pamplona; 4. Irulegui/Irulegi Castle; 5. San Saturnino, Artajona; 6. Santa María, Arlas, Peralta; 7. Santa María, Ujué; 8. Santa María, Sangüesa; 9. Plaza Biscós, Jaca. \*The map was created using QGIS 2.16 and is based on the map created by Alonso Checa (2015).

quantity and information because of the subjectivity of the authors, who usually focused on members of the clergy and/or nobility (Andrade Cernadas, 2014). Stable isotope analysis has frequently been used in medieval contexts to explore varying reliance on different crops (Alexander et al., 2015), animal protein (Jiménez-Brobeil et al., 2016), and aquatic resources (López-Costas and Müldner, 2018), dietary variations between different socio-economic status (Jordana et al., 2019; Lubritto et al., 2017; MacKinnon et al., 2019; Martínez-Jarreta et al., 2018; Pérez-Ramallo et al., 2022a; Jiménez-Brobeil et al., 2020), and to identify local and non-local individuals (Guede et al., 2017, 2018; López-Costas et al., 2021; Pérez-Ramallo et al., 2022b). Here, we analyse 82 human individuals and 42 faunal specimens from 8 different archaeological sites in a relatively small area in the northeast of the Iberian Peninsula that corresponds to the current regions of Navarre and Aragon (Fig. 1), using radiocarbon dating ( $^{14}\text{C}$ ) and stable isotope analysis ( $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}$ , and  $\delta^{13}\text{C}_{\text{ap}}$ ). Of these individuals, 20 were identified as pilgrims as they were buried with the scallop shell (*Pecten maximus*), a characteristic symbol obtained after reaching the tomb of St James in Santiago de Compostela (Jusué Simonena et al., 2010; Yeoman, 2018), enabling us to compare their diets and health indicators to those of individuals buried without this symbol and individuals reported in the wider literature. Overall, we aim to investigate potential dietary differences and geographic origins of individuals buried with this symbol compared to other individuals buried without the shell that were potential pilgrims or inhabitants of the different nuclei emerging and developing along a significant part of the *Camino de Santiago* across the medieval kingdoms of Navarre and Aragon. This study represents the first multidisciplinary study investigating pilgrimage along the *Camino de Santiago* via the largest number of pilgrims studied to date.

## 2. Background

### 2.1. Historical insights into medieval Iberian diets and pilgrims

Different historical records (e.g., diaries, wills, or hospital records) describe a variety of reasons for medieval pilgrims travelling across the Iberian Peninsula and beyond to worship the relics of St James in Santiago de Compostela (Andrade Cernadas, 2014). These include a desire for physical and spiritual healing, canonical or civil penalties, to make promises or vows, personal experience, adventure, and even pilgrimage on behalf of a deceased individual or someone else (Andrade Cernadas, 2014). Between the 11th and 13th centuries CE, a new devoted penitential spiritual enthusiasm attracted huge crowds to the relics and many individuals travelled to the site seeking physical and/or spiritual cures (Martínez García, 2004). Pilgrimage was often undertaken in groups, though social and cultural composition varied over time. Until the 11th century CE, only members of the clergy or nobility, accompanied by a large entourage, could afford the costs of making the journey (Martínez García, 2020). However, from the 12th century CE, the routes of the *Camino* became more accessible for all – safer thanks to the presence of military orders (e.g., Order of Solomon's Temple, Order of Saint John of Jerusalem, or the Teutonic Order) as well as the creation of an efficient network of healthcare and hospice centres (Martínez García, 2020). This changed who could be a pilgrim, opening the *Camino de Santiago* to all social strata from a variety of backgrounds (Martínez García, 2020, 2004).

Historical records provide broad expectations in terms of variation in diet in medieval Iberia, as well as its relationship to social status and historical and geographical context. The diets of the social and economic elites throughout the Iberian Middle Ages were primarily characterized by the significant consumption of meat (Jiménez-Brobeil et al., 2016; Pérez Samper, 2019). By contrast, meat, as well as dairy products, were available on a more limited basis for most of the rural population (Grau-Sologestoa, 2017; Pérez Samper, 2019). People from lower social groups in the countryside and in towns have been historically distinguished by diets reliant on local cereal crops, which varied by region as well as

between rural and urban contexts (Peña-Chocarro et al., 2019; Pérez-Ramallo et al., 2022a; Rosener, 1992). Based on historical and archaeological sources, rye was the most cultivated cereal across Iberia, with wheat preferred as a 'luxury' crop by the social and economic elites (Andrade Cernadas, 2009) that emerged in urban settings such as those of Navarre and Aragon between the 11th and 15th centuries CE. Meanwhile, individuals with lower social status often resorted to the  $\text{C}_4$  crop millet, particularly in drier areas or in years of poor harvests or famine, which was usually used for animal fodder (Peña-Chocarro et al., 2019; Pérez-Ramallo et al., 2022a; Weiss Adamson, 2004). Religious dietary restrictions affected all social strata. Christianity forbade meat consumption during certain fasting dates, with as many as 150 days per year requiring alternative protein sources (marine or freshwater fish, legumes, nuts, or vegetables), varying in quantity and quality between localities and individuals (Andrade Cernadas, 2009; Pérez Samper, 2019; Weiss Adamson, 2004).

During pilgrimage itself, inns, hostels, hospitals, monasteries, and churches would have provided a network of accommodation and food sources for pilgrims that expanded from the 11th century CE (Martínez García, 2020). The *Liber Sancti Jacobi* and *Codex Calixtinus* from the mid-12th century describe in great detail the wealth of foodstuffs such as bread, wine, milk and livestock available, varying following the needs of the traveller (Martínez García 2020). According to the ordinances recorded from several hospitals at the end of the 15th century CE, each pilgrim was entitled to a ration consisting of bread, wine, vegetables and a piece of meat. On days of religious abstinence, the meat was replaced by fish or eggs. For the sick, chicken meat was provided (Martínez García, 2020). Although the diet on pilgrimage would not overprint the isotopic signature of their daily lives reflected in bone tissue, this would vary according to the social status of the pilgrim, who could stay and eat in different places, as well as the hospital and its resources (Martínez García, 2020). Therefore, the social status of the individual was vital in shaping the diet during pilgrimage. The urban nature of the *Camino de Santiago* across Navarre and Aragon probably meant that travellers could be fed with meat and fish (Pérez-Ramallo et al., 2022a). Meanwhile, rural places would have more insufficient access to these foods in such a continuous way as in the cities and towns along the *Camino* (Pérez-Ramallo et al., 2022a). The formation and apogee of the *Camino de Santiago* occurred at a time of increasing urban development in the north of the Iberian Peninsula (López Alsina, 1990). The formation of these nuclei brought with them a new social class made up of craftsmen, merchants, and masons: the bourgeoisie (Pérez-Ramallo et al., 2022a). This allowed a different social status from the rural populations, and some of the wealthiest individuals even imitated the high social status of the time, made up of the nobility and the high clergy (Pérez-Ramallo et al., 2022a).

### 2.2. Stable isotope analysis and dietary reconstruction

Stable isotope analysis of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) of bone collagen is an effective method for past human and faunal dietary analysis (Ambrose and Norr, 1993; Makarewicz and Sealy, 2015; Webb et al., 2014; Yoder, 2012).  $\delta^{13}\text{C}$  variability in terrestrial ecosystems is driven by the two main  $\text{C}_3$  and  $\text{C}_4$  photosynthetic pathways as a result of differential enzyme action during  $\text{CO}_2$  fixation (Smith and Epstein, 1971).  $\delta^{13}\text{C}$  values for  $\text{C}_3$  plants vary from c.  $-36\text{‰}$  to  $-24\text{‰}$  (global mean  $-26.5\text{‰}$ ), while  $\text{C}_4$  plant values range from c.  $-17\text{‰}$  to  $-9\text{‰}$  (global mean  $-12\text{‰}$ ) (Smith and Epstein, 1971). These distinctions are carried into the tissues of consumers with a predictable fractionation effect and further minor trophic level results of 1–2 ‰ (Ambrose and Norr, 1993). While bone and dentine collagen  $\delta^{13}\text{C}_{\text{coll}}$  primarily reflect protein contributions to the diet (Howland et al., 2003; Jim et al., 2004; Yoder, 2012), tooth enamel  $\delta^{13}\text{C}_{\text{ap}}$  provides a 'whole diet' signature during the period of enamel formation (including carbohydrates, proteins, and lipids) (Yoder, 2012), though the periods of life covered by each tissue will vary depending on the exact element sampled

(Gregoricka et al., 2017).

$\delta^{15}\text{N}$  values vary significantly with trophic level, with trophic shifts of + 2 ‰ to + 6 ‰ from plants to herbivores and herbivores to carnivores being observed in aquatic and terrestrial systems (Deniro and Epstein 1981). The long length of marine and freshwater food chains leads to distinctively high  $\delta^{15}\text{N}$  values in marine and freshwater consumers compared to their terrestrial counterparts (Ambrose, 1991; Hedges and Reynard, 2007; Sponheimer et al., 2013). Interpreting the consumption of marine resources is aided by  $\delta^{13}\text{C}$  values that mimic those of  $\text{C}_4$  plants due to a different source of  $\text{CO}_2$  for primary producers in marine environments, though variability is more complex in freshwater ecosystems (Schoeninger and DeNiro 1984). Environmental conditions such as temperature, aridity, rainfall or manure can also influence  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values, making it important to measure fauna and/or plants from the same contexts as studied humans (Bogaard et al. 2007; Casey & Post 2011; Goude and Fontugne 2016).

### 2.3. $\delta^{18}\text{O}_{\text{ap}}$ analysis in tooth enamel

Stable oxygen isotopes ( $\delta^{18}\text{O}_{\text{ap}}$ ) measured from tooth enamel record the  $\delta^{18}\text{O}$  of imbibed water, providing a means to explore past human and animal mobility as a consequence of hydrological and climatic differences between regions (Daux et al., 2008; Makarewicz and Sealy, 2015). This variation is driven by changes in the  $\delta^{18}\text{O}$  of precipitation and groundwater that occur as a product of the “continental effect” (changes as air masses travel overland), the “amount effect” (whereby precipitation  $\delta^{18}\text{O}$  varies as a product of precipitation amount), altitude, temperature, and evaporative potential (Webb et al., 2014). Equations such as those presented by Longinelli (1984) or Levinson et al. (1987) are often used to convert tooth enamel carbonate or phosphate  $\delta^{18}\text{O}$  into a drinking water  $\delta^{18}\text{O}$ , yet significant errors and uncertainties are associated with this conversion (Lightfoot and O’Connell, 2016). Furthermore, changes in climate through time can affect local drinking water  $\delta^{18}\text{O}$ . As a result, when interpreting whether past human  $\delta^{18}\text{O}$  correlates to that of ‘local’ values, it is better to compare them to a local baseline of associated animal  $\delta^{18}\text{O}$ , albeit bearing in mind that the relationship between  $\delta^{18}\text{O}_{\text{ap}}$  and  $\delta^{18}\text{O}_{\text{dw}}$  drinking water varies by species. Even then intra-population variability is known to be significant (Lightfoot and O’Connell, 2016).

## 3. Materials and methods

### 3.1. Materials

To provide insights into the diets, social status, and origins of individuals buried with the scallop shell (pilgrims who perished after completing the Way of Saint James in their place of origin or on their way back to their place of origin) and other individuals buried at the same archaeological sites in Navarre and Aragon in the north-eastern Iberian Peninsula, we undertook an osteological and a multi-isotopic analysis ( $\delta^{18}\text{O}$ ,  $\delta^{13}\text{C}_{\text{ap}}$ ,  $\delta^{13}\text{C}$ , and  $\delta^{15}\text{N}$ ) of 81 human and 42 fauna from 8 different sites (Fig. 1). The samples were chosen based on their representation of similar geographic and climatic contexts with a chronology spanning from the 9th to 15th centuries CE. The archaeological sites, chronology, and number of individuals of the humans and fauna analysed are described in Tables 1, 2, 3, S2, and S4. To this dataset, we added additional published terrestrial fauna samples ( $\delta^{13}\text{C}$ , and  $\delta^{15}\text{N}$ ) from Plaza Biscós in Jaca ( $n = 13$ ), the Irulegui/Irulegi Castle, and Plaza San José in Pamplona ( $n = 4$ ) (Pérez-Ramallo et al., 2022a), as well as marine fish samples from Albarracín ( $n = 5$ ) (Alexander et al., 2015) as references (Tables 1, and S6).

In total, from the 81 individuals analysed, we sampled 117 human teeth and bones. We aimed to obtain rib samples that reflected the last years of life (Bartelink and Chesson, 2019) from each individual selected for palaeodietary analysis ( $n = 73$ ). However, for some individuals ( $n = 8$ ), because of poor collagen or the lack of ribs and alternative bones, we

**Table 1**

$\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ ,  $\delta^{18}\text{O}_{\text{ap}}$  and  $\delta^{18}\text{O}_{\text{dw}}$  (‰) mean  $\pm$  SD, range, and number of samples of fauna analysed in this study.

Site	Bos <i>taurus</i>	Ovicaprine	Sus <i>scrofa</i>	Marine Fish	$\delta^{18}\text{O}_{\text{ap}}$
Plaza de San José, Pamplona (present study and Pérez-Ramallo et al. (2022a))	$\delta^{15}\text{N}$ 4.7 and 6.5 ( $n = 2$ )	$\delta^{15}\text{N}$ 6.7 ( $n = 1$ )	$\delta^{15}\text{N}$ ( $n = 1$ ) 8.4	–	–
	$\delta^{13}\text{C}$ –21.5 and –20.6 ( $n = 2$ )	$\delta^{13}\text{C}$ –20.1 ( $n = 1$ )	$\delta^{13}\text{C}$ –20.9 ( $n = 1$ )	–	–
Santa María de Ujué, Ujué (present study)	$\delta^{15}\text{N}$ 4.5 and 6.1 ( $n = 2$ )	$\delta^{15}\text{N}$ 7.6 ( $n = 1$ )	–	–	–6.3 ( $n = 1$ )
	$\delta^{13}\text{C}$ –22.1 and –21.7 ( $n = 2$ )	$\delta^{13}\text{C}$ –21.0 ( $n = 1$ )	–	–	–
Santa María de Arias, Peralta (present study)	$\delta^{15}\text{N}$ 7.1 and 7.5 ( $n = 2$ )	$\delta^{15}\text{N}$ 8.0 and 8.5 ( $n = 2$ )	$\delta^{15}\text{N}$ 9.9 ( $n = 1$ )	–	–
	$\delta^{13}\text{C}$ –19.4 to –19.3 ( $n = 2$ )	$\delta^{13}\text{C}$ –20.4 and –20.1 ( $n = 2$ )	$\delta^{13}\text{C}$ –20.7 ( $n = 1$ )	–	–
San Saturnino de Artajona (present study)	$\delta^{15}\text{N}$ 7.2 ( $n = 1$ )	$\delta^{15}\text{N}$ 5.6 $\pm$ 1.2 (4.2 to 6.4) ( $n = 3$ )	$\delta^{15}\text{N}$ 9.0 ( $n = 1$ )	–	–
	$\delta^{13}\text{C}$ –20.2 ( $n = 1$ )	$\delta^{13}\text{C}$ –20.4 $\pm$ 0.6 (–20.9 to –19.7) ( $n = 3$ )	$\delta^{13}\text{C}$ –19.2 ( $n = 1$ )	–	–
Irulegui/Iruegi Castle (present study)	$\delta^{15}\text{N}$ 7.1 $\pm$ 1.6 (5.3 to 8.4) ( $n = 3$ )	$\delta^{15}\text{N}$ 5.3 and 5.8 ( $n = 2$ )	$\delta^{15}\text{N}$ 6.1 and 9.5 ( $n = 2$ )	–	$\delta^{18}\text{O}_{\text{ap}}$ –5.7 $\pm$ 1.6 (–8.6 to –4.0) ( $n = 19$ )
	$\delta^{13}\text{C}$ –21.4 $\pm$ 0.3 (–21.8 to –21.2) ( $n = 3$ )	$\delta^{13}\text{C}$ –21.3 and –20.2 ( $n = 2$ )	$\delta^{13}\text{C}$ –21.4 and –20.3 ( $n = 2$ )	–	–
Plaza Biscós, Jaca (present study and Pérez-Ramallo et al. (2022a))	$\delta^{13}\text{C}_{\text{ap}}$ –11.0 $\pm$ 0.2 (–11.2 to –10.8) ( $n = 3$ )	$\delta^{13}\text{C}_{\text{ap}}$ –11.7 and –10.0 ( $n = 2$ )	$\delta^{13}\text{C}_{\text{ap}}$ –12.3 and –11.4 ( $n = 2$ )	–	–
	$\delta^{15}\text{N}$ 4.9 $\pm$ 0.2 (4.8 to 5.1) ( $n = 3$ )	$\delta^{15}\text{N}$ 4.9 $\pm$ 1.2 (3.1 to 6.7) ( $n = 8$ )	$\delta^{15}\text{N}$ 8.4 and 8.6 ( $n = 2$ )	–	$\delta^{18}\text{O}_{\text{ap}}$ –5.9 $\pm$ 1.6 (–8.4 to –2.2) ( $n = 19$ )
Plaza Biscós, Jaca (present study and Pérez-Ramallo et al. (2022a))	$\delta^{13}\text{C}$ –20.7 $\pm$ 0.8 (–21.5 to –20.0) ( $n = 3$ )	$\delta^{13}\text{C}$ –20.7 $\pm$ 0.7 (–21.8 to –19.9) ( $n = 8$ )	$\delta^{13}\text{C}$ –20.6 and –20.5 ( $n = 2$ )	–	–
	$\delta^{13}\text{C}_{\text{ap}}$ –12.3 $\pm$ 1.3 (–14.4 to –11.0) ( $n = 11$ )	$\delta^{13}\text{C}_{\text{ap}}$ –12.2 $\pm$ 1.0 (–13.4 to –10.7) ( $n = 11$ )	–	–	–

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Table 1 (continued)

Site	<i>Bos taurus</i>	Ovicaprine	<i>Sus scrofa</i>	Marine Fish	$\delta^{18}\text{O}_{\text{ap}}$
Albarracín, Teruel (Alexander et al., 2015)	-10.6 (n = 8)	-	-	$\delta^{15}\text{N}$ (n = 5)	-
	-	-	-	10.6 ± 1.9 (8.1 to 12.6)	-
Total	$\delta^{15}\text{N}$ 6.0 ± 1.4 (4.5 to 8.4) (n = 13)	$\delta^{15}\text{N}$ 5.8 ± 1.5 (3.1 to 8.5) (n = 17)	$\delta^{15}\text{N}$ 8.6 ± 1.2 (6.1 to 9.9) (n = 7)	$\delta^{15}\text{N}$ 10.6 ± 1.9 (8.1 to 12.6) (n = 5)	$\delta^{18}\text{O}_{\text{ap}}$ -5.8 ± 1.6 (-8.6 to -2.2) (n = 27)
	$\delta^{13}\text{C}$ -20.8 ± 0.9 (-22.1 to -19.3) (n = 13)	$\delta^{13}\text{C}$ -20.6 ± 0.6 (-21.8 to -19.7) (n = 17)	$\delta^{13}\text{C}$ -20.5 ± 0.7 (-21.4 to -19.2) (n = 7)	$\delta^{13}\text{C}$ -10.8 ± 1.1 (-12.2 to -9.4) (n = 5)	$\delta^{13}\text{C}_{\text{ap}}$ -11.9 ± 0.6 (-13.4 to -10.0) (n = 13)
	$\delta^{13}\text{C}_{\text{ap}}$ -12.0 ± 1.2 (-14.4 to -10.6) (n = 12)	$\delta^{13}\text{C}_{\text{ap}}$ -12.0 ± 1.1 (-13.4 to -10.0) (n = 13)	$\delta^{13}\text{C}_{\text{ap}}$ -11.9 ± 0.6 (-12.3 to -11.4) (n = 2)		

sampled second molar roots to avoid breastfeeding influences (root formation between 6 and 7 and 12–14 years) (AlQahtani et al., 2010). According to their availability, we were able to analyse both a tooth and rib from 39 individuals. These two elements reflect the individual's diet during their earlier (tooth) (Wright and Schwarcz, 1999) and later years of life (rib) (Fahy et al., 2017; Hill, 1998). From the same teeth used for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  dentine analysis (40 s molars and two premolars), we sampled the  $\delta^{13}\text{C}_{\text{ap}}$  tooth enamel (second molar crown enamel formation between 2.5 and 3 and 7–8 years; and second premolar between 2 and 2.5 and 6–7 years) (AlQahtani et al., 2010). This allowed us to study the differences between whole diet and protein-based contributions (Fernandes et al., 2012). We used the same tooth enamel samples for palaeomobility studies via  $\delta^{18}\text{O}$  analysis.

### 3.2. The archaeological sites

All individuals analysed here were adults buried under the Christian rite of the time without evidence for the presence of other faiths in terms of funerary rite (east–west orientation, supine, arms flexed, hands crossed over the pelvis and legs straight). They were not buried with objects except for those individuals who were discovered with the pilgrim's shell. The tombs were rectangular, anthropomorphic, or irregular pits with most of them made with walls of cists or rectangular stones and, generally, all the tombs were covered with flagstones.

#### 3.2.1. Plaza de San José and Plaza del Castillo, Pamplona

Pamplona is the geographical and political centre of the region of Navarre, in the north of Spain. The city is located in a basin surrounded by hills, which open up towards the south and the high valley of the Ebro River. During the Middle Ages, Pamplona developed and reached its peak as the capital, firstly of the kingdom of Pamplona and, from the

Table 2

Summary data (range, mean, standard deviation, number of samples) for  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{18}\text{O}_{\text{ap}}$ ,  $\delta^{18}\text{O}_{\text{dw}}$ , and  $\delta^{13}\text{C}_{\text{ap}}$  measurements of humans analysed in this study displayed by origin and chronology. The “teeth” and “ribs” columns correspond to those individuals for whom we were able to analyse both samples from the same individual.

Site and Chronology	# on map (Fig. 1)	$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Ribs $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth enamel $\delta^{18}\text{O}_{\text{ap}}$ and $\delta^{13}\text{C}_{\text{ap}}$ (‰)
Plaza de San José, Pamplona, Navarre (12th-13th centuries CE)	2	$\delta^{15}\text{N}$ 10.6 ± 0.9 (9.8 to 12.0) (n = 7)	$\delta^{15}\text{N}$ 9.8 ± 0.9 (8.9 to 10.9) (n = 4)	$\delta^{15}\text{N}$ 10.2 ± 0.4 (9.8 to 10.6) (n = 4)	$\delta^{18}\text{O}_{\text{ap}}$ -6.3 ± 1.4 (-8.2 to -4.3) (n = 5)
		$\delta^{13}\text{C}$ -18.8 ± 1.8 (-21.0 to -15.3) (n = 7)	$\delta^{13}\text{C}$ -19.0 ± 2.1 (-20.9 to -15.9) (n = 4)	$\delta^{13}\text{C}$ -19.5 ± 1.2 (-21.0 to -18.1) (n = 4)	$\delta^{13}\text{C}_{\text{ap}}$ -13.4 ± 1.8 (-15.3 to -11.2) (n = 5)
Plaza del Castillo, Pamplona, Navarre (11th-12th centuries CE)	3	$\delta^{15}\text{N}$ 11.4 ± 0.7 (10.4 to 12.5) (n = 6)	$\delta^{15}\text{N}$ 12.2 (n = 1)	$\delta^{15}\text{N}$ 12.5 (n = 1)	$\delta^{18}\text{O}_{\text{ap}}$ -4.2 ± 1.0 (-5.4 to -2.9) (n = 4)
		$\delta^{13}\text{C}$ -19.1 ± 0.3 (-19.5 to -18.6) (n = 6)	$\delta^{13}\text{C}$ -18.8 (n = 1)	$\delta^{13}\text{C}$ -19.5 (n = 1)	$\delta^{13}\text{C}_{\text{ap}}$ -11.7 ± 0.3 (-12.1 to -11.5) (n = 4)
San Saturnino, Artajona, Navarre (14th-15th centuries CE)	5	$\delta^{15}\text{N}$ 12.7 (n = 1)	$\delta^{15}\text{N}$ 12.9 (n = 1)	$\delta^{15}\text{N}$ 12.7 (n = 1)	$\delta^{18}\text{O}_{\text{ap}}$ -4.7 (n = 1)
		$\delta^{13}\text{C}$ -18.5 (n = 1)	$\delta^{13}\text{C}$ -18.0 (n = 1)	$\delta^{13}\text{C}$ -18.5 (n = 1)	$\delta^{13}\text{C}_{\text{ap}}$ -11.0 (n = 1)
Santa María, Arlas, Peralta, Navarre (14th-15th centuries CE)	6	$\delta^{15}\text{N}$ 11.7 ± 0.9 (11.1 to 13.0) (n = 4)	$\delta^{15}\text{N}$ 11.8 ± 0.6 (11.2 to 12.4) (n = 3)	$\delta^{15}\text{N}$ 11.9 ± 0.3 (11.3 to 13.0) (n = 3)	$\delta^{18}\text{O}_{\text{ap}}$ -4.9 ± 1.7 (-6.7 to -2.8) (n = 4)
		$\delta^{13}\text{C}$ -18.9 ± 0.3 (-19.1 to -18.6) (n = 4)	$\delta^{13}\text{C}$ -19.0 ± 0.1 (-19.1 to -18.8) (n = 3)	$\delta^{13}\text{C}$ -18.8 ± 0.3 (-19.1 to -18.6) (n = 3)	$\delta^{13}\text{C}_{\text{ap}}$ -12.3 ± 0.8 (-13.0 to -11.1) (n = 4)
Santa María, Ujué, Navarre (9th-15th centuries CE)	7	$\delta^{15}\text{N}$ 10.9 ± 1.0 (9.4 to 12.5) (n = 9)	$\delta^{15}\text{N}$ 10.5 ± 1.1 (8.7 to 12.4) (n = 7)	$\delta^{15}\text{N}$ 10.8 ± 1.0 (9.4 to 12.5) (n = 7)	$\delta^{18}\text{O}_{\text{ap}}$ -4.6 ± 1.3 (-6.6 to -3.1) (n = 8)
		$\delta^{13}\text{C}$ -18.7 ± 0.4 (-19.4 to -18.2) (n = 9)	$\delta^{13}\text{C}$ -18.9 ± 0.5 (-19.3 to -17.9) (n = 7)	$\delta^{13}\text{C}$ -18.7 ± 0.4 (-19.4 to -18.2) (n = 7)	$\delta^{13}\text{C}_{\text{ap}}$ -11.9 ± 0.6 (-12.7 to -11.1) (n = 8)
Santa María, Sangüesa, Navarre (11th-12th centuries CE)	8	$\delta^{15}\text{N}$ 10.3 ± 1.5 (9.0 to 11.9) (n = 3)	$\delta^{15}\text{N}$ 10.7 ± 1.3 (9.5 to 12.1) (n = 3)	$\delta^{15}\text{N}$ 10.2 ± 1.5 (9.0 to 11.9) (n = 3)	$\delta^{18}\text{O}_{\text{ap}}$ -4.4 ± 1.1 (-5.6 to -3.5) (n = 3)
		$\delta^{13}\text{C}$ -19.1 ± 0.2 (-19.3 to -18.7) (n = 3)	$\delta^{13}\text{C}$ -18.7 ± 0.1 (-18.8 to -18.6) (n = 3)	$\delta^{13}\text{C}$ -19.1 ± 0.2 (-19.3 to -18.9) (n = 3)	$\delta^{13}\text{C}_{\text{ap}}$ -11.7 ± 0.8 (-12.6 to -10.8) (n = 3)

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Table 2 (continued)

Site and Chronology	# on map (Fig. 1)	$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Ribs $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth enamel and $\delta^{18}\text{O}_{\text{ap}}$ and $\delta^{13}\text{C}_{\text{cap}}$ (‰)
Plaza Biscós, Jaca, Aragon (13th-15th centuries CE)	9	$\delta^{15}\text{N}$ 9.9 ± 0.8 (8.3 to 12.3) (n = 51)	$\delta^{15}\text{N}$ 9.9 ± 1.0 (8.1 to 12.5) (n = 26)	$\delta^{15}\text{N}$ 9.8 ± 0.8 (8.3 to 11.6) (n = 26)	$\delta^{18}\text{O}_{\text{ap}}$ -5.4 ± 1.1 (-8.1 to -2.7) (n = 24)
		$\delta^{13}\text{C}$ -18.4 ± 1.1 (-19.8 to -15.3) (n = 51)	$\delta^{13}\text{C}$ -17.0 ± 2.6 (-19.4 to -9.1) (n = 26)	$\delta^{13}\text{C}$ -18.2 ± 1.1 (-19.6 to -15.3) (n = 26)	$\delta^{13}\text{C}_{\text{cap}}$ -10.9 ± 2.4 (-13.6 to -2.7) (n = 24)

12th century CE onwards, of the kingdom of Navarre (Serrano Larráyoz, 2014). The city, like different places across the Camino de Santiago in the northern Iberian Peninsula, was populated by Franks and other ethnicities (Martínez García, 2004). The city was divided into three burghs that coexisted from the 11th century CE, but primarily from 12th to 15th centuries CE: San Nicolás, formed by free individuals from the kingdom and foreigners; San Cernín, where Frankish merchants and artisans lived; and Navarrería with population from Pamplona (Jusué Simonena et al., 2010).

Between 2007 and 2010, the company *Gabinete Trama*, under the direction of Mercedes Unzu, discovered several tombs and 8 individuals corresponding to the medieval cemetery of the cathedral of Santa María of Pamplona related to the Navarrería (Jusué Simonena et al., 2010). Here we increased the stable isotope analyses previously conducted on 8 human individuals (Pérez-Ramallo et al., 2022a). Among them, two human individuals (one female and one male) were found buried with the pilgrim's scallop shell that is associated with the completion of a medieval pilgrimage to *Santiago de Compostela*. The radiocarbon dating conducted there by Pérez-Ramallo et al. (2022a) indicated that the sampled human remains were from between the 12th and 13th centuries CE, just before the Navarrería War in 1276 CE (Jusué Simonena et al., 2010). This suggests that those individuals discovered with scallop shells could belong to individuals who had undertaken the *Camino de Santiago* and/or members of Pamplona's St James brotherhood (Jusué Simonena et al., 2010).

In Plaza del Castillo, the remains of the Convent of Santiago and its cemetery were found. This monastery, founded in the 11th century CE, was in use until the beginning of the 16th century CE. There was a chapel under the invocation of St James since the 12th century CE, with a hospital for pilgrims (Jusué Simonena et al., 2010). Three female individuals were identified as pilgrims because of the presence of the scallop shell. Next to them, the remains of individuals who had previously occupied the burial space were analysed. In total, 6 humans and one faunal sample were studied.

### 3.2.2. Irulegui Castle

This medieval fortress is located at the eastern end of the Aranguren Valley at an altitude of 893 m above sea level in the central part of Navarre (Aiestaran de la Sotilla et al., 2022; Bucos Cabello et al., 2013). This had strategic importance on the eastern border of Pamplona, with exceptional visual control of the capital of the Navarre kingdom and the roads that led to the Pyrenean ports (Aiestaran de la Sotilla et al., 2022; Bucos Cabello et al., 2013). It stands out for its historical relevance as a defensive fortress of the Kingdom of Navarre against Islamic attacks and, later, as a defence against assaults from neighbouring Christian kingdoms. It was destroyed by the Navarrese kings at the end of the 15th

Table 3

Summary data (range, mean, standard deviation, number of samples) for  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ ,  $\delta^{18}\text{O}_{\text{ap}}$ ,  $\delta^{18}\text{O}_{\text{dw}}$ , and  $\delta^{13}\text{C}_{\text{cap}}$  measurements from humans analysed in this study displayed by origin and chronology. \*The mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  (‰) of all individuals analysed (n = 81) have been obtained from the rib collagen (n = 73), together with the collagen of the dentine from those individuals for whom we were not able to analyse a rib (n = 8).\*\* Mean  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  (‰) from those individuals (n = 39) for whom we were able to analyse dentine and rib collagen.

Reference	$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Ribs $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth enamel and $\delta^{18}\text{O}_{\text{ap}}$ and $\delta^{13}\text{C}_{\text{cap}}$ (‰)
<b>Total</b>	$\delta^{15}\text{N}$ 10.3 ± 1.1 (8.3 to 13.0) (n = 81)	$\delta^{15}\text{N}$ 10.4 ± 1.2 (8.1 to 12.9) (n = 36)	$\delta^{15}\text{N}$ 10.4 ± 1.1 (8.3 to 13.0) (n = 36)	$\delta^{18}\text{O}_{\text{ap}}$ -5.2 ± 1.3 (-8.2 to -2.7) (n = 48)
	$\delta^{13}\text{C}$ -18.6 ± 1.0 (-21.0 to -15.3) (n = 81)	$\delta^{13}\text{C}$ -17.9 ± 2.2 (-20.9 to -9.1) (n = 36)	$\delta^{13}\text{C}$ -18.6 ± 1.0 (-21.0 to -15.3) (n = 36)	$\delta^{13}\text{C}_{\text{cap}}$ -11.6 ± 1.9 (-15.3 to -2.7) (n = 48)
<b>Females</b>	$\delta^{15}\text{N}$ 10.2 ± 1.0 (8.9 to 12.5) (n = 31)	$\delta^{15}\text{N}$ 10.9 ± 1.2 (8.7 to 12.9) (n = 15)	$\delta^{15}\text{N}$ 10.8 ± 1.3 (8.9 to 12.7) (n = 15)	$\delta^{18}\text{O}_{\text{ap}}$ -5.0 ± 1.2 (-8.1 to -3.1) (n = 18)
	$\delta^{13}\text{C}$ -18.7 ± 1.1 (-21.0 to -15.3) (n = 31)	$\delta^{13}\text{C}$ -18.6 ± 1.2 (-20.9 to -15.2) (n = 15)	$\delta^{13}\text{C}$ -18.9 ± 0.7 (-21.0 to -18.2) (n = 15)	$\delta^{13}\text{C}_{\text{cap}}$ -12.0 ± 1.2 (-15.3 to -9.8) (n = 18)
<b>Males</b>	$\delta^{15}\text{N}$ 10.4 ± 1.0 (8.3 to 13.0) (n = 45)	$\delta^{15}\text{N}$ 10.0 ± 1.1 (8.1 to 12.5) (n = 22)	$\delta^{15}\text{N}$ 10.2 ± 1.0 (8.3 to 13.0) (n = 22)	$\delta^{18}\text{O}_{\text{ap}}$ -5.2 ± 1.3 (-8.2 to -2.7) (n = 29)
	$\delta^{13}\text{C}$ -18.4 ± 1.0 (-19.7 to -15.3) (n = 45)	$\delta^{13}\text{C}$ -17.4 ± 2.6 (-19.8 to -9.1) (n = 22)	$\delta^{13}\text{C}$ -18.4 ± 1.1 (-19.7 to -15.3) (n = 22)	$\delta^{13}\text{C}_{\text{cap}}$ -11.2 ± 2.2 (-13.0 to -2.7) (n = 29)
<b>Individuals buried without the scallop shell</b>	$\delta^{15}\text{N}$ 10.2 ± 1.0 (8.3 to 12.3) (n = 61)	$\delta^{15}\text{N}$ 10.2 ± 1.1 (8.3 to 12.5) (n = 24)	$\delta^{15}\text{N}$ 10.1 ± 1.0 (8.3 to 11.9) (n = 24)	$\delta^{18}\text{O}_{\text{ap}}$ -5.4 ± 1.4 (-8.2 to -2.7) (n = 32)
	$\delta^{13}\text{C}$ -18.5 ± 0.9 (-19.8 to -15.3) (n = 61)	$\delta^{13}\text{C}$ -17.7 ± 2.4 (-19.4 to -9.1) (n = 24)	$\delta^{13}\text{C}$ -18.7 ± 0.6 (-19.6 to -17.3) (n = 24)	$\delta^{13}\text{C}_{\text{cap}}$ -11.7 ± 2.0 (-15.3 to -2.7) (n = 32)
<b>Female individuals buried without the scallop shell</b>	$\delta^{15}\text{N}$ 10.0 ± 0.8 (8.9 to 11.9) (n = 22)	$\delta^{15}\text{N}$ 10.4 ± 1.1 (8.7 to 12.1) (n = 9)	$\delta^{15}\text{N}$ 10.1 ± 1.0 (8.9 to 11.9) (n = 9)	$\delta^{18}\text{O}_{\text{ap}}$ -5.2 ± 1.4 (-8.1 to -3.1) (n = 11)
	$\delta^{13}\text{C}$ -18.6 ± 1.1 (-19.8 to -15.3) (n = 22)	$\delta^{13}\text{C}$ -18.2 ± 1.2 (-19.3 to -15.2) (n = 9)	$\delta^{13}\text{C}$ -18.8 ± 0.4 (-19.4 to -18.4) (n = 9)	$\delta^{13}\text{C}_{\text{cap}}$ -11.9 ± 1.0 (-13.6 to -9.8) (n = 11)
<b>Male individuals buried without the scallop shell</b>	$\delta^{15}\text{N}$ 10.6 ± 1.0 (8.3 to 12.3) (n = 34)	$\delta^{15}\text{N}$ 10.2 ± 1.1 (8.1 to 12.5) (n = 13)	$\delta^{15}\text{N}$ 10.2 ± 0.9 (8.3 to 11.5) (n = 13)	$\delta^{18}\text{O}_{\text{ap}}$ -5.4 ± 1.4 (-8.2 to -2.7) (n = 20)
	$\delta^{13}\text{C}$ -18.4 ± 0.9 (-19.6 to	$\delta^{13}\text{C}$ -17.4 ± 3.0 (-19.3 to	$\delta^{13}\text{C}$ -18.6 ± 0.7 (-19.6 to	$\delta^{13}\text{C}_{\text{cap}}$ -11.4 ± 2.3 (-13.0 to

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Table 3 (continued)

Reference	$\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Ribs $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ (‰)	Teeth enamel $\delta^{18}\text{O}_{\text{ap}}$ and $\delta^{13}\text{C}_{\text{ap}}$ (‰)
Individuals buried with the scallop shell	-15.3)	-12.5)	-17.3)	(-2.7)
	(n = 34)	(n = 13)	(n = 13)	(n = 20)
	$\delta^{15}\text{N}$ 10.6	$\delta^{15}\text{N}$ 10.7	$\delta^{15}\text{N}$ 10.9	$\delta^{18}\text{O}_{\text{ap}}$ -4.7
	$\pm 1.2$	$\pm 1.4$	$\pm 1.3$	$\pm 0.9$
	(9.0 to 13.0)	(8.9 to 12.9)	(9.2 to 13.0)	(-6.0 to -2.8)
Female individuals buried with the scallop shell	n = 20	n = 14	n = 14	n = 16
	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$	$\delta^{13}\text{C}_{\text{ap}}$
	-18.7 $\pm$ 1.2	-18.3 $\pm$ 1.7	-18.5 $\pm$ 1.3	-11.3 $\pm$ 1.8
	(-21.0 to -15.3)	(-20.9 to -14.0)	(-21.0 to -15.3)	(-15.3 to -7.3)
	(n = 20)	(n = 14)	(n = 14)	(n = 16)
Male individuals buried with the scallop shell	$\delta^{15}\text{N}$ 11.3	$\delta^{15}\text{N}$ 11.6	$\delta^{15}\text{N}$ 11.7	$\delta^{18}\text{O}_{\text{ap}}$ -4.8
	$\pm 1.1$	$\pm 1.1$	$\pm 1.0$	$\pm 0.9$
	(9.7 to 12.7)	(10.0 to 12.9)	(10.3 to 12.7)	(-5.7 to -3.4)
	(n = 9)	(n = 6)	(n = 6)	n = 7
	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$	$\delta^{13}\text{C}_{\text{ap}}$
Female individuals buried with the scallop shell	-19.1 $\pm$ 0.8	-19.1 $\pm$ 1.0	-19.1 $\pm$ 1.0	-12.0 $\pm$ 1.6
	(-21.0 to -18.2)	(-20.9 to -18.0)	(-21.0 to -18.2)	(-15.3 to -11.0)
	(n = 9)	(n = 6)	(n = 6)	n = 7
	$\delta^{15}\text{N}$ 10.0	$\delta^{15}\text{N}$ 9.9	$\delta^{15}\text{N}$ 10.2	$\delta^{18}\text{O}_{\text{ap}}$ -4.7
	$\pm 1.1$	$\pm 1.1$	$\pm 1.2$	$\pm 1.0$
Male individuals buried with the scallop shell	(9.0 to 13.0)	(8.9 to 12.4)	(9.2 to 13.0)	(-6.0 to -2.8)
	(n = 11)	(n = 8)	(n = 8)	(n = 9)
	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$	$\delta^{13}\text{C}$	$\delta^{13}\text{C}_{\text{ap}}$
	-18.4 $\pm$ 1.4	-17.7 $\pm$ 2.0	-18.1 $\pm$ 1.6	-10.8 $\pm$ 1.9
	(-19.7 to -15.7)	(-19.8 to -14.0)	(-19.7 to -15.3)	(-12.8 to -7.3)
(n = 11)	(n = 8)	(n = 8)	(n = 9)	

century CE (Aiestaran de la Sotilla et al., 2022; Buces Cabello et al., 2013). Between 2007 and 2022, the castle was excavated and investigated by *Sociedad de Ciencias Aranzadi*, under the supervision of Javier Buces Cabello, Mattin Aiestaran, and Juanxo Agirre. A total of 13 excavated fauna samples from between 11th-13th centuries CE were sampled to contribute to help build an ecological isotopic baseline for the region. The chronology is relative and established based on the archaeological remains.

### 3.2.3. Santa María de Arlas, Peralta (14th century CE)

The village of Arlas is in the centre of the alluvial plain formed by the river Arga as it passes through the municipalities of Falces and Peralta. This region was on the border between the territory of Pamplona and the Banū Qasī (linked to al-Andalus). Between the 11th and 12th centuries CE, the Village of Peralta was the centre of an important border "tenure" (VV.AA., 2010). It is believed that the place was uninhabited following the plague in the 14th century CE (Sesma Sesma, 1997). In 1997, under the direction of Jesús Sesma, an archaeological intervention was carried out that brought to light several medieval tombs. Among them, an individual buried with the scallop shell was identified (1 male). In this study we analyzed all adult individuals (n = 6) from a total of 9 discovered, together with seven domestic fauna.

### 3.2.4. Santa María la Real de Sangüesa (11th-12th centuries CE)

Sangüesa is in the central eastern portion of Navarre, 45 km from the capital of the region. The inhabitants of the town or city of Sangüesa received the charters first from King Sancho Ramírez in 1090 CE, before they were extended by Alfonso I the Battler in 1122 CE (Mateo Pérez and Duró Cazorla, 2017). The church of Santa María was donated in 1131 by King Alfonso I "El Batallador" to the order of Saint John of Jerusalem

(Mateo Pérez and Duró Cazorla, 2017; Milton Weber, 1959). Its location near the border of the Kingdom of Aragon made Sangüesa an important defensive location. In the year 2014, in the surroundings of the temple, a tomb was discovered. This prompted an archaeological intervention between 2016 and 2017 by the company Olcairum Estudios Arqueológicos S.L., under the direction of Alexandre Duró Cazorla (Mateo Pérez and Duró Cazorla, 2017). The remains of a necropolis with an intensive occupation were revealed, as reflected in three levels of tombs. The remains of 3 new individuals, buried following the Christian rites, were excavated and exhumed, one of which being identified as a pilgrim because of the presence of the scallop shell (1 male). All individuals were analysed.

### 3.2.5. Santa María de Ujué (12th-15th centuries CE)

The town of Ujué is in the eastern part of Navarre, between the Central Zone and the Sierra of Ujué, with an altitude of 815 m above sea level (Unzu Urmeneta et al., 2011). Between 2007 and 2009, Gabinete Trama S.L., was entrusted with the archaeological monitoring and control of the restoration project of the interior of the church of Santa María de Ujué. This is a Romanesque and Gothic temple, with archaeological remains that corroborate the presence of a pre-Romanesque shrine. The place had a watchtower over the riverbank, and it became an important centre of pilgrimage in the Middle Ages, especially since the rule of the king Carlos II (1349-1387) (Jusué Simonena et al., 2010). Under the graveyard that surrounds the temple, two individuals were sampled with a relative chronology between the 12th and 15th centuries CE. One of them was buried with the scallop shell (1 female). Inside the temple, six graves were discovered related to the pre-Romanesque temple and with a chronology ranging between the 9th and 11th centuries CE (Unzu Urmeneta et al., 2011). We analysed 8 individuals from these graves.

### 3.2.6. San Saturnino de Artajona (14th-15th centuries CE)

Artajona is in the central zone of Navarre at 456 m above sea level and would have allowed a great panoramic overview and control of the surrounding territory, giving it an important strategic and defensive character. The Gothic church of San Saturnino is a resistive element of the walled enclosure (Sesma Sesma et al., 2011). Interestingly, Artajona is far from any of the main pilgrimage routes to Santiago (Jusué Simonena et al., 2010). In 2008, during redevelopment work around the church of San Saturnino, an archaeological intervention was carried out by Gabinete TRAMA S.L., leading to the discovery of a tomb with the remains of a woman buried with the scallop shell (Faro Carballa et al., 2009).

### 3.2.7. Jaca, Zaragoza (13th-15th centuries CE)

Jaca is a city in north-eastern Spain in the province of Huesca, located near the Pyrenees and the border with France. Jaca was the city out of which the County and Kingdom of Aragon developed. It was the capital of Aragon until 1097 CE (Buesa Conde, 2002). When Jaca became the first royal seat of Ramiro I (1006-1063 CE), people dedicated to administration and merchants began to arrive, transforming it from a village exclusively devoted to livestock and agriculture into an urban centre (Buesa Conde, 2002). Between 2006 and 2007, archaeological excavations were carried out in Biscós Square in Jaca, next to Saint Peter's Cathedral. These were directed by Julia Justes Floría and Rafael Domingo Martínez. The necropolis emerged in the 11th century CE and was in continuous use until the first half of the 16th century CE (Justes Floría and Domingo Martínez, 2007). Our sample included individuals from two sets of isotope analyses, a group of 27 individuals analysed for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  in bone collagen at the University of Durham and a more recent analysis of a further 21 individuals for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  from bone and dentine and  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  from tooth bioapatite analysed at the Max Planck Institute of Geoanthropology, Jena. From those, 13 individuals were buried with the scallop shell.



### 3.3. Radiocarbon dating

To confirm and/or provide the absolute chronology for the samples, we selected 4 bones (ribs) for radiocarbon-dating from burial contexts included in this study. The human bone from the necropolis of Plaza del Castillo, Pamplona; Santa María de Arlas, Peralta; Santa María de Sangüesa; and Plaza Biscós in Jaca (Huesca, Aragon), were radiocarbon dated at the Oxford Radiocarbon Accelerator Unit (ORAU). Prior to extensive sampling of human skeletal remains, we screened small (3–5 mg) sub-samples of drilled bone powder by measuring the elemental nitrogen concentration. This is a useful proxy for protein, and therefore presence of collagen in the bone (Brook et al., 2010; Jacob et al., 2018). Samples with  $> \sim 0.5$  %N were passed for full collagen extraction treatment for AMS dating. The methods used are outlined in Brook et al. (2010). Briefly, collagen was extracted using an acid-base-acid procedure followed by gelatinization and lyophilization (Brook et al., 2010). The extracted gelatine was filtered using pre-cleaned Vivaspin™30kD MWCO ultra-filters (Brown et al., 1988; Higham et al., 2006). Ultrafiltration removes low molecular weight contaminants and produces a better purified collagen fraction as indicated by improved C:N atomic ratios and carbon mass on combustion. The filtered collagen was freeze-dried and combusted in a CHN analyser in continuous flow mode linked to a Europa isotope ratio mass spectrometer (EA-CF-IRMS) using He as carrier gas.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values, nitrogen and carbon content, and bone C:N atomic ratios were determined. The purified  $\text{CO}_2$  was then reduced to graphite using  $\text{H}_2$  in a reaction catalysed by 2 mg of Fe powder at  $560^\circ\text{C}$  for 6 hr. The graphite was pressed into an Al target holder prior to radiocarbon measurement using AMS (Ramsey et al., 2004). We tested the reliability of dating bone with collagen yields of this size and the models showed that none were outliers. All other analytical parameters measured, including the carbon to nitrogen atomic ratio, were acceptable. We therefore consider the results to be robust. The calibration and the calibration curve were performed by OxCal V4.4 Bronk Ramsey (2021): r.5: IntCal20 atmospheric curve (Reimer et al., 2020).

### 3.4. Stable isotope analysis of bone and dentine collagen, and tooth enamel

#### 3.4.1. $\delta^{18}\text{O}_{\text{ap}}$ and $\delta^{13}\text{C}_{\text{ap}}$ analysis in tooth enamel

Analysis of tooth enamel for  $\delta^{18}\text{O}_{\text{ap}}$  and  $\delta^{13}\text{C}_{\text{ap}}$  analysis was also conducted at the Isotope Research Laboratory, Max Planck Institute for the Science of Human History in Jena, Germany. Enamel powder was removed from clean locations using a tungsten drill, with the vertical edge of the occlusal surface being sampled to provide a long-term average signal. Powdered enamel for  $\delta^{18}\text{O}_{\text{ap}}$  and  $\delta^{13}\text{C}_{\text{ap}}$  analysis was collected and placed in a 1.5 ml Eppendorf tube. Samples were treated with 1 ml of 1 % NaClO for 60 min, then rinsed with MilliQ® water three times to remove any remaining bleach, before being treated with 0.1 M acetic acid for 10 min. Samples were then again rinsed three times with MilliQ® water to remove any remaining acid. Enamel samples were then covered, frozen and lyophilized for 4 h. From each sample, approximately 3 mg of enamel powder was weighed into 12 ml borosilicate glass vials and sealed with a rubber septa. Samples were then flush-filled with helium at 100 ml/min for 10-min. Following reaction with 100 % phosphoric acid, gases evolved from the samples were analysed to stable carbon and oxygen isotopic composition using a Thermo Gas Bench 2 connected to a Thermo Delta V Advantage Mass Spectrometer at the Department of Archaeology, Max Planck Institute of Geoanthropology (formerly the Max Planck Institute for the Science of Human History). Stable oxygen ( $\delta^{18}\text{O}$ ) and carbon isotope ( $\delta^{13}\text{C}$ ) values were calibrated against international standards (IAEA NBS 18, IAEA 603, IAEA CO8) registered by the International Atomic Energy Agency: IAEA NBS 18:  $\delta^{13}\text{C} - 5.014 \pm 0.032$  ‰,  $\delta^{18}\text{O} - 23.2 \pm 0.1$  ‰; IAEA 603:  $\delta^{13}\text{C} + 2.46 \pm 0.01$  ‰,  $\delta^{18}\text{O} - 2.37 \pm 0.04$  ‰; IAEA CO8:  $\delta^{13}\text{C} - 5.764 \pm 0.032$  ‰,  $\delta^{18}\text{O} - 22.7 \pm 0.2$  ‰; and USGS44:  $\delta^{13}\text{C} = \sim -42.1$  ‰. Replicate analyses of standards suggest that machine measurement error

is  $c. \pm 0.1$  ‰ for  $\delta^{13}\text{C}$  and  $\pm 0.2$  ‰ for  $\delta^{18}\text{O}$ . Overall measurement precision was studied through the measurement of repeat extracts from a bovid tooth enamel standard ( $n = 20$ ,  $\pm 0.2$  ‰ for  $\delta^{13}\text{C}$  and  $\pm 0.4$  ‰ for  $\delta^{18}\text{O}$ ). Human enamel  $\delta^{18}\text{O}_{\text{ap}}$  were converted to  $\delta^{18}\text{O}_{\text{dw}}$  following Chenery et al. (2012) and Daux et al. (2008):  $\delta^{18}\text{O}_{\text{cVSMOW}} = (1.03091 \times \delta^{18}\text{O}_{\text{ap}}) + 30.91$ ;  $\delta^{18}\text{O}_{\text{ap}} = (1.0322 \times \delta^{18}\text{O}_{\text{c}}) - 9.6849$ ;  $\delta^{18}\text{O}_{\text{dw}} = (1.590 \times \delta^{18}\text{O}_{\text{cVSMOW}}) - 48.634$ .

#### 3.4.2. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis of bone and dentine collagen

Collagen extraction and analysis were conducted in two different laboratories - the Max Planck Institute of Geoanthropology (formerly the Max Planck Institute for the Science of Human History) in Jena, Germany (samples from 56 individuals), and the University of Durham, U.K. (samples from 25 individuals). In both laboratories, a modified Longin (1971) method was used which involved decalcification using HCl, followed by solubilisation in a pH3 HCl at  $75^\circ\text{C}$  for 48 h acid solution before filtration and freeze drying for 48 h. After calculating the collagen yield, all purified collagen samples (0.5–1 mg) were weighed in tin capsules to be analysed in duplicate by the elemental analyser/continuous flow isotope ratio mass spectrometry (EA-IRMS). The accuracy was determined by measurements of international standard reference materials within each analytical run. The standards used in each laboratory, as well as the reported analytical parameters, are reported in the Supplementary Information (see S1.1 to S1.2). The atomic C:N ratio along with the collagen yields were used in order to determine the quality of collagen preservation. Collagen yields over 1 wt% were considered acceptable for carbon and nitrogen values (van Klinken, 1999), while the C:N ratio should have a range between 2.9 and 3.6 (DeNiro, 1985). Small inter-lab variations are expected (0.2 ‰ and 0.4 ‰ for  $\delta^{13}\text{C}_{\text{col}}$  and  $\delta^{15}\text{N}_{\text{col}}$  respectively) (Pestle et al., 2014), but these small differences are not expected to impact dietary interpretation (typically 1 ‰; Sealy et al. 2014).

### 3.5. Statistical analysis

Shapiro-Wilk W tests were used to determine whether the resulting data was normally distributed or not. For two samples or groups, the Mann-Whitney U pairwise test, and the parametric Student's *t* test (*t*-test) with Monte Carlo permutation, were utilised. The significance level ( $\alpha$ ) was set at 0.05. These tests were used to determine if there were significant differences based on pilgrims (individuals buried with the scallop shell) and non-pilgrims, between the biological sexes, and between teeth and ribs from the same individuals (Sup. Inf. Tab. S3 and S4). The Kruskal-Wallis *u* test for equal medians, and Mann-Whitney pairwise test with Bonferroni correction, were used to test whether there were significant variations between herbivorous and omnivorous species. Boundaries of  $\delta^{18}\text{O}_{\text{ap}}$  intra-sample variation were calculated the Tukey's inter-quartile range method (IQR) considering 1.5xIQR and 3xIQR (Lightfoot and O'Connell, 2016). The free software 'PAST' was used for all statistical analyses (Hammer et al., 2001).

## 4. Results

Fig. 2 and Table S1 display the radiocarbon results for samples dated in this study while  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ ,  $\delta^{13}\text{C}_{\text{ap}}$ , and  $\delta^{18}\text{O}_{\text{ap}}$  results for faunal and human samples can be found in Tables 1, 2, 3, S2, and S4; and in Figs. 3–6.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  and collagen quality indicators for each analysed sample, as well as the results of the statistical tests, can be found in Tables S2–S5 in the Supplementary Information, respectively. From 36 of 81 individuals, we were able to analyse two osteological samples per individual for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  analyses. In total we conducted 117  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  collagen analyses (Tables 3, and S4).

Our radiocarbon dating results provide a more accurate chronology than that offered by existing archaeological data for four of the seven sites analysed here which, together with previous radiocarbon dating studies that had already been conducted in the remaining archaeological

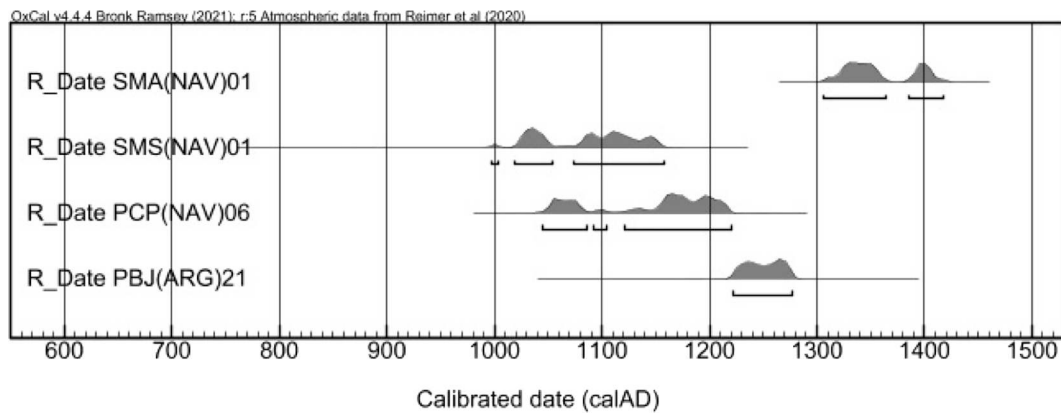


Fig. 2. Radiocarbon dating results calibrated using OxCal. v4.4 Bronk Ramsey (2021) and the IntCal13 atmospheric curve (Reimer et al., 2020). PCP(NAV): Plaza del Castillo, Pamplona; SMA(NAV): Santa María de Arlas, Peralta; SMS(NAV): Santa María de Sangüesa; PBJ(ARG): Plaza Biscós, Jaca.

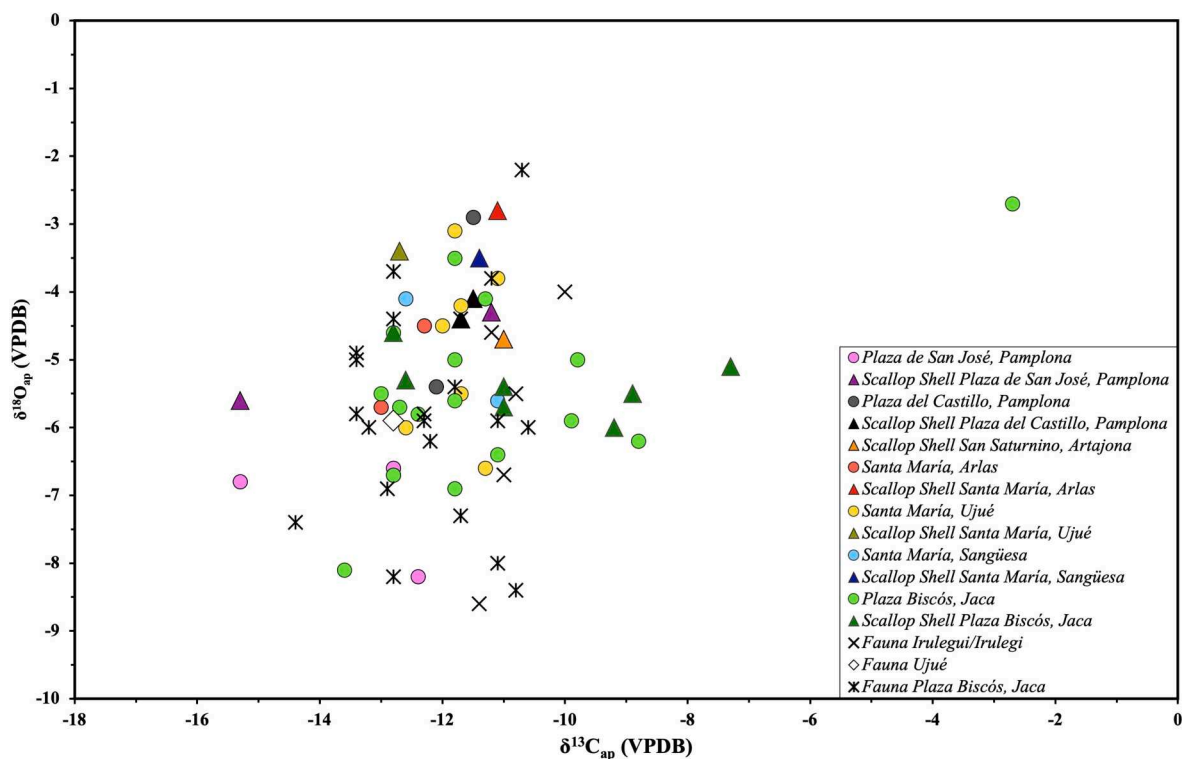


Fig. 3.  $\delta^{18}\text{O}_{\text{ap}}$  and  $\delta^{13}\text{C}_{\text{ap}}$  of archaeological fauna and human tooth enamel from the present study.

sites (Jusué Simonena et al., 2010; Pérez-Ramallo et al., 2022a), confirms that our samples span the 9th-15th centuries CE (Fig. 2, Tab. S1). Alongside the fact that the analysed sites are all from similar geographic and climatic contexts, this provides us with a solid basis for comparing our isotopic data between sites and individuals.

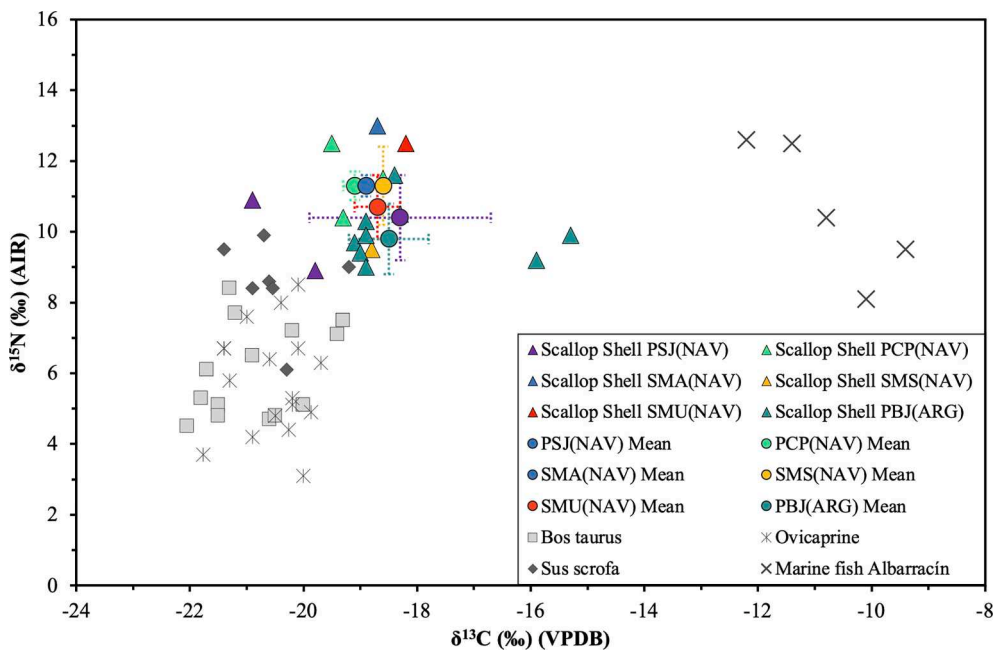
The  $\delta^{18}\text{O}_{\text{ap}}$  values of the fauna analysed ( $n = 28$ ) range between  $-8.6 \text{ ‰}$  to  $-2.2 \text{ ‰}$  (Mean  $\pm$  SD =  $-5.8 \pm 1.5 \text{ ‰}$ ) (Fig. 3, Tables 1 and S2).  $\delta^{18}\text{O}_{\text{ap}}$  values for humans ( $n = 48$ ) ranged from  $-8.2 \text{ ‰}$  to  $-2.7 \text{ ‰}$  (Mean  $\pm$  SD =  $-5.7 \pm 1.5 \text{ ‰}$ ) (Fig. 3, Tables 2 and S4). The  $\delta^{18}\text{O}_{\text{ap}}$  values by site, sex, and individuals buried with and without the scallop shell are shown in Table 3.

Stable isotope results for all analysed terrestrial fauna, together with the additional published terrestrial fauna samples from Plaza Biscós, Jaca; and Plaza San José, Pamplona (Pérez-Ramallo et al., 2022a) (Table 1 and S2; Figs. 3 and 4) ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$   $n = 37$ , and  $C_{\text{ap}}$   $n = 27$ ), range between  $3.1 \text{ ‰}$  and  $9.9 \text{ ‰}$  for  $\delta^{15}\text{N}$  (Mean  $\pm$  SD =  $6.4 \pm 1.7 \text{ ‰}$ ), between  $-22.1 \text{ ‰}$  and  $-19.2 \text{ ‰}$  for  $\delta^{13}\text{C}$  (Mean  $\pm$  SD =  $-20.7 \pm 0.7 \text{ ‰}$ ),

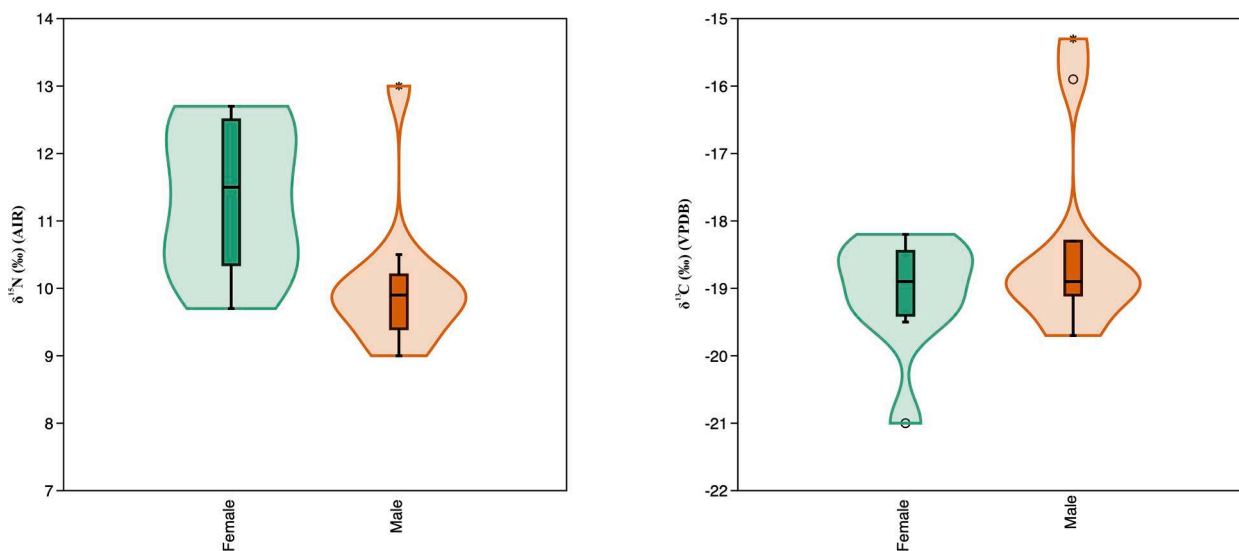
and between  $-14.4$  and  $-10.0 \text{ ‰}$  for  $\delta^{13}\text{C}_{\text{ap}}$  (Mean  $\pm$  SD =  $-12.0 \pm 1.1 \text{ ‰}$ ). The  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values by species, and between pure herbivores and omnivores, are displayed in Table 1. Statistical tests (see Table S3) demonstrate significant differences in  $\delta^{15}\text{N}$  values between herbivorous and omnivorous species, though there was no difference for  $\delta^{13}\text{C}$  and  $\delta^{13}\text{C}_{\text{ap}}$ . Comparison of herbivores between sites illustrates significant differences for  $\delta^{15}\text{N}$ , but not for  $\delta^{13}\text{C}$  and  $\delta^{13}\text{C}_{\text{ap}}$  (Table S3).

The measured human ( $n = 81$ ) (Table 2 and S4, Figs. 3 to 6)  $\delta^{15}\text{N}$  ranges between  $8.3 \text{ ‰}$  and  $13.0 \text{ ‰}$  (Mean  $\pm$  SD =  $10.3 \pm 1.1 \text{ ‰}$ ), with  $\delta^{13}\text{C}$  spanning from  $-21.0 \text{ ‰}$  to  $-15.3 \text{ ‰}$  (Mean  $\pm$  SD =  $-18.6 \pm 1.0 \text{ ‰}$ ) and  $\delta^{13}\text{C}_{\text{ap}}$  ( $n = 48$ ) between  $-15.3 \text{ ‰}$  and  $-2.7 \text{ ‰}$  (Mean  $\pm$  SD =  $-11.6 \pm 1.9 \text{ ‰}$ ). The  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values by site, sex, and for individuals buried with and without the scallop shell are presented in Table 3.

For 39 individuals, tooth dentine and rib samples were taken from the same individual for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  analyses (Tables 2, 3). Roots showed  $\delta^{15}\text{N}$  values ranging from  $8.1 \text{ ‰}$  to  $12.9 \text{ ‰}$  (Mean  $\pm$  SD =  $10.3 \pm 1.2 \text{ ‰}$ ) and  $\delta^{13}\text{C}$  between  $-20.9 \text{ ‰}$  and  $-9.1 \text{ ‰}$  (Mean  $\pm$  SD =  $-17.9 \pm$



**Fig. 4.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  of human samples from the present study based on their site of origin, the presence of the scallop shell, and fauna analysed in the present study. We added the marine and terrestrial fauna available in the literature from Plaza Biscós, Jaca (Pérez-Ramallo et al., 2022a); and Albarracín (Alexander et al. 2015). PSJ (NAV): Plaza de San José, Pamplona; PCP (NAV): Plaza del Castillo, Pamplona; SMA (NAV): Santa María de Arlas, Peralta; SMS (NAV): Santa María de Sangüesa; SMU (NAV): Santa María de Ujué; SSA: San Saturnino de Artajona; PBJ(ARG): Plaza Biscós, Jaca.



**Fig. 5.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  boxplot of human individuals buried with the scallop shell samples displayed by sex from the present study data.

2.1 ‰). Meanwhile, ribs showed  $\delta^{15}\text{N}$  values between 8.3 ‰ to 13.0 ‰ (mean and SD:  $10.3 \pm 1.2$  ‰) and  $\delta^{13}\text{C}$  values  $-21.0$  ‰ to  $-15.3$  ‰ (Mean  $\pm$  SD =  $-18.6 \pm 0.9$  ‰) (Tab. 3). While some fractionation is expected (Fahy et al., 2017), there were no significant differences between the tissues, suggesting a certain dietary stability in the populations analysed (Tab. S5). We also compared the  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  data by the estimated sex of the skeleton (dentine and ribs) and found no statistically significant differences (see Table S5).

We were able to analyse root teeth and ribs from the same individual (n = 14) between those pilgrims who were able to complete the Camino de Santiago and returned to their place of origin or perished on the way back as the scallop shell discovered in their tombs indicated (n = 20) (Table 3; Fig. 4). The statistical tests (Tab. S5) indicated significant differences between sexes among those identified as pilgrims (Fig. 5). Comparison between individuals buried with and without the scallop shell illustrated no differences in  $\delta^{15}\text{N}$ ,  $\delta^{13}\text{C}$ , and  $\delta^{13}\text{C}_{\text{ap}}$  (Fig. 6; Table S3).

## 5. Discussion

### 5.1. Radiocarbon dating

The obtained radiocarbon determinations confirm the chronology expected for most of the archaeological sites studied, providing similar chronologies to other sites from this investigation that already had previous radiocarbon dating analyses - Plaza de San José and Santa María de Ujué (Pérez-Ramallo et al., 2022a; Unzu Urmeneta et al., 2011). The consumption of marine or freshwater foodstuffs by humans can lead to issues in the interpretation of radiocarbon ages through the ‘reservoir effect’ (Fernandes et al., 2016; Makarewicz and Sealy, 2015). However, except for individuals SMA(NAV)01 ( $\delta^{15}\text{N}$  12.4 ‰ and  $\delta^{13}\text{C}$   $-19.1$  ‰), and PCP(NAV)06 ( $\delta^{15}\text{N}$  12.5 ‰ and  $\delta^{13}\text{C}$   $-19.5$  ‰), there is limited evidence for marine resource consumption in individuals selected for radiocarbon dating (Tab. S1). Besides, these results fit with the relative chronology provided by the archaeological context

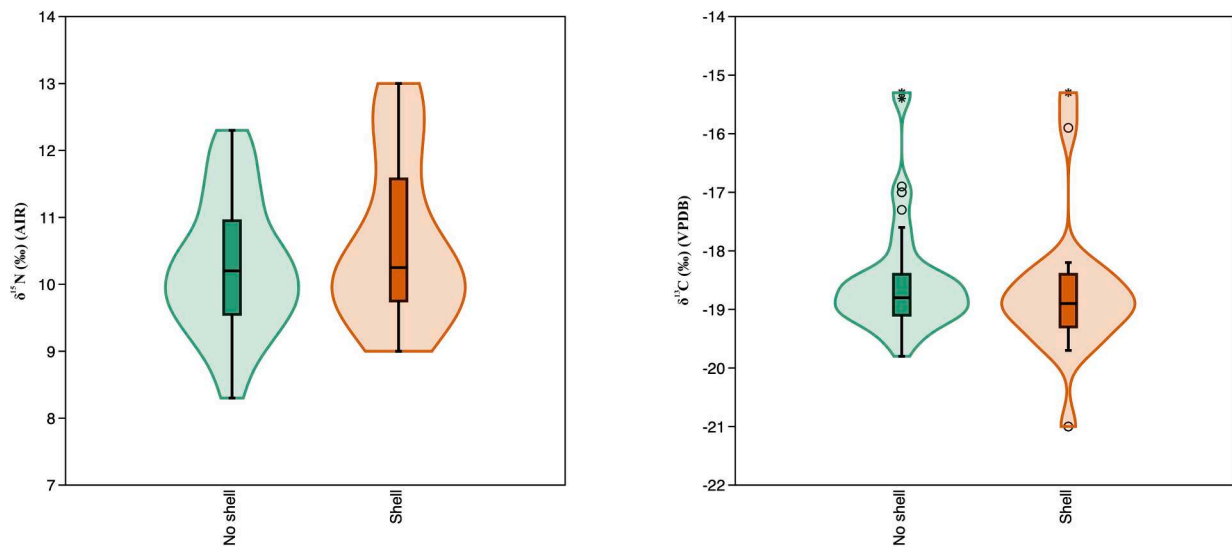


Fig. 6.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  boxplot comparison between individuals buried with ("Shell") and without the scallop shell ("No Shell") from the present study.

suggesting that major discrepancies are unlikely. Nevertheless, some marine and/or freshwater inputs cannot necessarily be discarded (Fig. 4; Table S4).

In Santa María de Ujué, two previous  $^{14}\text{C}$  dates indicated that the necropolis had two different phases of use between the 9th and 13th centuries CE, and between the 14th and 15th centuries CE (Jusué Simonena et al., 2010). In Santa María de Arlas in Peralta, our radiocarbon dating results yielded a date between the 14th and 15th centuries CE, extending the use of the place by one or two centuries beyond what had been previously estimated by archaeologists (Jusué Simonena et al., 2010; Unzu Urmeneta et al., 2011). In Santa María la Real de Sangüesa, the radiocarbon dates suggested an earlier use than previously estimated by archaeologists. It was previously estimated that the necropolis dated to between the 13th and 15th centuries CE (Mateo Pérez and Duró Cazorla, 2017). However, our results suggest its use between the 10th–12th centuries CE. We observe something similar at the Plaza del Castillo, Pamplona, where the  $^{14}\text{C}$  data indicate that the individuals analysed died between the 11th and 12th centuries CE (Jusué Simonena et al., 2010). Finally, the Plaza Biscós in Jaca is a cemetery with a continuous occupation that goes from the 11th to the 15th centuries CE (Justes Floría and Domingo Martínez, 2007). Our results partially confirm this interpretation, indicating that at least some of these individuals were buried during the 13th century CE.

The remaining individuals analysed fall between the 11th and 13th centuries CE, coinciding with the peak medieval fluorescence of the *Camino de Santiago*. Additionally, our radiocarbon dates allow us to observe that, based on our small dataset at least, the scallop shell does not seem to have been used as a pilgrims symbol before the 11th century CE. This agrees with the historical records that suggest the use of this insignia emerged in the later 11th century CE (Yeoman, 2018).

## 5.2. Geographical mobility

The  $\delta^{18}\text{O}_{\text{ap}}$  results obtained for the faunal and human individuals analysed here provide information about their origin. The  $\delta^{18}\text{O}_{\text{ap}}$  values of fauna and humans overlap, suggesting that all individuals analysed here (with and without the shell) were from the same broad geographical area or a region with a similar environment (Fig. 3; Tables 1, 2, S2, and S4). The 1.5xIQR and 3xIQR method (Lightfoot and O'Connell, 2016) did not allow us to identify any potential non-local individuals for the whole dataset. Still, until future analyses are conducted (e.g.,  $^{87}\text{Sr}/^{86}\text{Sr}$  or aDNA), we cannot discard an origin from a region with  $\delta^{18}\text{O}_{\text{ap}}$  that overlaps with our local values.

## 5.3. Diet and social status

The isotopic data from the fauna analysed illustrate diets dominated by  $\text{C}_3$  plants. As expected,  $\delta^{15}\text{N}$  differences between pure herbivores (*Bos taurus* and ovicaprids) and omnivores (*Sus scrofa*) were found. Despite the sites being relatively close, with a similar geography and climate, there are significant differences between the fauna of Jaca (Mean and SD =  $\delta^{15}\text{N}$   $5.5 \pm 1.7$  ‰, and  $\delta^{13}\text{C}$   $-20.7 \pm 0.6$  ‰) and Arlas (Mean and SD =  $\delta^{15}\text{N}$   $8.5 \pm 1.5$  ‰, and  $\delta^{13}\text{C}$   $-20.1 \pm 0.7$  ‰) (Tables 1, S2, and S3). Santa María de Arlas, which illustrates the highest  $\delta^{15}\text{N}$  values, is the southernmost town analysed. It is located next to the Arga River, a tributary of the Aragon River. Its geographical location and environment likely gave its population easy access to freshwater resources as well as crops growing in rich alluvial soils (Sesma Sesma, 1997). The use of manure from the domestic local fauna as fertilizer may also explain the elevated  $\delta^{15}\text{N}$  values (Bogaard et al., 2007). Meanwhile, other researchers, who analysed the near Islamic community of Tauste, have also suggested that their anomalously high  $\delta^{15}\text{N}$  values might be influenced, besides manuring, by the local geological substratum, and environmental conditions (Guede et al., 2017). By contrast, the fauna from Plaza Biscós in Jaca come from a higher altitude location (elevation: 820 m) (www.jaca.com), explaining the lower  $\delta^{15}\text{N}$  values (Männel et al., 2007).

Human  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values for the entire dataset (i.e., individuals with and without the shell) suggest diets mainly based on  $\text{C}_3$  foods, but with different inputs of higher trophic level foods,  $\text{C}_4$  plants (e.g., millet), and/or marine or freshwater proteins (Tables 2, 3, and S4; Figs. 3 and 4). Enamel  $\delta^{13}\text{C}_{\text{ap}}$  offers information that allows us to tentatively distinguish individuals with diets rich in  $\text{C}_4$  plants or marine and freshwater protein inputs, although the tissue reflect different periods of life (Fig. 3). In contrast to collagen  $\delta^{13}\text{C}$ , which primarily reflects the protein components of the diet, enamel  $\delta^{13}\text{C}_{\text{ap}}$  reflects inputs into the whole diet (Ambrose and Norr, 1993), meaning that low protein foods such as plants will be potentially more evident.  $\delta^{13}\text{C}$ ,  $\delta^{15}\text{N}$ , and  $\delta^{13}\text{C}_{\text{ap}}$  values from the primarily male sample set from Plaza Biscós in Jaca indicates the prevalent consumption of  $\text{C}_4$  plants, probably millet, and low animal protein inputs. In some cases, we observed important dietary variations between teeth and ribs from the same individual (PBJ(ARG)01, PBJ(ARG)02, PBJ(ARG)03, PBJ(ARG)03b) (Fig. 4; Tab. S4). We observed a variation from abundant  $\text{C}_4$  to  $\text{C}_3$  protein sources in  $\delta^{13}\text{C}$  during their lives when comparing root tooth dentine and rib collagen from the same individuals (Tab. S4). This could be a consequence of socio-economical changes involved in moving to Jaca. Interestingly,

none of the individuals with evidence for dietary variation from significant C<sub>4</sub> to C<sub>3</sub> resources during life were buried with the scallop shell (Table S4).

#### 5.4. Medieval pilgrims

The individuals buried with the scallop shell, i.e. pilgrims who completed the Camino de Santiago and returned to their place of origin or perished on the way back, had  $\delta^{15}\text{N}$  (Mean  $\pm$  SD =  $10.5 \pm 1.3$  ‰) and  $\delta^{13}\text{C}$  (Mean  $\pm$  SD =  $-18.5 \pm 1.3$  ‰) (Table 3) indicative of a heterogeneous group with diets mainly based on C<sub>3</sub> foods that differ in contributions of animal protein, and marine or C<sub>4</sub> plant inputs (Figs. 3, 4, and 6; Tables 3 and S4). At both extremes, and following the historical sources described above, we find individuals with diets typical of people from the social elite, as well as for the poor or marginalized. Individuals PCP(NAV)03, PCP(NAV)06, SMA(NAV)01, SMU(NAV)01, SSA(NAV)01, and PBJ(ARG)32 seem to have had diets with high animal and marine protein inputs based on their  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values (López-Costas et al., 2021; Pérez-Ramallo et al., 2022a,b). Four of them (PCP(NAV)06, SMA(NAV)01, SMU(NAV)01, and SSA(NAV)01), illustrate  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values closer to those observed among Iberian social elite individuals from the same period available in the literature (Jiménez-Brobeil et al., 2016; López-Costas et al., 2021; Pérez-Ramallo et al., 2022a). By contrast, we also observed two individuals with limited inputs of animal protein and with a high percentage of C<sub>4</sub> plants in their diets (PBJ(ARG)34 and PBJ(ARG)38). This, following the historical sources (Peña-Chocarro et al., 2019; Pérez-Ramallo et al., 2022a), could be reflective of poor or marginalized individuals. However, this interpretation must remain tentative until future analyses, including more individuals and archaeological sites, can confirm this picture.

Interestingly, the  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  of a number of individuals from Arlas, Ujué, Artajona and Plaza Biscós identified as pilgrims, who completed the Camino de Santiago and returned to their place of origin or perished on the way back as they were buried with the scallop shell ( $n = 6$ ), show diets with higher contributions of animal proteins than those observed in other individuals buried at the same archaeological site without the pilgrim shell (SMA(NAV)01; SMU(NAV)01, SSA(NAV)01, and PBJ(ARG)32) (Fig. 4). This is also apparent when we compare those individuals from Plaza del Castillo and Plaza de San José in Pamplona. As described above, the city of Pamplona was divided into three burghs that coexisted from the 11th century CE, but primarily between the 12th and 15th centuries CE: San Nicolás, formed by free Navarrese individuals and foreigners; San Cernín, where Frankish merchants and artisans lived; and Navarrería, that was populated mainly by local individuals (Jusué Simonena et al., 2010). Individuals from Plaza del Castillo ( $n = 7$ ) ( $\delta^{15}\text{N}$  Mean  $\pm$  SD =  $11.4 \pm 0.7$  ‰, and  $\delta^{13}\text{C}$  Mean  $\pm$  SD =  $-19.1 \pm 0.3$  ‰) represent the pilgrims who died on their way to or from Santiago de Compostela as they were found in a pilgrims hospital. By contrast, those from Plaza de San José ( $n = 7$ ) ( $\delta^{15}\text{N}$  Mean  $\pm$  SD =  $10.6 \pm 0.9$  ‰, and  $\delta^{13}\text{C}$  Mean  $\pm$  SD =  $-18.8 \pm 1.8$  ‰), were likely local individuals buried at their hometown. This, together with the observed dietary diversity among pilgrims, suggests that the improvements in shelters, hospitals, and security granted to the walkers since the 12th century CE allowed individuals with different social statuses to do the Camino (Martínez García, 2020).

Historical records show that many pilgrims were also relatively wealthy individuals who could afford the costs of pilgrimage and had the freedom to undertake the Camino de Santiago (Andrade Cernadas, 2014; Martínez García, 2020). Indeed, historical sources imply that long-distance pilgrimage, such as the Camino de Santiago, was mainly carried out by individuals with a particular social and/or economic status (Andrade Cernadas, 2014; Martínez García, 2020). At the same time, peasants, and other individuals without social or economic privileges, who comprised the majority of the Iberian population, could undertake shorter pilgrimage routes to the shrines closer to their place of residence (Andrade Cernadas, 2014). This perhaps explains the overall absence of

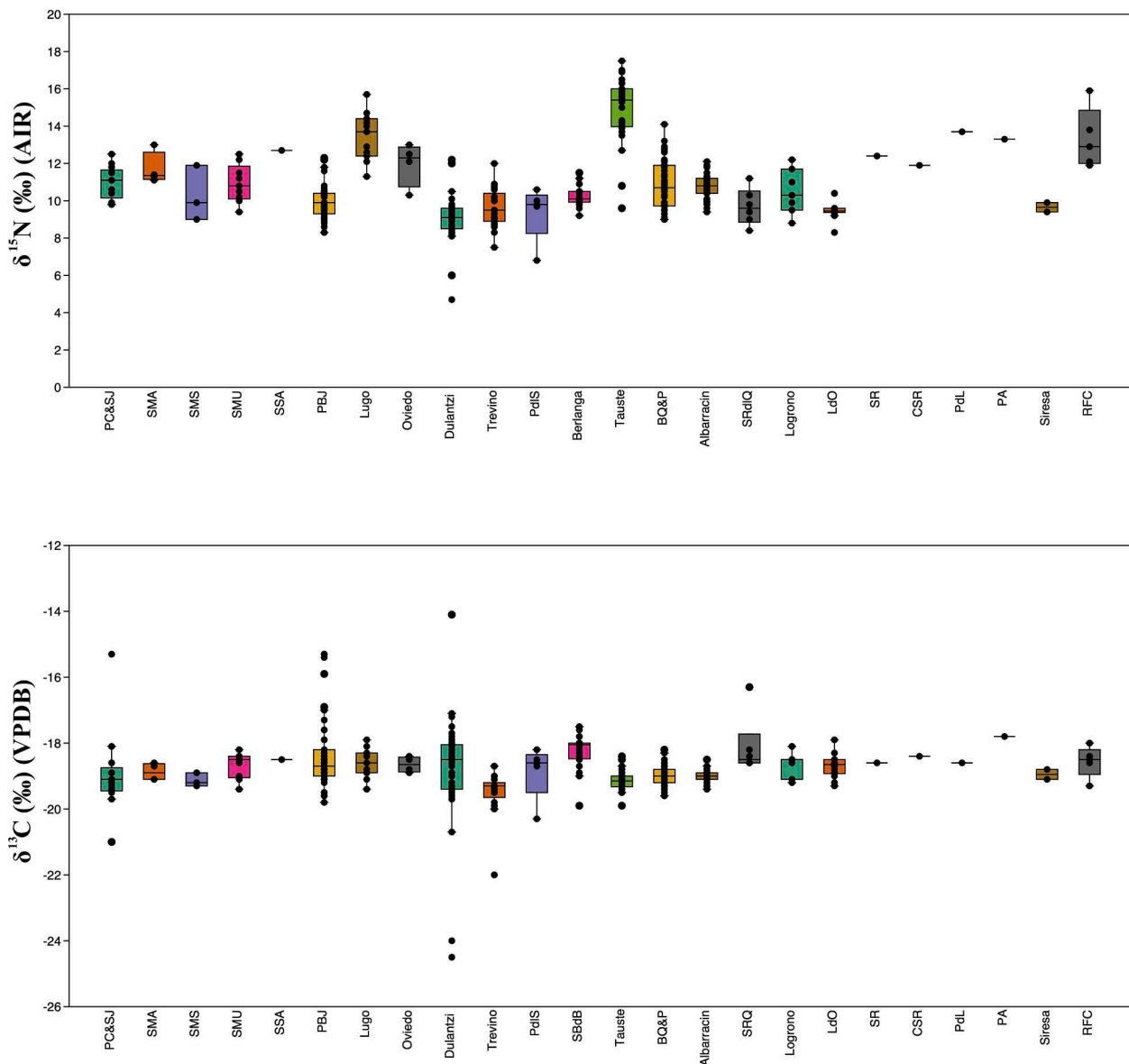
non-local individuals among the pilgrims analysed based on  $\delta^{18}\text{O}_{\text{ap}}$  and further emphasizes the importance of the Camino to local culture and the stimulation of local economies in rural and urban regions in northern Spain (Gallegos Vázquez, 2016). Interestingly, most of the pilgrims analysed here were found in urban nuclei, suggesting that this was mainly an urban phenomenon with an Iberian origin, helping to integrate the medieval Christian Kingdoms and their urban networks. However, given known issues in interpreting stable oxygen values, we must remain cautious with this interpretation given the possibility of individuals also coming from a place with a similar environment and hydrological context.

Sex dissimilarities are evident when comparing  $\delta^{15}\text{N}$  values between those individuals identified here as pilgrims due to the presence of a scallop shell ( $n = 18$ ) ( $p < 0.05$ ) (Fig. 5; Tables 3, and S5). Medieval dietary differences between sexes have previously been observed across the Iberian Peninsula (e.g., Alexander et al. 2015; Guede et al. 2017; Jiménez-Brobeil et al. 2020). In contrast to our data, dissimilarities are ascribed to male individuals who acquired larger animal protein inputs than females. However, there are also studies of northern Iberian medieval populations without significant differences between sexes (e.g., López-Costas & Müldner 2016, 2018; Lubritto et al. 2017). Our data suggest that female pilgrims had larger animal and/or fish protein inputs than male pilgrims during adulthood. Therefore, women possibly required a better socio-economic position than men to undertake the journey. Historical records illustrate that from the 11th and 13th centuries CE, the presence of women was commonly found across the Camino de Santiago as pilgrimage was one of the activities considered 'appropriate' for them (González Vázquez, 2008). This shifted between the 14th and 15th centuries with a new religious fervour that placed greater restrictions on the freedoms of women within medieval Christian society (González Vázquez, 2008). However, we cannot discard possible differences due to the place of origin since a significant part of the male pilgrims come from Plaza Biscós in Jaca. Sex differences require future research with new analyses and an increase in the number of individuals to investigate this question properly.

#### 5.5. Comparison with data from northern Iberia

All the populations analysed in the present study had the rank of towns or city thanks to the charters and privileges provided by the monarchy to its inhabitants. The connection with the Camino de Santiago, their geographical location, capital status in the case of Pamplona, or even a place of pilgrimage (Ujué) saw these centres stimulated by increasingly solidified cultural and economic networks. The urban characteristics of the populations analysed are also evident when they are compared with published urban and rural populations with a similar chronology. We undertook a broad comparison of our data with other geographically (north-northeastern of Iberia) and chronologically proximate (11th-15th centuries CE) datasets (Fig. 7; Tab. S6). Most of the rural populations such as Dulantzi (Mean and SD =  $\delta^{15}\text{N}$   $9.1 \pm 1.2$  ‰, and  $\delta^{13}\text{C}$   $-18.8 \pm 1.4$  ‰) (Castillo et al., 2013), Treviño (Mean and SD =  $\delta^{15}\text{N}$   $9.6 \pm 1.1$  ‰, and  $\delta^{13}\text{C}$   $-19.5 \pm 0.7$  ‰) (Lubritto et al., 2017), Palacios de la Sierra (Mean and SD =  $\delta^{15}\text{N}$   $9.4 \pm 1.5$  ‰, and  $\delta^{13}\text{C}$   $-18.9 \pm 0.8$  ‰) (Jiménez-Brobeil et al., 2016); San Roque de las Quintanillas (Mean and SD =  $\delta^{15}\text{N}$   $9.7 \pm 1.0$  ‰, and  $\delta^{13}\text{C}$   $-18.1 \pm 0.9$  ‰) (Pérez-Ramallo et al., 2022a), and Lobera de Onsella (Mean and SD =  $\delta^{15}\text{N}$   $9.5 \pm 0.5$  ‰, and  $\delta^{13}\text{C}$   $-18.7 \pm 0.3$  ‰) (Pérez-Ramallo et al., 2022a) demonstrate lower  $\delta^{15}\text{N}$  values than shown in our data (Mean and SD =  $\delta^{15}\text{N}$   $10.5 \pm 1.1$  ‰, and  $\delta^{13}\text{C}$   $-18.6 \pm 1.0$  ‰). However, our values are closer to those provided by Jiménez-Brobeil et al. (2020) for San Baudelio de Berlanga (Mean and SD =  $\delta^{15}\text{N}$   $10.3 \pm 0.5$  ‰, and  $\delta^{13}\text{C}$   $-18.2 \pm 0.4$  ‰). As the authors of that study suggest, these values could be a product of geological and environmental features, as well as livestock farming (Jiménez-Brobeil et al., 2020).

Comparison of our compiled dataset with other Islamic and Christian urban nuclei illustrate greater similarities in  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values:



**Fig. 7.**  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  of fauna and humans from the present study and the ‘Christian’ and ‘Muslim’ compiled literature data for the same region and period (Tab. S6). PSJ&SJ = Plaza de San José and Plaza del Castillo in Pamplona; SMA(NAV) = Santa María de Arlas, Peralta; SMS = Santa María de Sangüesa; SMU = Santa María de Ujué; SSA = San Saturnino de Artajona; PBJ = Plaza Biscós, Jaca; Lugo = Capela do Pilar, Santa María Cathedral, Lugo; Oviedo = San Salvador Cathedral, Oviedo; Dulantzi = EM Dulantzi, Alegría-Dulantzi, Álava; Treviño = Treviño, Condado de Treviño, Burgos; PdIS = Palacios de la Sierra, Burgos; SBdB = San Baudelio de Berlanga, Soria; Tauste = Tauste, Zaragoza; BQ&P = Bab al-Qibla and Predicadores, Zaragoza; Albarracín = Albarracín, Teruel; SRQ = San Roque de las Quintanillas, Burgos; Logroño = Portales, Logroño; LdO = Lobera de Onsella; SR = Saint Raymond William or San Ramón de Roda; CSR = Sancho Ramírez, Count of Ribagorza; PdL = Bishop Pedro de Librana; PA = Unknown Princess of Aragon; Siresa = San Pedro de Siresa; RFC = Castile Royal Family, Santa María de la Sede Cathedral, Seville.

Logroño (Mean and SD =  $\delta^{15}\text{N}$   $10.5 \pm 1.2$  ‰, and  $\delta^{13}\text{C}$   $-18.6 \pm 0.4$  ‰) (Pérez-Ramallo et al., 2022a), the Islamic populations of Zaragoza (Mean and SD =  $\delta^{15}\text{N}$   $10.9 \pm 1.4$  ‰, and  $\delta^{13}\text{C}$   $-19.0 \pm 0.3$  ‰), and Albarracín (Mean and SD =  $\delta^{15}\text{N}$   $10.8 \pm 0.6$  ‰, and  $\delta^{13}\text{C}$   $-19.0 \pm 0.2$  ‰) (Mundee, 2009). However, those Islamic individuals from Tauste (Mean and SD =  $\delta^{15}\text{N}$   $15.0 \pm 1.7$  ‰, and  $\delta^{13}\text{C}$   $-19.1 \pm 0.5$  ‰) (Guede et al., 2017) show higher  $\delta^{15}\text{N}$  values. This, as we observed in the fauna and individuals from Santa María de Arlas, could be a consequence of their geographical location on the banks of Ebro River, the second largest river in the Iberian Peninsula, which could grant access to freshwater resources and rich alluvial soils (Guede et al., 2017). The individuals analysed from Jaca show  $\delta^{15}\text{N}$  values lower than for other nearby Christian and Muslim urban nuclei. The fauna analysed here from Jaca also illustrate lower  $\delta^{15}\text{N}$  values in comparison with the fauna

from other location. This suggests that there may be environmental factors at play as Jaca is located at a high altitude in the Pyrenees (Fig. 1).

The palaeodietary analysis of different historical personages that belonged to the social elite illustrate  $\delta^{15}\text{N}$  higher values than are observed in our data on average: the king Pedro I of Castille and other members of the royal family buried at the Cathedral of Seville (Mean and SD =  $\delta^{15}\text{N}$   $13.3 \pm 1.5$  ‰, and  $\delta^{13}\text{C}$   $-18.6 \pm 0.5$  ‰) (Jiménez-Brobeil et al., 2016); priests from Capela do Pilar, Cathedral of Santa María, Lugo (Mean and SD =  $\delta^{15}\text{N}$   $13.6 \pm 1.3$  ‰, and  $\delta^{13}\text{C}$   $-18.6 \pm 0.5$  ‰) (Kaal et al., 2016; López-Costas et al., 2021); San Salvador Cathedral, Oviedo (Mean and SD =  $\delta^{15}\text{N}$   $12.0 \pm 1.2$  ‰, and  $\delta^{13}\text{C}$   $-18.6 \pm 0.2$  ‰) (MacKinnon et al., 2019); the historical personages analysed by Pérez-Ramallo et al. (2022a): Sancho Ramirez ( $\delta^{15}\text{N}$   $11.9$  ‰, and  $\delta^{13}\text{C}$   $-18.4$

‰), Saint Raymond William or San Ramón de Roda ( $\delta^{15}\text{N}$  12.4 ‰, and  $\delta^{13}\text{C}$  -18.6 ‰), Pedro de Librana, bishop of Zaragoza ( $\delta^{15}\text{N}$  13.7 ‰, and  $\delta^{13}\text{C}$  -18.6 ‰), and the unknown princess from the royal pantheon of San Pedro el Viejo ( $\delta^{15}\text{N}$  13.3 ‰, and  $\delta^{13}\text{C}$  -17.8 ‰). However, as described above, a significant number of pilgrims ( $n = 4$ ) (PCP(NAV)06, SMA(NAV)01, SMU(NAV)01, and SSA(NAV)01), illustrate values closer to those observed in different historical personages and/or social elite or urban populations in the published literature. Following the historical sources, the presence of individuals from the medieval social elite, such as bishops, kings, or other nobles, was frequent on the *Camino de Santiago* since the 9th century CE (Andrade Cernadas, 2014; López Alsina, 2015; Martínez García, 2020, 2004). Indeed, King Alfonso I was the very first 'pilgrim' to make the journey between 820 and 830 CE (López Alsina, 2015). It is not surprising then, that some of these 4 individuals could have been members of the social or economic elite of the populations in which they have been discovered.

## 6. Conclusions

Our results provide a small window into the experience of individuals (identified as pilgrims and non-pilgrims) living in the vicinity of, or moving along, the *Camino de Santiago* in the medieval Kingdoms of Navarre and Aragon. Our radiocarbon dating results corroborate the use of the scallop shell as a pilgrims symbol, for those who had completed the *Camino*, from at least the 11th century CE. The economic impacts of the emergence of the *Camino de Santiago* also resulted in a spatial reorganisation of the population, attracting individuals to live in many of the new urban nuclei that emerged or grew along the *Camino*.

For those individuals identified here as pilgrims on the basis of burial with a scallop shell, which was obtained once they completed the *Camino de Santiago*, none were evidently non-local on the basis of their  $\delta^{18}\text{O}_{\text{ap}}$  values. This implies that many were buried at their place of origin, or that they at least came from a geographical area with similar hydrological conditions, suggesting that pilgrimage was initially primarily a practice for populations from the northern Iberian Peninsula - although further multidisciplinary work would be needed to confirm this. In addition, our data further support that individuals from a variety of different social statuses were connected to the *Camino de Santiago*. This is consistent with the historical sources which show that improvements in infrastructure and means granted by different Iberian rulers to the *Camino de Santiago* since the 12th century CE (e.g., hospitals, shelters, and protection through military orders), allowed a greater variety of individuals with different social statuses to make the pilgrimage (Martínez García, 2020, 2004). Interestingly, most of the pilgrims documented here were found in the urban nuclei of Pamplona and Jaca, implying that pilgrimage may have been a largely urban phenomenon since at least the 11th century CE.

Without future analysis, we cannot, of course, rule out that some individuals buried *without* the shell were also pilgrims as the archaeological and historical context would suggest (e.g., the hospital for pilgrims in Plaza del Castillo, Pamplona). Interestingly, we found that almost 50 % of individuals identified as pilgrims because of the scallop shell were female, signifying that social perceptions of sex did not impede undertaking the *Camino de Santiago*. Significant differences in the diets between sexes during adulthood may, however, suggest that women generally still required a better social status to avoid social restrictions placed upon pilgrimage participation. However, even though the individuals analysed come from archaeological sites which are close in terms chronology and climate, we cannot ignore potential geographical, temporal or climatic differences (e.g., Plaza Biscos in Jaca). Further research is needed to shed light on these issues.

## 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.

## Data availability

No data was used for the research described in the article.

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## Appendix A. Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2023.103847>.

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