University of Évora

ARCHMAT
(ERASMUS MUNDUS MASTER IN ARCHaeological MATerials Science)

Mestrado em Arqueologia e Ambiente (Erasmus Mundus – ARCHMAT)

Diet and dynamic of the last Muslims in Algarve during the 12th-13th AD

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Évora, October 2019

Co-funded by the Erasmus+ Programme of the European Union

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Évora, Outubro 2019

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ABSTRACT

Diet and dynamic of the last Muslims in Algarve during the 12th-13th AD

Carbon and nitrogen stable isotope analysis was done on bone collagen from 65 human samples and 20 faunal samples originating from Loulé, south Portugal; and 38 from these were analyzed for sulfur stable isotope. The human bone samples were excavated from 2 cemeteries outside the medieval wall of the city, while the faunal bones were excavated from trash pits in the historical center of Loulé. All samples represent Muslims dating from the Almohad period (c. 12^{th}-13^{th} AD), who were probably the last persons living under Islamic rule, before the conquest of Algarve in 1249.

Faunal samples consumed a diet based mainly on C_3-plants, differences were found in the $\delta^{15}N$ values of fauna which allowed differentiation between wild and domestic animals. These diversity in values could reflect differences in animal foddering practices among the population. Results indicate that these individuals consumed a diet based on C_3-plants (wheat, barley, olives, figs, etc.) with probably some inputs of C_4-plants (sorghum and millet); and animal protein. An enrichment in $\delta^{15}N$ and $\delta^{13}C$ is seen in part of the individuals that might reflect marine protein consumption, which is supported by the $\delta^{34}S$ values obtained and the presence of fish bones in the zooarchaeological context. $\delta^{34}S$ values evidenced that diet from the individuals from both cemeteries was partly composed by non-local products, evidencing a possible trading system. Differences between diet in humans from both cemeteries was noticed. This difference may be due to social or ethnical causes.

Keywords: stable isotope analysis, diet, al-Andalus, Portugal, bone collagen

RESUMO

Dieta e dinâmica dos últimos muçulmanos no Algarve durante os séculos XII e XIII d. C.

A análise de isótopos estáveis de carbono e azoto foi feita em colágeno ósseo a partir de 65 amostras humanas e 20 amostras faunais provenientes de Loulé, no sul de Portugal; e 38 delas foram analisadas para isótopo estável de enxofre. As amostras de ossos humanos foram escavadas a partir de dois cemitérios que se encontram da muralha medieval da cidade, enquanto os ossos faunais foram escavados a partir de poços de lixo no centro histórico de Loulé. Todas as amostras representam muçulmanos que datam do período almóada (séculos XII-XIII d. C.), que foram provavelmente as últimas pessoas a viver sob o domínio islâmico, antes da conquista do Algarve em 1249.

Amostras faunais consumiram uma dieta baseada principalmente em plantas C_3, cujas diferenças foram encontradas nos valores $\delta^{15}N$ da fauna, o que permitiu diferenciar animais selvagens de domésticos. Esta diversidade de valores poderia refletir diferenças entre a população em matéria de práticas de criação de animais. No que diz respeito a humanos (individuos) os resultados indicam que estes consumiram uma dieta baseada em plantas C_3 (trigo, cevada, azeitonas, figos, entre outros) com alguma contribuição de C_4-plantas (sorgo e milho painço); e proteína animal. Um enriquecimento em $\delta^{15}N$ e $\delta^{13}C$ foi verificado em parte dos indivíduos, o que pode refletir o consumo de proteínas marinhas, que é apoiado pelos valores de $\delta^{34}S$ obtidos e pela presença de ossos de peixe no contexto zooarqueológico. Valores de $\delta^{34}S$ evidenciaram que a dieta dos indivíduos de ambos os cemitérios foi parcialmente composta por produtos não-locais, fazendo notar um possível sistema de comércio. Foram determinadas diferenças entre as dietas em humanos de ambos os cemitérios, que podem ser justificadas com base nas causas sociais ou étnicas.

Palavras-chave: análise isotópica estável, dieta, al-Andalus, Portugal, colagénio ósseo

ACKNOWLEDGEMENTS

First, I am very grateful of having this opportunity to participate in this project. I would like to thank my main supervisor, Professor Anne-France Maurer, for her expert guidance throughout the lab work, her infinite support and patience, and her constant help in solving any of my (constant) doubts throughout this thesis project, as well as Professor Cristina Dias for her continuous encouragement and inspiration, and Professor Maria João Valente, for providing the zooarchaeological materials for this thesis and for her useful suggestions. I would like to thank Professor Isabel Luzia for providing the human bone remains from both cemeteries for this thesis and for her helpful comments related to Loulé's history.

I am grateful to all the people from the HERCULES lab who were always keen to help, particularly to Pedro Barrulas who always helped me find things that I needed, even when he was busy; and Nicasio Jimenez Morillo and Vera Palma for their assistance with the IR-MS analyses.

I owe an enormous thank you to Rebecca A. MacRoberts for preparing most of the samples from Quinta da Boavista and her continual support and assistance through all this process. I would also like to thank Anna Tsoupra for helping me with the corrections of my thesis (which I sent continuously).

I am thankful to all my friends and colleagues from the 5th generation of the ARCHMAT, for their support and friendship through the duration of this Master. I am really happy that I found a new family in you.

This project would have been impossible without the support of the Erasmus ARCHMAT Master scholarship.

Now in Spanish. Quiero agradecer a mi familia que me apoyo siempre estando lejos, que quizá no llamaba mucho porque los extrañaba bastante y no quería que se dieran cuenta. A mis amigos que siempre me hicieron reír a distancia y me echaban porras para seguir adelante (los 5 de siempre, Aislinn, Luis). Y obviamente a mi novio, Alvaro Ortega (churro), quien es mi equipo y siempre me expresó su apoyo y me amó/a para poder concretar este proyecto.

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LIST OF ABBREVIATIONS

AD: Anno Domini

AIR: Ambient Inhalable Reservoir

BP: before present

C:N: carbon to nitrogen ratio

C:S: carbon to sulfur ratio

N:S: nitrogen to sulfur ratio

CAM: Crassulacean Acid Metabolism

EA-IRMS: Elemental Analyzer- Isotope Ratio Mass Spectrometry

IAEA: International Atomic Energy Agency

LHM: Loulé Hospital da Misericordia

LQB: Loulé Quinta da Boavista

OSC: Oficina do Senhor Carrilho

VCDT: Vienna Canyon Diablo Troilite

VPDB: Vienna Pee Dee Belemnite

Chapter 1. INTRODUCTION

1.1 Objectives and Research Aims

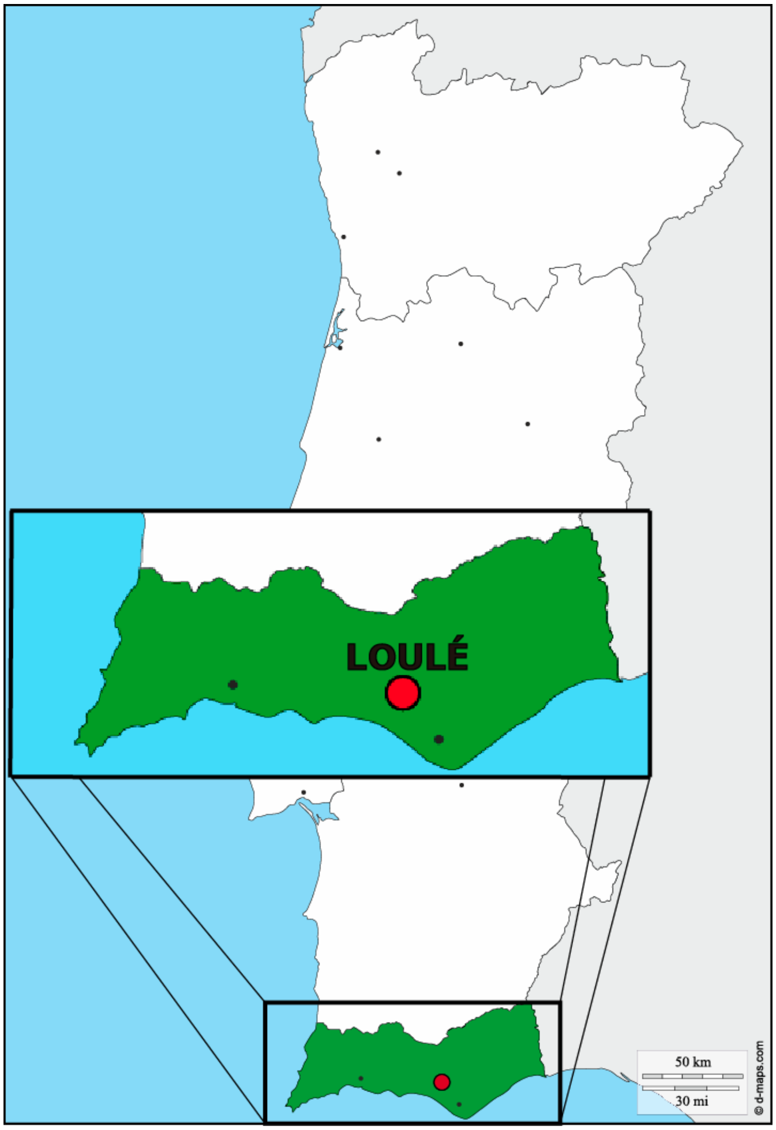


Figure 1. Map showing the Algarve in green and Loulé in red. Adapted from d-maps.com

This thesis aims to shed some light to the diet of the population from Loulé (fig. 1), Portugal; living under Islamic rule in al-Andalus period (12th – 13th AD), through a multidisciplinary approach between disciplines such as history, archaeology, anthropology and stable isotope studies, in order to better understand this practice. The al-Andalus period in the Iberian peninsula, a process of Islamization that began in 711 AD (Gonzaga, 2018) with the immigration of Arabs and Berbers defines the beginning of a period that covers more than 500 years. The written records regarding this period in Portugal is scarce, leaving a gap for the comprehension of Portugal's history (Botão, 2009). However, the small written testimony referring to diet of the individuals from this period is in regards of the privileged class, and, lamentably, little is known of the diet of the common population.

This thesis aims to obtain "part of this picture" and to explore the links between diet, social class and culture through an approach that will join the historical-anthropological sources and results derived from the analysis of the geochemical composition of medieval skeletons. This method of investigation could reveal differences in the access to food stuffs between sexes (Guede, et al., 2017), age groups and possibly, social classes (Jiménez-Brobeil, et al., 2016; Toso, et al., 2019).

Dietary habits and mobility patterns are archived in the skeleton during the life of the individuals, through the ingestion of dietary components whose specific chemical composition depends on their nature and location. Stable isotopic analysis relies on reading the different food stuffs chemical signatures left in the skeleton (Renfrew & Bahn, 2012).

This study will focus on the analysis of carbon, nitrogen and sulfur stable isotopic composition of the skeletal remains from two cemeteries in the city of Loulé, in the region of the Algarve, south of Portugal. Carbon stable isotopes will provide information on the type of plant ingested by the individuals; nitrogen, together with carbon, will supply information regarding the trophic level of the individuals, and sulfur will give information of the consumption of marine or freshwater products. Both cemeteries were used during the Almohad rule (12^{th}-13^{th} centuries) at the end of the al-Andalus in Portugal, and the individuals buried there were probably the last Muslims before the definitive conquest of the Algarve in 1249.

Some pre-hypothesis related to the diet of Muslim individuals from the al-Andalus period are that millet and sorghum -C_4 plants- were appreciated plants (Alexander, et al., 2015) and abstention from pork and shellfish (Pickard, et al., 2017).

For this master's thesis, 65 human and 20 faunal bone samples have been selected for study. The carbon and nitrogen stable isotopes analyses were conducted at the HERCULES Laboratory of the University of Évora, Portugal; and sulfur stable isotope analysis was conducted at the Faculdade de Ciências da Universidade de Lisboa (Lisbon, Portugal).

1.2 Diet and Culture

Culture can be defined as all the shared practices and beliefs of a certain group of persons; who identify themselves as part of this specific culture, and this culture shapes their identity in a symbiotic relation. Diet depends on cultural habits and can be viewed as an aggregation of localized, idiosyncratic cultural solutions to common nutritive problems, conditioned by religious, environmental, and even political spheres (Cohen, 1987). Food is used to express not only who we are but also who we wish to be (Twiss, 2007); studying the diet of a society would provide information about the identity of the consumers and how they used food for identifying themselves in a group or to differentiate from others. In the case of al-Andalus society, which, according to historical sources, was fragmented in terms of religion and ethnicity, it could be related if food was one of the forms used by the diverse religious and ethnic groups for differentiating from others, if food was used in a way of social/economical differentiation or if foodstuffs were a social differentiation tool within the same culture .

For example, in the Islamic tradition, pork is considered a prohibited foodstuff; but, why? One of the answers could be that pork was consumed by Christians and it was a form to differentiate from them. Another answer would be related to the environmental conditions: pigs tend to live near forests where they can eat nuts, but forests are scarce around the Mediterranean, so pig is prohibited by the simple fact that there is none available. If pig was limited to places close to forests, maybe they were present in small number and became expensive to the rest of the population, which were not able to buy it. This single foodstuff prohibition or food choice is embedded in a web of multiple social realities (Ross, 1987) and environmental too.

In diet related studies [Alexander, et al., 2015; Dury, et al., 2018; Curto, et al., 2019; Fuller, et al., 2010; Guede, et al., 2017; Inskip, et al., 2018; Jiménez-Brobeil, et al., 2016; Pickard, et al., 2017; Toso, et al., 2019], the investigation of all these intricated variables is required to reach accurate conclusions.

Social scientists turn to historical sources and ethnographical studies regarding the food ways of the past, which express the cultural and religious context of specific moments; however, to which extent the written sources reflect what was the reality for every individual? For example, Islam prohibits the consumption of pork, but in which degree this prohibition was fulfilled by a small population? Did the availability of certain food stuffs conditioned the diet of the individuals, or did the individuals change the environment in order to consume a certain type of dish? Was religion a strong influence for food choices or just a recommendation?

Stable isotope analysis of archaeological skeletons, when combined with ethnographical studies, historical sources and archeological, archaeobotanical and archaeozoological evidence can provide some answers to these questions. Nevertheless, it is usually not possible to differentiate between specific foodstuffs, but information on the relative importance of different food resources to diet can be obtained, and how this links to food as an identity or differentiation element.

The following chapter briefly describes the historical context of Loulé in the al-Andalus period, its geological and climatic characteristics, the religion of the population, and the information regarding diet based on the historical and ethno-anthropological sources.

Chapter 2. RESEARCH BACKGROUND

2.1 Historical Context

Loulé's history began in the 2nd century BCE with the Romanization of the south of Portugal, when the Algarve was integrated into the Roman Empire. With the foundation of the province of Lusitania, a political and administrative structure was created. Inside this structure, Loulé evolved amongst other new capitals, such as Balsa (Torre de Ares, Tavira) and Ossonoba (Faro), where Loulé was included. The Roman route, which linked the main urban nuclei, had a structuring and commercial function. Faro at that time was composed of agricultural houses, villas or villages, many of which exploited marine resources and were involved in other activities such as agriculture, mining, or weaving. The territory of Loulé was fully integrated into the vast commercial network of the Roman Empire, as evidenced by amphorae carrying food, and other ceramics coming from neighboring Bética (now Andalusia), the Italic Peninsula, Gaul, North Africa and the eastern Mediterranean (Pereira, 2017).

During the 5th century AD, there was a definite decline of the Roman Empire, with the Algarve being dominated entirely by the Visigoths. The Visigothic population did not substantially influence the pre-existing populations of the territory, but mixed their influence to the Roman ones, giving rise to some new religious, political, economic, and cultural models (Estremoz, 1994; Museu Nacional de Arqueologia, et al., 2017).

The Islamic occupation in the Iberian Peninsula began in 711, with the introduction of Muslim and Berber communities from North Africa. In the following two years the Muslim armies conquered all Spain and Portugal (including the Algarve), integrating it into the Umayyad caliphate of Damascus. When they arrived into the Algarve (Gharb), the Muslims occupied the capital of the Visigothic diocese, Ossonoba. Ossonoba maintained this name until the eleventh century, when it began to be known as Santa Maria de Faro (al Harun). The caliphate of Damascus ended in the 8th century and gave place to the Emirate of Córdoba, in which a slow Arabization and Islamization were taking place (Gonzaga, 2018; Catarino, 1997/1998). Parallel to these events, new Islamic settlements, the *alcarias* (non-fortified rural settlements) were emerging around Faro. Initially, these first alcarias would have been relatively small facilities disseminated across the best agricultural lands, later becoming developed rural centers and then, with a greater urban concentration, ascended to the category of cities, with its respective agricultural district. This seems to be the evolution of the Alcaria of Loulé, which was surrounded by old villae (Morgado de Apra, Torre de Apra, Fonte de Apra, Alfarrobeira and Fazenda do Cotovio (Palma, 2015).

The studies developed up to nowadays, mainly archaeological, do not allow to define with certainty, the date of foundation of the Alcaria of Loulé. The earliest evidence recovered so far were the ceramic materials exhumed in the convent of the Espiritu Santo that correspond to pre-Almohad chronologies, associating it with the Almoravid period (Palma, 2015).

The Almoravid period in al-Andalus began from 1091. At that time al-Andalus was extended from the south of Western Sahara to the Ebro valley and from the Atlantic coasts to the central Maghreb. The beginning of the Almoravid rule finished with the first taifa kingdoms period, which were regional power centers consequence of the rupture of the caliphate of Cordoba (Catarino, 1997/1998). The Almoravid dominion would mark a transformation in the behavior towards the *Mozarabs* (Christians who lived under Muslim rule), who were treated with more intransigence by the fanatics of Islam (Catarino, 1997/1998).

The Almoravid regime disappeared in 1147 under the beginnings of the Almohad movement. This movement was founded in the Maghreb, by a group of Berbers, the masmūda of the Moroccan High Atlas (sedentary rural population); they first expanded their territories in the Maghreb before extending their rule into al-Andalus (Guichard, 2000; Remie Constable, 1997).

Going back to the foundation of the Alcaria of Loulé, all the evidence found in the written sources seems to point out to a Muslim foundation (Botão, 2009). The earliest written reference to the city appears in the late Arab sources of the 12th, 13th and 14th centuries, as for example in the anonymous chronicle of the Marinid and in the work of Ibn Saide. The city is indicated as *madinat Al-'Ulyã*, being located to the west and northwest of Faro (Palma, 2015). The meaning of the word *Al-'Ulyã* refers to a high place, hill, or elevation, a sense that fits with the orographic configuration of the present historical center of the city of Loulé.

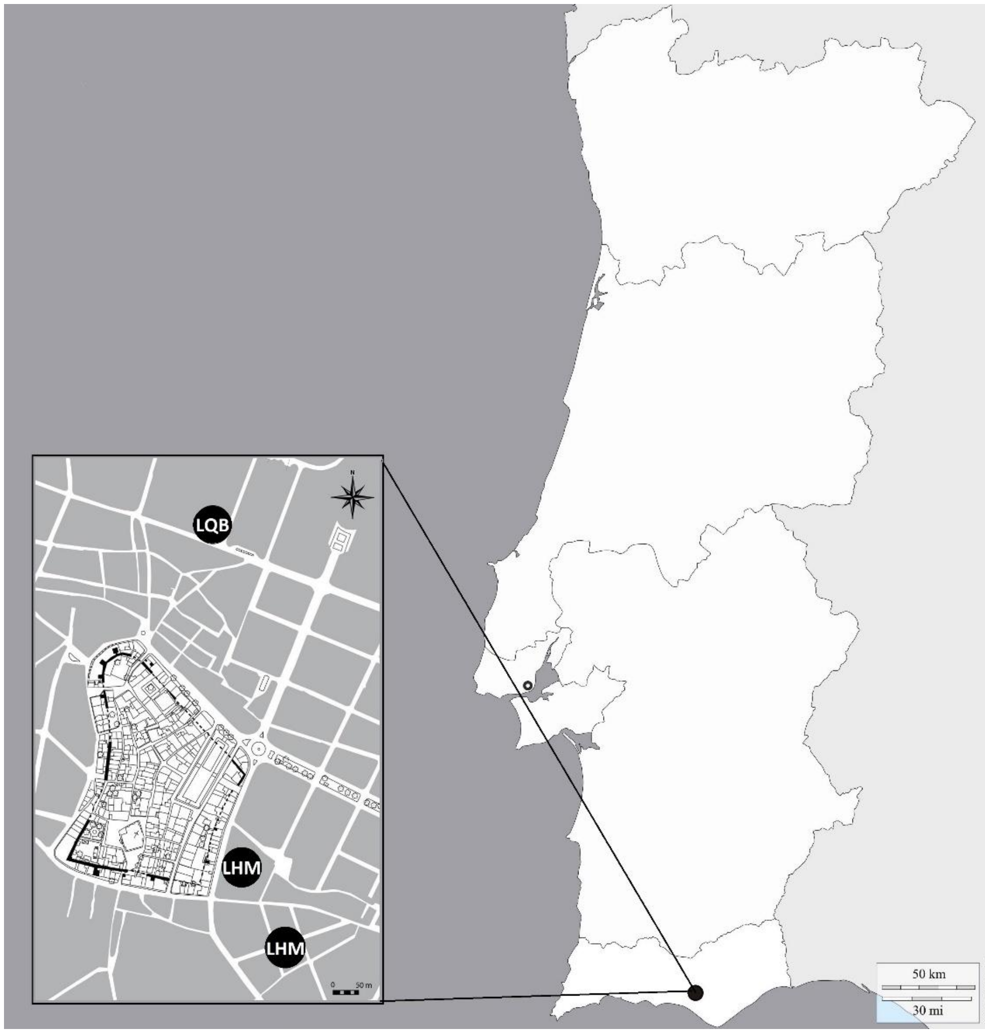


Figure 2. Map showing Loulé's medieval urban area. Black circles show the 2 Islamic cemeteries. Adapted from d-maps.com and (Pires & Luzia, 2017)

With the presence of the Almohad in the Algarve, an economic development took place throughout the 11th and 12th century that was reflected in the creation of local subunits in new agricultural districts, and in the fortifications that were actively urbanized in order to make them strategic points of defense. Great alcarias were promoted to true cities with improved defenses. Loulé followed this trend, becoming "madîna AI-'Ulyã" (city; true urban nucleus) and the headquarters of the rural district, possibly at the end of the 11th century. The expansion of this structure resulted from the need to welcome an increasing population that needed protection from the progressive military assaults resulting from the advance of the Christian Reconquista, as well as to ensure the surveillance and control of strategic points and natural passages (Palma, 2015; Botão, 2009).

When Madinat Al-'Ulyã was consolidated (fig. 2), the city became also an important administrative, civil, military and religious center, strategically positioned, acquiring a role of economic center, producer and redistributor of goods, particularly of manufactured goods, associated with agricultural techniques, art, and products of livestock (Palma, 2015). In this period were built the mosque of Loulé (actual Igreja Matriz, with oratory to São Clemente), the *hammam* (Arab baths), and the two cemeteries in the outskirts of the city (Catarino, 2017).

In this context, Loulé, one of the few Islamic-founded cities in the country (Palma, 2015), was an important urban center with a more or less vast territory with its own authority, individuality and jurisdiction, benefiting greatly from the place of implantation: important crossing of land routes, easy access to the sea, surroundings with fertile land and great abundance of water.

In the middle of the 13th century, Afonso III of Portugal, in the company of the master D. Paio Peres Correia from the Order of Santiago, advanced to Loulé in their Reconquista, whose settlement had already been prepared and provided for the siege. Despite the strong consistency of the city wall and the energetic resistance of its occupants, the Almohads and the population could not resist, succumbing to Christian rule in 1249. Supported by the Chronicle of the Conquest of the Algarve, José Garcia Domingues (Portuguese historian) says: "All that we can say is that Loulé, in time of the Arabs, was a town of some importance and, of course, played a certain role, opposing prolonged resistance upon the final conquest of the Algarve by the Portuguese". The state of calcination of the urban built structures of Al-'Ulyã highlights the devastating character of the assault on the city (Palma, 2015).

With the Reconquista, as in other cities, there were also transformations in Loulé: part of the Muslims fled to the remaining Muslim territories of Granada (Guichard, 2000), and those who stayed (who were called *Mudejares*) were relegated to outer neighborhoods (or *Mourarias*) where some accepted Christianity and others were kept by the conquerors to labor and pay tribute (which was a common arrangement in the great areas given to the religious-military Order of Santiago) (Stanislawski, 1963); there were demographic decreases and suburbs that disappeared; churches were created (São Clemente and São Sebastião), collegiate and urban and suburban convents were also created; the Mosque was replaced by the Igreja Matriz and the cemeteries became part of the intramural city; the urban fabric was altered and so, a new city emerged (Catarino, 2017).

2.2 Geology and Geography

During al-Andalus, two great geographical areas were distinguished: Sharq al-Andalus, corresponding to the eastern regions, and Garb al-Andalus, in the western territory, comprehended by the lands whose rivers flowed into the western extreme (most of the former province of Lusitania) (Catarino, 1999). The actual region of Algarve (al-Gharb, "the west" in arabic) is conformed now by a narrow stretch of land, stretching from east to west over a length of 155 km and a maximum width of 23 km. One of the region's particularities comes in part from its petrographic composition (mostly calcareous soils, favorable to the development of trees), its southern location, and its proximity to the sea that results in a singular climate and vegetation. Facing south, the region is protected from the winds of the north by the Serra Algarvia (composed by Serra de Monchique and Serra do Caldeirão), which allows the southern winds to act entirely in the region (Feio, 1983).

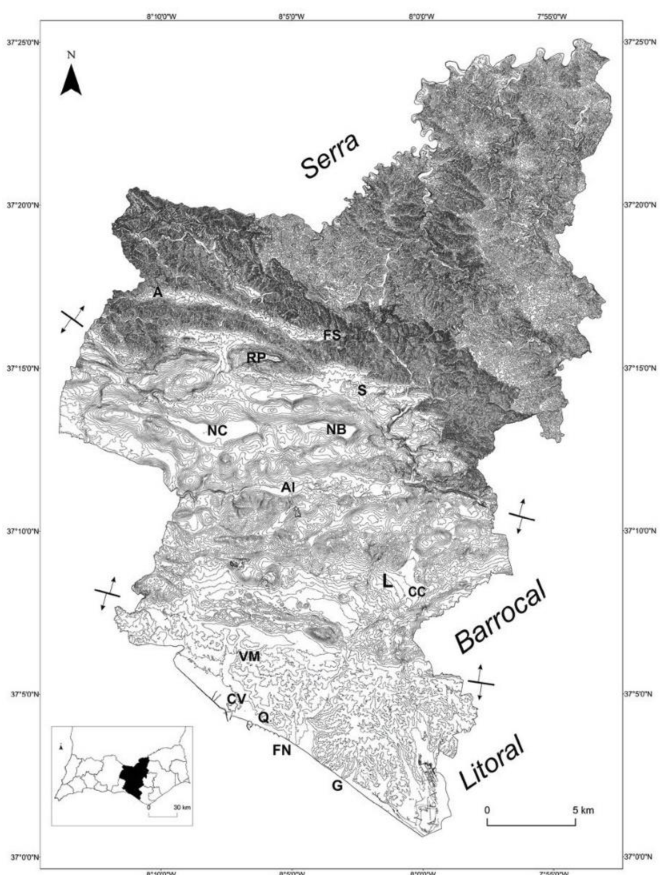


Figure 3. Map showing the sub-regions. Map by (Ramos-Pereira, 2017)

Between the Atlantic and the Serra do Caldeirão, the Algarve came to embrace a broad space that gradually conformed a region composed by the territories of Albufeira and Silves (the west), that of Almodôvar (the north), Alcoutim and Tavira (the east) and Faro (from east to southeast). To the south, in a stretch of 15 km, the coast stretched from Ludo to the Ribeira de Quarteira (along 4.5 km), and the north, conformed by the tortuosity of the high hills and deep valleys, which characterize the Serra Algarvia (Botão, 2009).

Respecting to its geological characteristics, it is formed by Mesozoic and Cenozoic deposits that cover the Iberian Massif. The "sandstones of Silves" (of red color), of the Triassic, are covered by series of Jurassic strata of extraordinary thickness, which are composed mainly of limestones and dolomites (Lautensach, 1967). In the case of Loulé, the soil consists mainly of Faro-Quarteira sands, a reddened fine sand (Oliveira, 1992).

The Algarve is divided into three natural sub-regions: Litoral (the coastline), Barrocal, and the Serra (Serra algarvia) (Feio, 1983) That can be observed in fig. 3.

The Serra sub-region is a homogeneous territory formed mainly by steep slopes, whose limit is eminently morphological: a relief dissected by the hydrographic network and the Barrocal. It consists essentially of schists and greywackes. The position of the mountainous slopes makes the Serra an easy prey for water erosion, destroying the soils that cover the slopes and forming an elongated relief that borders the Serra, dominated by calcareous plateaus and a detrital constitution (known as "Grés" de Silves) rich in nutrients that allowed the development of good soils, good for arboriculture. In the lands, which are difficult to reach and with scarce natural resources, the population is sparse and they crowd into small nuclei, as has been the case for centuries (Ramos-Pereira, 2017).

In the center of the Algarve, a central mountain range of up to 400m in relative height lays a sub-region between the schist mountains on the north and the Litoral to the south (Stanislawski, 1963). This sub-region of the Algarve is called Barrocal. Its geological constitution is very particular, it consists predominantly of Jurassic limestones elevations, which are arranged in an irregular form, called *barrocos* (Feio, 1983); also dolomites and marls are present. The calcareous nature of the soil is favorable for many evergreen trees and shrubs (Botão, 2009).

The Litoral sub-region has a regular relief marked by a smoothly inclined surface to the sea - the denominated coastal platform. This surface is carved in Cretaceous materials (limestones, marls and sandstones), partially covered by Quaternary detrital materials (Ramos-Pereira, 2017). The area along the coast is usually unproductive, although of the sandy matrix provides relatively fertile soils, widely used in vine growing (Varela Gomes, 2002). The Litoral is a good sub-region for the extraction of salt, for example the case of the saline of Castro Marim (Catarino, 1997/1998).

2.3 Climate, Flora and Fauna

A peculiar climate is the main characteristic of the regional characters produced by the extremely southern situation of the Algarve within the western periphery. This means short height of annual precipitations and a prolonged summer drought. The Algarve shares the climate of the Mediterranean, which gives the region an extremely hot and prolonged summer (Lautensach, 1967).

Throughout the year the climate is characterized by little cloudiness, good visibility, a high degree of insolation, and little wind. Rainfall comes in the late fall and in the winter months when the zone of North Atlantic fronts had spread to the south; but as the Algarve is almost at the extreme reach of these storms, they appear on relatively few days of the year and are of brief duration (Stanislawski, 1963).

The Algarve, with more or less volatile proportions over time, has been subordinated to influential geographical dominions, such as latitude, relief or proximity to the sea, factors that, existing beyond the administrative limits and historical or economic changes, do not fail to condition them (Botão, 2009).

The flora of the Algarve is conditioned by its regional climate, latitude and geology. As a result of oceanic influences, Mediterranean climatic conditions, and the calcareous nature of the soil, spontaneous formations of Mediterranean origin are common; for example: the carob tree (*Ceratonia siliqua*), which was used as food for horses, mules, cattle and rarely for men (Stanislawski, 1963; Lautensach, 1967); the saw palmetto (*Chamaerops humilis*), the oak kernel (*Quercus coccifera*), the wild olive tree (*Olea europea var oleaster*), the lentisk (*Pistacia lentiscus*), the strawberry tree (*Arbutus unedo*), many cists (*C. monspeliensis, C. albidus*, etc.), thymus, Ulex argenteus, fig (*Ficus carica*), peas, some herbs for pasture, etc. (Feio, 1983; Ribeiro, 1992). It is important to note that carob, fig, almond and olive constitute the traditional agrarian system in calcareous lands, being the carob tree the most common, followed by fig and almond trees in the case of the Algarve (Ramos-Pereira, 2017).

The coastal waters provide plants for feeding cattle and manuring. For example, the *sapeira* (*Salicornia*), a fleshy plant that is used to feed donkeys, cattle, sheep and pigs; and the cord grass (*Spartina maritima*) which is given to cattle mixed with straw. Both grow in the area of tidal oscillation and are used for farm manure. Another aquatic plant used for farm manure and bedding is the eelgrass (*Zostera marine*) (Feio, 1983; Botão, 2009).

The cereals are of low yield in the Algarve, the areas devoted to the cultivation of cereals are small and scattered, because of the climate conditions and stony soils that are interrupted by calcareous outcrops along the area (Feio, 1983). Because of these conditions, arboriculture is the most exploited activity, in means of cultivation.

During the Muslim period in the Algarve, new plants were introduced to the region, like the lemon and the bitter orange. Rice, cotton, and a type of sweet orange may also have been brought. The introduction of these new species to a not so rich soil was possible because of new irrigation systems; nevertheless, the substratum rocks of marly and detrital nature (like terra rossa, a clayey soil), particulars from the Barrocal, are good for the production of citrus fruits. It is important to mention that the Arabs who settled in the Algarve came originally from Yemen, a country with a long history of irrigation, which may have also introduced new techniques of irrigation to the Iberian peninsula (Stanislawski, 1963; Ramos-Pereira, 2017).

Regarding fauna, during the medieval period native fauna would have been much more diversified than the present one, since many species are now extinct due to changes in the vegetation cover and human predatory action. The red deer (*Cervus elaphus*) which is common in archaeological sites of the period where animal hunting was a regular activity, was present during the Middle Ages and now is extinct (Aleixo, et al., in press); the fallow deer (*Dama dama*), the European roe deer (*Capreolus capreolus*), the wild horse (*Equus caballus*) and the donkey (*Equus asinus sp.*) were also present (Varela Gomes, 2002; Aleixo, et al., in press).

The coastal fauna represented a major food resource; the intense consumption of tuna, corvina, gilt-head bream (*dourada*), shellfish and sardines was also evidenced by the analysis of faunal remains found in Loulé. Although the presence in the diet of other types of fauna was evidenced too, such as ovi-caprids, chickens and various birds (Botão, 2009).

2.4 Religion and Diet

Climate and geology influence on distinct variables such as soil, flora and fauna, but people would adjust these variables to their needs and concerns, while shaping their identity. These needs and concerns would be influenced by culture.

In Portugal's territory during the Islamic period (8th-13th CE) there was not an abruptly cut off from the socio-religious and cultural identities of late antiquity to the ones brought by the Muslims. It was a gradual transformation as the Arab and Berber populations settled in what is now the Algarve, (for example, Yemeni tribes that established in the area of Silves), while the local people started to Arabize (*Mozarabs*) and Islamize (*Muladi*), acquiring new habits of speaking, thinking, acting, living and inhabiting the spaces inherited from Antiquity (Catarino, 2017).

Islam was not only a system of belief and cult; it was also a system of state, society, law, thought and art (Lewis, 1993). Islam is governed by a set of norms that dictate various daily behaviors, such as worship, prayer, fasting and pilgrimage that require special efforts by its adherents, who would be reciprocated in the spiritual realm. Adherents also frequently have to extend these behaviors in food consumption-related practices (Mumuni, et al., 2018; Gonzaga, 2018). For example, *halal* is a concept in Islam that refers to any object or action that is permissible under Islamic principles and practices. It is one of five designations used to define the boundaries between lawful and unlawful— *fard* (compulsory), *mustahabb* (recommended), *halal* (allowed), *makruh* (disliked) and *haram* (forbidden). Of these, halal and haram are the most common in the daily lives of Muslims. Therefore, they are also widely viewed as two opposites that guide their choices, including the dietary ones, defining Muslims' food consumption norms and practices. A person who strictly adheres to the Islamic faith is expected to avoid food products that are deemed *haram* and is permitted to consume only those that are *halal*. Specifically, nine categories of food are *haram* in Islam: blood, all kinds of intoxicants, pork and products derived from pigs, carnivorous animals with fangs, birds with sharp claws (birds of prey), land animals such as frogs or snakes, permissible animals (e.g., cows, sheep, etc.) that are slaughtered without pronouncing the name of God (Allah), permissible animals killed in a manner that prevents their blood from being fully drained from their bodies and meat of permissible animals that died without being properly slaughtered (Mumuni, et al., 2018, p. 587).

Beside religious prohibitions, one of the ways in which we can get to know the diet of Muslims in al-Andalus is through the recipe books or treaties conserved of the epoch. Between the written documents we can find the *Tratado dos Alimentos*, made by *Abd Al-Malik B. Abi L-Ala Ibn Zuhr* (or Avenzoar, his latinized name) which is a manual about foods which contains guidelines for a healthy life, where diverse foods were classified by taste, utility and digestibility, based on the humorism theory (medieval medicine theory that divided meat and cereals in dry, wet, cold or hot characteristics that related to four humors: yellow bile, black bile, phlegm and blood); and the *Calendário de Córdova* written by *Ibn Zyad* (Recemundo) which described the agricultural labor that had to be carried out each month, as well as the progress and developments that each crop should follow, based on the evolution and change of the seasons; for example it is mentioned that in February "horses abound in the pastures and in the stables and feed on barley for most of the year". *La cocina hispano-magrebí según un manuscrito anónimo* (Hispanic-magrebí cuisine according to an anonymous manuscript) is a recipe book made by an anonymous author or compiler and was edited and translated by

Ambrosio Huici Miranda. Of the 500 recipes that it contains, there are more than 300 prepared with meat, being the most mentioned those of poultry, rabbit, sheep and lamb. Meat recipes are followed in numerical order by sweets, most of them prepared fried and with many nuts. Recipes made of fish are about 20, and the few remaining recipes are dishes prepared with pasta, eggs and thick soups or porridges (Marín, 2008; Nasrallah, 2007; Catarino, 1997/1998; García Sánchez, 1995).

Another source of historical information of the al-Andalus period are the *hisba* treatises; these are manuals written by the *almotacenes*, which were the "police of the markets" (souks) that watched over merchants in order to avoid possible frauds. Souks were spaces strongly linked to the economic life of the cities, they were open markets were not only food stuffs were bought, but also consumed (Guichard, 2000). These treatises not only mention the type of frauds committed in the souks, but also many of the foods that were prepared in these open-air markets, sold and consumed.

In the following paragraphs I will describe the food consumed in al-Andalus according to the previously mentioned historical sources.

Regarding meat consumption, it was considered a luxury practice in the Arab-Islamic world as well as in the medieval Christian one. It was only consumed, among the common population, on special occasions. Lamb was the most appreciated and was reserved mostly for the wealthy classes, as it was considered the best quality meat (Marín, 2008; García Sánchez, 1986). Lamb was followed by goat (easily adapted to poor and dry lands, which are abundant in the Algarve) (Telles Antunes, 1996). Oxen had a high price and, therefore, their meat was little used in food; cattle's farming was limited because of the poor environmental conditions, and it was more valuable as a labor provider, than for its meat or milk. Concerning the consumption of milk and its derivatives, Muslims preferred the milk of goat, followed by the one of sheep, cow, and finally camel. Fresh cheese constituted an excellent food, and butter was used in the preparation of various cooked meals (Catarino, 1997/1998).

Chicken was considered a complementary food, but it was also consumed, especially the one of young hens (García Sánchez, 1986). Pig was less appreciated, because of its *haram* condition; it is hard to recognize in archaeological contexts if the remains correspond to pig (domesticated) or from wild boar. Pig farming was not impossible, despite the Qur'anic precepts; but it would not be probable. The slaughtering of some wild boar might not have been a serious sin, if hunger was a major problem (Telles Antunes, 1996). Equids remains in

Al-Andalus contexts would suggest an episode (or episodes) of food shortage, because horse was not normally consumed (Telles Antunes, 1996).

In medieval times hunting was an entertainment for nobles and a solution for famine (Pimenta, et al., 2009). Hunting represents a small portion of food, for an exhaustive activity. Game meat was considered a supplement for a large part of the population and it was appreciated from an economic point of view (Telles Antunes, 1996). Between the animals that were hunted in al-Andalus were red deer, hare (also rabbit was domesticated for consumption), partridge, etc. (García Sánchez, 1986). Most of the hunting activities could have taken place in the Serra Algarvia or in the Barrocal.

The Algarve has an important littoral which provides the region with different kinds of fish. Fish was quite consumed by the popular classes of the Algarve, thanks to its abundance on the littoral; it was consumed as a substitute for meat. However, fish was a food that did not enjoy great esteem among the upper classes of al-Andalus or the Algarve, because it was considered just a complement to meat (García Sánchez, 1995). García Sánchez mentions that the rejection to fish may be of socio-religious matter, because Muslims wanted to distinguish themselves from the Christian population that consumed fish a lot in Lent (García Sánchez, 1996). When fish was consumed, it was seasoned with herbs and spices; or fried. But it could also have been dried or salted, seasoned with pickle sauce (Catarino, 1997/1998).

Cereals occupied a prominent position in the diet of al-Andalus. In the market of cereals, the most important in the souks, were sold, aside from diverse varieties of wheat, coarse grains like barley, rye, and sorghum. The main food prepared with these cereals was bread, also sold in the souks. In al-Andalus, wheat bread was eaten daily and was part of every meal; although there were different types of it, according to the variety and quality of the wheat flour used. The candeal wheat (durum wheat; *Triticum durum*), was reserved for the manufacture of luxury white bread (García Sánchez, 1995). The wealthy inhabitants of the al-Andalus were fed, generally, with wheat of excellent quality (durum wheat); but often, and especially in winter, the poor, the inhabitants of rural areas and the workers of the countryside fed on sorghum (hard), barley (that was cultivated together with wheat), millet or pulses used as bread-making cereals. These coarse grains were just eaten by the high classes when there were deficiency times (García Sánchez, 1983; García Sánchez, 1995).

During years of hunger, two types of bread were present in al-Andalus, the 'substitution bread' and the 'bread of hunger'. The first one was the one made of coarse grains, legumes or other starchy grains; and the second one was the one made with wild plants, roots, fruits, etc., that was present during famine times (García Sánchez, 1983). Another cereal used for bread-making was rice, a grass plant that Muslims acclimatized in al-Andalus (García Sánchez, 1983).

As mentioned before, the Algarve had small and scattered spaces for cereal cultivation, and an unfavorable climate for cereal growing; what made necessary to export cereals and even bread from Mértola, Serpa and Beja, via Guadiana river (Catarino, 1997/1998).

The traditional vegetable gardens (*almuinha*) where the ones that supply many of the food base products of Muslim recipes, such as onion, leek, coriander, mint, thyme, marjoram, carrots, cabbages and spinach (Botão, 2009). Almonds, figs, carob and oranges (who were introduced by the Muslims) were consumed also in al-Andalus, fresh or dry. Pulses like beans, lentils, chickpeas and peas were also predominantly consumed. The flour of these pulses used to be mixed with a small amount of flour of other cereals, like barley or wheat (García Sánchez, 1983); their consumption was part of the substitution breads that were made in hunger times or for the rural and poor populations (García Sánchez, 1995).

The consumption of olives was widely distributed in al-Andalus; it was stored in clay pots or used as oil for the preparation of the majority of the foods (Catarino, 1997/1998). Regarding spices, saffron was the most used in wealthy houses, while the other most abundant local spices and, therefore, the most commonly used at the popular level, were cumin, caraway, anise, fennel, mint, oregano, peppermint, savory, sesame, rue, and coriander (García Sánchez, 1995).

Among the al-Andalus there was a marked inclination toward sweets at all social levels. The abundance of the basic ingredients to make the sweets was within reach of all economies. These basic ingredients were, apart from honey and/or sugar, almonds and nuts (García Sánchez, 1996).

The influence of al-Andalus cuisine was really strong; some of the recipes are still prepared in the Algarve or Andalucía. After the Reconquest, despite the efforts made by the old Christians to impose their habits, the forms of food of Muslim origin remained in the Moorish world as well as in the converted one and ended up mixing with the old Christian's diet (García Sánchez, 1995).

But, to rely on a cookbook or agricultural treaty to establish general eating habits among the population of al-Andalus would be a clear mistake. We need to find more information from economical sources, archaeological and anthropological evidence (Marín, 2008).

Chapter 3. ARCHAEOLOGICAL SITES: THE TWO MAQBARAS

As it was mentioned previously, the written testimony about the Islamic period in Loulé is almost non-existent (Botão, 2009), the work in the area of Archeology is of great interest and importance for the comprehension of the history of Loulé and, in a bigger scale, of Portugal. One of the sources for information about the period are the necropolises, because mortuary practices reflect the status of individuals and correlations between status and access to resources can be evaluated (MacKinnon, 2015). In the Islamic period the necropolises were usually located beyond the limits of the cities, far from its walls, in places that were accessible and ventilated. Cemeteries grew in the outskirts of the cities, but along the main roads of communication. These set of precepts could suggest that Muslim necropolises would have occupied vast lands in the suburbs, where sometimes the presence of more than one space dedicated to the dead was common (Pires & Luzia, 2017). That is the case of Loulé, where excavations revealed the presence of two Islamic cemeteries: the cemetery of Quinta da Boavista and the cemetery of Hospital da Misericordia.

The existence of two Islamic necropolises in Loulé (fig. 4) raised the question of the chronology of both. Since the necropolis of Quinta da Boavista, identified in 1999, had been dated to the Almohad period by some ceramics found in the site, it was hypothesized that the necropolis of Hospital da Misericordia was the necropolis of the *Mouraria*, established after the

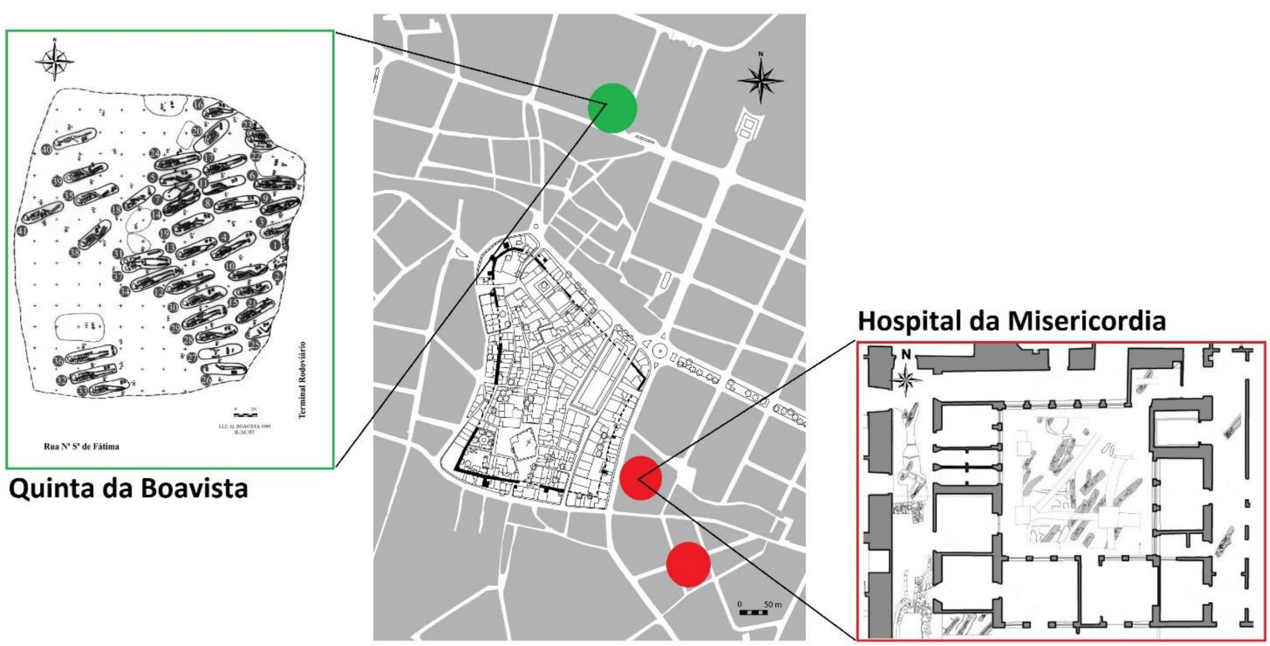


Figure 4. Map showing the two Islamic cemeteries from Loulé. Adapted from (Pires & Luzia, 2017)

Reconquista. Thus, in order to clarify the chronological question, Pires and Luzia made radiocarbon dating of three samples from each of the cemeteries, thus hoping to clarify the sequence of use of the burial sites (Pires & Luzia, 2017); Burials, from Hospital de la Misericordia, 6, 16 and 17 were chosen for radiocarbon dating (Benisse, 2009).

	Ref. Laboratório	Osso	$\Delta^{13}C$ (‰)	Idade (Anos BP)	1 sigma Cal AD	2 sigma Cal AD
Misericórdia	Sac-2502	Fémur	-19,60	940±40	1033-1054 (0,213435) 1078-1153(0,786565)	1019-1185 (1,)
	Sac-2503	Tíbia	-20,62	1000±40	989-1045 (0,756495) 1097-1119 (0,203398) 1142-1147 (0,040107)	975-1115 (1,)
	Sac-2504	Fémur	-19,03	820±40	1187-1199 (0,146346) 1206-1261 (0,853654)	1058-1072 (0,013395) 1155-1277(0,986605)
Quinta da Boavista	Sac-2505	Fémur	-17,83	870±45	1051-1082 (0,224987) 1126-1135 (0,056522) 1152-1220 (0,71849)	1041-1109 (0,267541) 1116-1257 (0,732459)
	Sac-2506	Fémur	-19,70	810±40	1193-1195 (0,01928) 1208-1267 (0,98072)	1160-1277 (1,)
	Sac-2507	Fémur Costelas	-19,78	930±40	1041-1058 (0,177307) 1064-1107 (0,432833) 1116-1155 (0,38986)	1023-1187 (0,98824) 1199-1206 (0,01176)

Figure 5. Image showing the results from the radiocarbon dating. Image took from (Pires & Luzia, 2017)

Observing the dates obtained for both necropolises (fig. 5), these seem to point to a simultaneous use of both sepulchral spaces during the Almohad period (12^{th}-13^{th}) (Pires & Luzia, 2017). This information requires new interpretations that may explain the existence of two coeval necropolises in Loulé. Is its population of different ethnic groups? thus justifying the existence of separate sepulchral spaces? Or is a matter of social status?

3.1 Cemetery of Quinta da Boavista

The terrain of the Islamic cemetery of Quinta da Boavista is located north of Loulé (fig. 6), implanted along the road connecting Loulé to Salir, which is situated on a gentle slope about 250m from one of the old gates of the city wall (Porta da Vila). Quinta da Boavista's terrain was submitted to diverse processes of purchase, sale and exchange, and subsequently a Bus Terminal was located at the opposite end of the area. At the end of 1998, the urbanization for the remaining land was approved; at that time Quinta da Boavista was a long abandoned agricultural land with large almond trees (that were once cultivated there); the works began at the end of January of 1999. During the works, human bones were exposed, and some of them were destroyed by the machinery; the Museum team, alerted about this situation, promptly took all possible and necessary steps, by immediately contacting the owners of the land in question, as well as contacting the Chamber through the Division of Culture and Historical Heritage and the I.P.A. The emergency excavation began during the month of February of 1999, were the limits of the excavation coincided with those of the area less affected by earthworks and removal of land, being restricted to about 125 m2 (Luzia, 1999/2000; Gonzaga, 2018; Pires & Luzia, 2017).

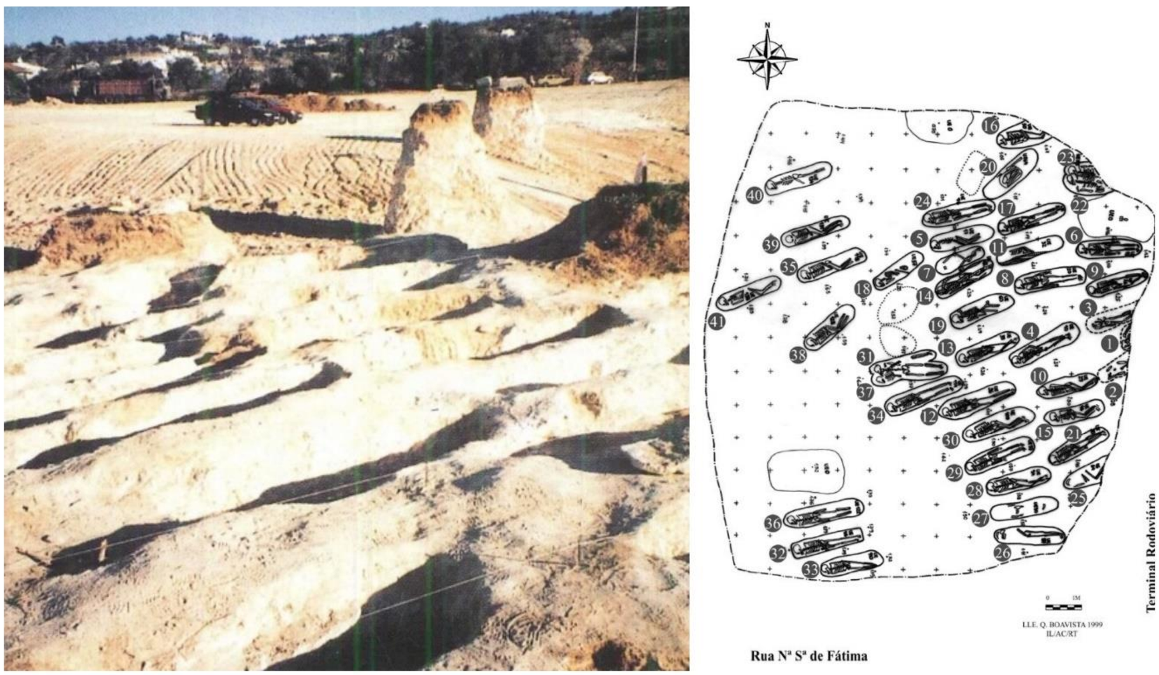


Figure 6. Figure showing the map of cemetery of Quinta da Boavista and a photo from the excavation. Adapted from (Luzia, 1999/2000; Pires & Luzia, 2017)

The works were carried out by the technical team of the Municipal Museum of Archeology. Conformed by the archaeologist Maria Isabel Correia Luzia, assisted by the museography technician Maria João Catarino, and Antonieta Canteiro, Karina Drapeau, Paula Guerreiro, Ricardina Inácio Miranda, Regina Palminha and Zélia Ponte, and the volunteer Rosária Cabrita. For the excavation, the principles described by Barker, Carandini and Harris were followed (Luzia, 1999/2000).

Despite the many constraints that the archaeological intervention had, it was possible to identify and exhume 41 human graves which showed evidence of ancient destruction, both for the work of farming and the construction of the bus station in the late 1980's. The human remains were buried in calcareous rock trenches with an average length of 1.82m, an average width of 40 cm, and an average depth of 36 cm. The trenches had a rectangular-oval shape and were oriented West (head)/ East (feet), the face of the skeletons was oriented Southeast, to Mecca and were buried with no accompanying grave goods (Luzia, 1999/2000; Gonzaga, 2018). Of the total number of burials identified, only 15 showed remnants of cover with slabs of limestone, with its spatial distribution apparently random, and the distribution of male and female individuals also random.

Between the artifacts found are numerous fragments of pottery, glass, metal and stone. The fragments of ceramics exhumed in this excavation were divided into three main groups: common ceramics, glazed ceramics and building materials. None of the ceramic remains found had a direct association with the burials, which made difficult the possibility to give a precise chronology for each burial; however, the fragments collected pointed to Almohad contexts (Luzia, 1999/2000).

The osteological vestiges were transported to Coimbra, where an anthropological study was carried out by the team of Prof. Eugénia Cunha of the Faculty of Science and Technology of the University of Coimbra (Luzia, 1999/2000). 43 skeletons were counted, 7 non-adults and 36 adults. Of the 7 non-adults, 6 were teenagers while the remainder would be a newborn (Cunha, et al., 2001).

The majority of the depositions were of primary nature, with the exception of the grave 20, which contained remains of an individual and in the center had a rectangular depression that was used as an ossuary; burial 31 was the only one with traces of two burials in one pit, it contained the skeleton of an adult woman and also bones belonging to a newborn or fetus in end of gestation (Pires & Luzia, 2017). The depositions of the bodies were in dorsal decubitus in 17 of the burials, and lateral decubitus for 10 of the burials. The extremities were extended or flexed (Cunha, et al., 2001; Departamento de Antropologia, 2000).

The 43 skeletons that compose the population sample had several degrees of preservation: preserving the entire skeleton (46.5%) or only preserving a few bones. Taphonomic alterations were common to all bones; the bone surface showed a corroded aspect, as a result of the action of the almond trees roots (fig. 7), the limestone nature of the soil combined with factors such as humidity, temperature and salinity (Cunha, et al., 2001).

Figure 7. Photo showing an almond tree root destroying one of the burials. Photo taken by (Cunha, et al., 2001)

The methodologies used to estimate the age of death of the adult individuals were: the coxal, the alterations in the auricular surface of the ilium, the metamorphosis of the pubic symphysis and the obliteration of the cranial sutures. For the non-adults, eruption and dental calcification, the length of the long bones and the appearance of the union of the epiphyses to the metaphyses were used (Departamento de Antropologia, 2000; Cunha, et al., 2001).

Several methodologies were used for the sexual diagnosis. Whenever possible, the iliac bone was used; if it was not possible, the sexual characteristics of the skull and the morphology of the jaw were used. Of the 36 adult skeletons, sexual determination was possible to concretize in 30 individuals. It was concluded that there was a small female superiority (45% female, 39% male) and in the remaining 16% of the cases the determination of sex was not possible (Pires & Luzia, 2017; Departamento de Antropologia, 2000). The mean height of men is around 165 cm (n = 9) while that of women is 149 cm (n = 7) (Cunha, et al., 2001).

The degenerative pathology was not frequent in this population; there is only a high incidence of laminar spikes. 8.6% of the individuals presented at least one cariogenic lesion; hypoplasia was frequent (Cunha, et al., 2001). There is a high incidence of a certain discrete character: the septal opening of the humerus and the recurrent absence of the fusion of the first vertebra of the sacrum (n=6) (Departamento de Antropologia, 2000).

In the burial 32 there was presence of 14 iron nails and 2 crossbow bolts (associated to the superior part of the skeleton); in burial 38, 3 crossbow bolts were found also associated to the superior part of the skeleton. Iron nails were also found in burials 12 (1 nail), 25 (3 nails), and 34 (5 nails) (Luzia, 1999/2000).

A summary of the anthropological report can be found in the Appendix 1.

3.2 Cemetery of Hospital da Misericordia

In the eastern exit of the city, in the road connecting to Faro (Avenida Marçal Pacheco), is located Hospital da Misericórdia (fig. 8), where, during the renovation of the building, a second Islamic cemetery was identified. The cemetery was placed particularly next to the old mouraria of Loulé. The burial characteristics denounced the Islamic character of this funerary nucleus with the characteristic right lateral decubitus deposition and the southwest-northeast orientation (head-feet) and individuals facing southeast (Pires & Luzia, 2017; Gonzaga, 2018).

The arrival at the site of the archeology team of the archaeology department of the municipality took place in November 2008 after the underground workings of renovation were completed in the entire northern and eastern part of the main building. During a displacement of the works made in the building, the team found that, in the opening of a trench for the installation of sewage, located near the south of the building, human osteological material had been detected. Throughout the cleaning of the trench, it was verified the existence of two cuts made in the rocky stratum, corresponding to graves. The graves were orientated southeast/ northeast and that individuals were deposited in the right lateral decubitus position with the face oriented southeast. The orientation and the type of deposition of the graves clearly indicated the presence of a necropolis according to the Islamic ritual (Pires & Luzia, 2017).The work of excavation of the contexts belonging to the necropolis took place in two distinct phases. In the first one, 12 graves were identified containing traces of 11 articulated skeletons and two secondary depositions. In the second phase, the inner courtyard of the building was excavated, where 25 graves with traces of primary burials and three ossuaries were identified (Pires & Luzia, 2017). In general, the bone pieces were poorly preserved because of the clay composition of the soil and were very susceptible to touch and handling.

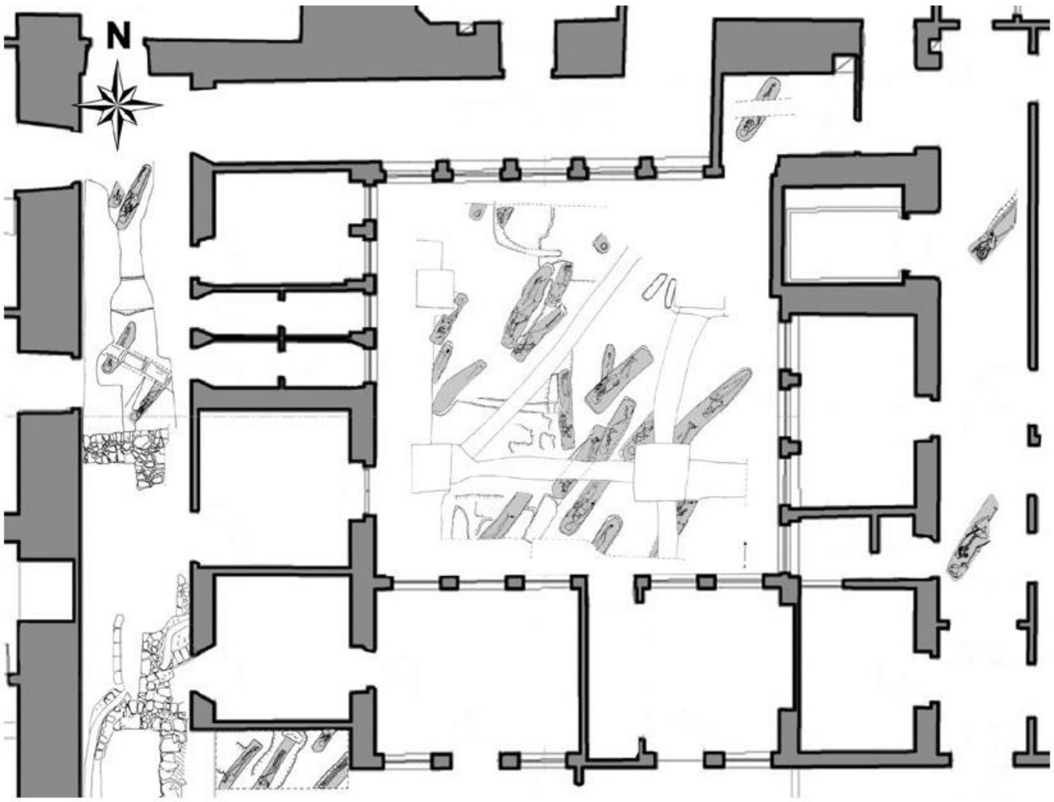


Figure 8. Map from the cemetery of Hospital da Misericordia. Image by (Pires & Luzia, 2017)

The work of biological anthropology was carried out by the anthropologist Vanda Benisse (Pires & Luzia, 2017). It was possible to identify 37 graves, containing traces of 36 primary depositions and five secondary depositions. Twenty-five primary inhumations revealed adult individuals and 11 contained non-adult individuals of different ages, from the perinatal period to adolescence. Among adults, it was possible to attribute sex to 13 individuals based on the coxal and/or cranial morphology; female (n=5), male (n=8); the sex of the remaining 12 is to be determined (Pires & Luzia, 2017; Benisse, 2009).

Between the discrete characters found in the bones, the septal opening was the most observed in a significant percentage of the individuals. Some nails were found associated with burial 34 (Benisse, 2009). A summary of the anthropological report can be found in table 22 in appendix 1.

Chapter 4. SCIENTIFIC BACKGROUND

As mentioned in the introduction, the isotopic analysis is an approach for the reconstruction of past diet. The isotopic analysis of bone collagen can reveal information about long-term food intake, as the individual's tissue reflects the isotopic composition of the consumed foods.

4.1 Bone composition and structure

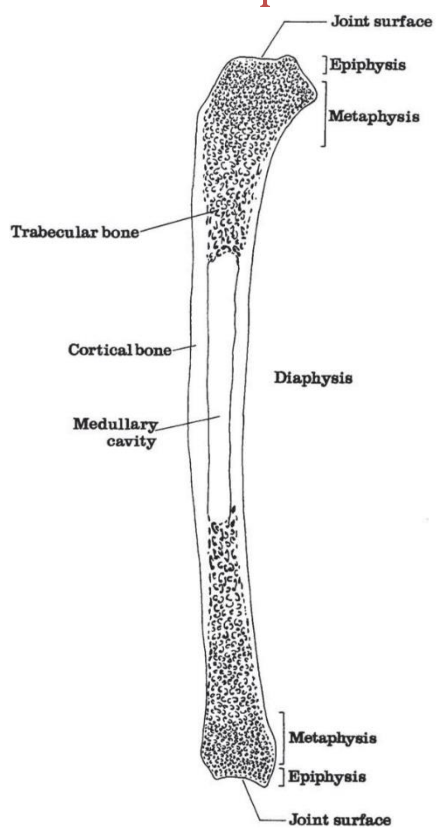


Figure 9. Long bone structure (Mays, 1998, p. 4)

Bone is the predominant material of animal origin to survive within the archaeological environment. Its study reveals considerable information to the conservator, the bone specialist and the archaeological scientist (Child, 1995).

There are 206 separate bones in the adult human skeleton. They are divided into five classes according to their basic shape: long bones (found in the limbs), flat bones (like the bones which make up the skull vault), irregular bones (which do not fit into either of the categories, for example the vertebrae), short bones (the carpals and tarsals) and sesamoid bones (found in the tendons). Bones have two basic structural components: compact and spongy bone (fig. 9). The compact or cortical bone is the solid and dense bone that is found in the walls of bone shafts and on external bone surfaces; while the spongy or trabecular bone has a more porous, lightweight, honeycomb structure, and is found under protuberances where tendons attach. The molecular and cellular compositions of compact and trabecular bone tissue are identical; it is only the difference in porosity that separates these anatomical bone types. Regarding its composition, bone is a composite material formed from an organic (≈35%) and an inorganic/mineral part (≈65%), where the organic component is mainly protein: collagen, and the mineral portion, which is embedded in a matrix of collagen fibers, is in majority carbonate hydroxyapatite, $Ca_{10}(PO_4)_6(OH)_2$ (Mays, 1998; White, et al., 2012).

The mineral component gives bone its rigidity, and the organic component gives bone its strength. Collagen type I molecules, which constitute about 90% of the organic content of bone, intertwine to form flexible, slightly elastic fibers in bone. In mature bones, the collagen is stiffened by a dense inorganic filling of the second component, hydroxyapatite. Hydroxyapatite crystals, a form of calcium phosphate, impregnate the collagen matrix of bone (Mays, 1998; White, et al., 2012; Bou-Gharios & Crombrugghe, 2008).

Collagen type I, is a structural protein that is part of the fibrillar collagens; which its characteristic feature is that they consist of a long continuous triple helix that assembles itself into highly organized fibrils. These fibrils have a very high-tensile strength, which play a key role in providing structural framework for body structures such as the skeleton, for example. Type I collagen is also the most abundant protein in vertebrates and is present in many organs. Compact and trabecular bone are formed by the deposition in layers of these collagen fibrils; in compact bone, these layers are laid down in rings around the osteon (Bou-Gharios & Crombrugghe, 2008; Child, 1995).

Bones follow different growth patterns. Growth is the process through which bone increases in size by increasing the number of cells and the intercellular material between them. The main phase of growth is completed at adulthood, but bone tissue continues to remodel or "turnover"; which involves the combined resorption of older bone and formation of new bone that occurs during normal life. Remodeling rates vary according to age and bone type; the rate of turnover is important in stable isotopic analysis, since it determines the period of dietary history analyzed; as new bone forms, it incorporates the isotopic composition of the individual’s diet (Fahy, et al., 2017).The annual turnover rate of the human skeleton was calculated from the turnover of calcium and strontium using various quantitative histological methods. Young children have high rates of turnover: 100-200% at 1 year, 10% at 3-7 years, and 1% at 8 years. Turnover during adolescence is small, while the values calculated for adults (between 20 and 60 years of age) range from 0.3 to 3%. Collagen turnover in adult bones is also slow, requiring at least 10–30 years for complete replacement. Trabecular bone turns over 3-10 times faster than cortical bone (trabecular, 10% per year; cortical, 2.5% per year) (Mays, 1998; Cox & Sealy, 1997).

However, bone remodeling rates of 10% per year is an averaged figure for the entire human skeleton, remodeling rates differ from bone to bone, because of surface to volume ratio differences in bone size and shape. Ribs, humeri and metacarpals have the highest rate of bone remodeling (Fahy, et al., 2017), they remodel completely every 5 to 10 years; whereas load-bearing bones such as the femur and tibia are thought to remodel slower, and would remodel completely every 10 to 25 years (Meier-Augenstein, 2010; MacKinnon, 2015). Although, Fahy et al. mention (2017), in their recent study, that femur and tibia have medium to high remodeling rates, while the occipital has the lowest rates (Fahy, et al., 2017).

4.2 Stable isotopes and Diet

Bone collagen is often preserved long after burial and is thus an ideal material for dietary and environmental reconstruction based on the analysis of the isotopic composition (Mays, 1998; Ambrose, 1990).

Isotopes are atoms of an element with different masses, each have the same number of electrons and protons but differ in the number of neutrons. In terms of its chemistry, an isotope behaves like other isotopes of the same element, but at a finer level, different isotopes can react at slightly different rates (DeNiro, 1987). Most elements exist as mixtures of two or more isotopes, that may be radioactive (for example carbon-14) and steadily decay, transmuting into other elements, or stable— that is, they are not radioactive and so do not change over time (Mays, 1998). The difference of neutrons of a particular element do not affect greatly its chemical properties, but adds mass to its atoms, which slows their rates of movements, chemical reaction and state transition, which cause fractionation of the isotopes, usually the lighter against the heavier isotopes of an element (Ambrose, 1993). There are two types of fractionation: equilibrium and kinetic. Equilibrium fractionation results from the differential exchange of isotopes between two physical phases that are in equilibrium with one another (Brown & Brown, 2011), for example the evaporation and condensation of water; isotopically heavy water ($^{1}H_2{}^{18}O$, atomic weight= 20) would evaporate more slowly than light water ($^{1}H_2{}^{16}O$, atomic weight= 18). Since isotopically light water molecules evaporate at a faster rate, the remaining liquid water becomes enriched in heavy isotopes (Ambrose, 1993). Kinetic fractionation occurs during a unidirectional physical or chemical reaction, that usually involves preferential reaction of the lighter isotope against the heavier ones; the reaction resultant product therefore becomes enriched for the lighter isotopes (Brown & Brown, 2011). An example of kinetic fractionation is the photosynthetic process.

Fractionation would lead to differences in the natural proportion of stable isotopes, these differences are very small, on the order of a few thousandths of a percent, but can be measured with great precision using modern instrumentation and measurement strategies

(Ambrose, 1993); for example, carbon occurs in two stable isotopes: ^{12}C and ^{13}C, the average relative abundances of these is about 98.9% and 1.1% respectively. ^{14}N and ^{15}N, the stable isotopes of nitrogen, have relative abundances of approximately 99.6% and 0.4% (Child, 1995). These small differences in isotope ratios are often difficult to contemplate and the absolute abundance of each isotope is not completely determined. Isotope geo-chemists use as a strategy the measurement of the ratio of the heavier to the lighter isotope, with references to the ratio of a standard reference material. For example, to measure the relative abundance of carbon, the standard used is the calcium carbonate in the shell of a fossil belemnite from the PeeDee Formation in South Carolina (PDB; now VPDB) and to measure the one for nitrogen, the standard is AIR (atmospheric N2). Stable isotope ratios are expressed as delta units (δ) in terms of parts per thousand ('per mil', ‰) and calculated according to the formulae below (Brown & Brown, 2011; Ambrose, 1993; DeNiro, 1987):

$$\left(\frac{\dfrac{\text{amount of } ^{13}\text{C in sample}}{\text{amount of } ^{12}\text{C in sample}}}{\dfrac{\text{amount of } ^{13}\text{C in standard}}{\text{amount of } ^{12}\text{C in standard}}} - 1 \right) \times 1000\ \text{‰}$$

Figure 10. (DeNiro, 1987, p. 182)

Isotope analysis is based on the idea that human and animal body tissues reflect the isotopic composition of the food stuffs and water ingested (Müldner & Richards, 2007; Saragoça, et al., 2016). In bones, collagen (composed by amino acids and compounds of carbon, nitrogen, hydrogen, oxygen and sulfur) is the main constituent of its organic part and is thought to survive through time because of its close association with the bone mineral phase (apatite), which protects it against enzyme attack (Child, 1995). The isotopic ratios incorporated into bone collagen derive mainly from dietary proteins, while bone apatite reflects the isotopic composition of the complete diet including carbohydrates and lipids (Saragoça, et al., 2016).

To analyze the stable isotopes from bone collagen, the collagen is extracted and purified. The resulting material is then burnt, and the gases produced are analyzed using a mass spectrometer. This gives the relative abundance of the different isotopes present in relation to the standard reference material. The majority of biological materials have less ^{13}C than the VPDB standard, so most $\delta^{13}C$ values are less than zero (negative), while most biological samples would have more ^{15}N than atmospheric nitrogen (AIR), so most $\delta^{15}N$ values would be greater than zero (DeNiro, 1987).

4.21 Carbon stable isotopes

Carbon occurs in the atmosphere as carbon dioxide with a constant ratio of $^{13}C/^{12}C$ of about 1:100. When atmospheric carbon dioxide is incorporated into plant tissues through photosynthesis, plants use relatively more ^{12}C than ^{13}C and the ratio is altered; carbon stable isotope ratios in plants vary according to the photosynthetic pathway used by the particular plant to manufacture carbohydrates from the atmospheric carbon dioxide (Mays, 1998; Renfrew & Bahn, 2012).

There are three groups of plants, based on their photosynthetic pathway: C_3, C_4 and CAM pathways. C_3 plants are the ones that fix CO_2 by the action of the enzyme ribulose bisphosphate carboxylase (RuBisCo), which involves the production of a three-carbon compound as its first step; C_3 plants are isotopically distinct from C_4 plants (O'Leary, 1988), where the mean $\delta^{13}C$ value for the first clusters around –27 to –28‰ (Mays, 1998). A more negative $\delta^{13}C$ means more ^{12}C, or lighter in mass; a more positive $\delta^{13}C$ means more ^{13}C, or heavier. Trees, shrubs, and temperate grasses are C_3 plants (most temperate zone vegetation) (O'Leary, 1988).

The C4 photosynthetic pathway is the one in which CO_2 is initially taken up through carboxylation of phosphoenolpyruvate, involving the creation of a four-carbon compound as the first step. C4 plants have $\delta^{13}C$ values of approximately -14‰ (O'Leary, 1988). The plants from tropical and sub-tropical areas (maize, millet, and sugar cane, for example) adapted to conditions of high temperature and high light intensity, use this photosynthetic pathway (Mays, 1998).

The CAM pathway is the one of desert plants and other succulents. They absorb CO_2 by the pathway known as Crassulacean acid metabolism (CAM). At night, these plants open their stomates and absorb CO_2 in order to synthesize malic acid by use of phosphoenolpyruvate carboxylase and malate dehydrogenase in a process similar to that seen in C_4 plants. These plants accumulate high levels of malic acid overnight. During the following morning, stomates close and this malic acid is decarboxylated. The CO_2 thus formed is taken up by RuBisCo in a process like the one in the bundle sheath cells of C_4 plants. Most often $\delta^{13}C$ values for CAM plants are in the range -10 to -20‰ (O'Leary, 1988, p. 331).

Carbon in marine environments derives from dissolved bicarbonate, which is enriched in ^{13}C compared with atmospheric carbon dioxide. Marine plants and plankton (which are mainly C_3) therefore have less negative $\delta^{13}C$ values than terrestrial C_3 plants (Mays, 1998), on average about 7.5‰ less negative than those of terrestrial C_3 plants (DeNiro, 1987).

As animals eat plants, the three different ratios of the plants photosynthetic pathways are passed along the food chain and are eventually fixed in human and animal bone collagen. The ratio found in bone collagen by means of a mass spectrometer, thus has a direct relation to that in the plants that constituted the main foods of the consumer. The ratios can show then whether diet was based on land or marine plants, and whether on C_3 or C_4 land plants (fig. 11). Only archaeological evidence, (plants and animals macroremains and microremains), can provide more detail about which species of plants or animals contributed to the diet by help of archaeobotanical studies and zooarchaeology (Renfrew & Bahn, 2012).

It is important to mention that since the Industrial Revolution, the burning of fossil fuels has made the delta value of atmospheric carbon dioxide about 1.5‰ more negative. Because carbon in terrestrial food chains ultimately derives from atmospheric carbon dioxide, to estimate $\delta^{13}C$ values for terrestrial foods in antiquity about 1.5‰ needs to be added to modern figures (Mays, 1998).

4.22 Nitrogen stable isotopes

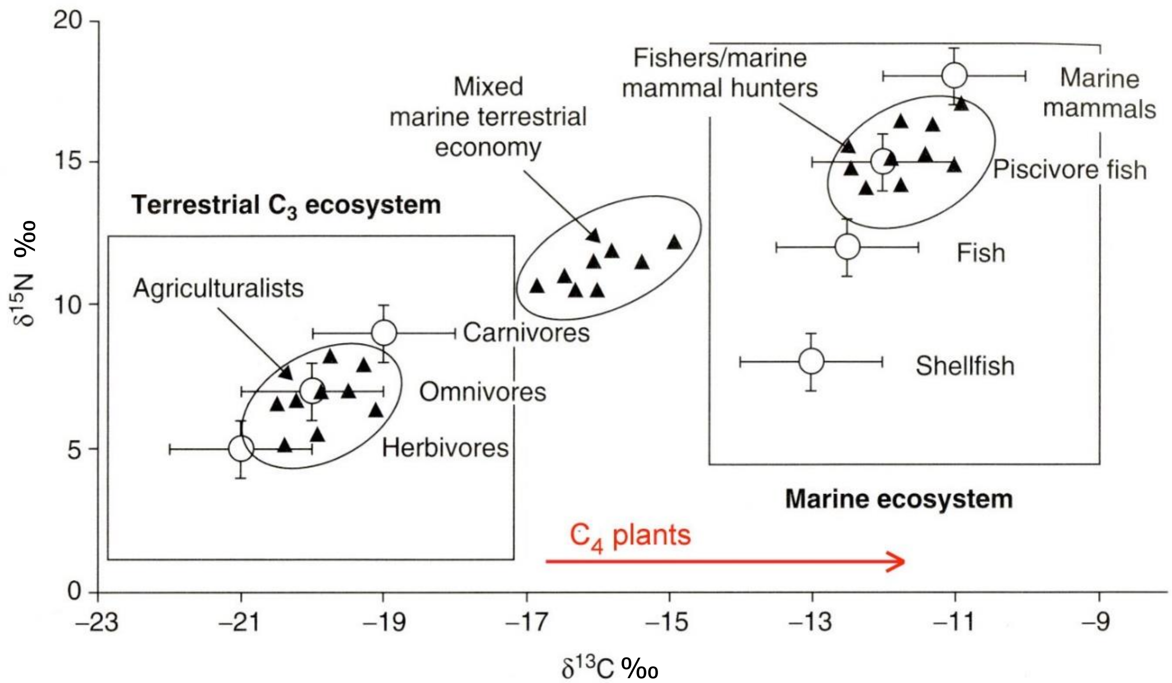


Figure 11. Figure depicting trophic levels by (Mundee, 2010)

As with carbon, the isotope ratios of nitrogen divide terrestrial plants into two groups: non-legumes, which rely on soil nitrogen since they cannot fix N_2; and legumes, which use both atmospheric N_2 and nitrate and ammonium ions in soil as nitrogen sources (DeNiro, 1987). The $\delta^{15}N$ values for leguminous plants lie between 0 and +4, for other plants they are about + 5‰. Unlike CO_2, the delta value for atmospheric nitrogen (which is 0‰) appears to have remained unchanged. Factors which affect the precise $\delta^{15}N$ values of plants include temperature, altitude, rainfall, the salinity of the soil, and the application of natural fertilizers (Mays, 1998).

The $\delta^{15}N$ value of animal tissues are determined by the $^{15}N/^{14}N$ ratios of their diets. Diet nitrogen isotope ratios ultimately depend on the $\delta^{15}N$ values of plants at the base of the food chain. Marine plants have higher $\delta^{15}N$ values than terrestrial plants because of the dissolved nitrates in seawater, which provide a major nitrogen source for them, and this difference in ^{15}N content is carried up in food chains, causing marine animals to have higher $\delta^{15}N$ values than terrestrial animals (marine fish have $\delta^{15}N$ values of about +11 to + 16‰, and marine mammals of about +11 to +23‰.) (see fig. 11). In both the terrestrial and marine environments, there is enrichment of ^{15}N as nitrogen passes from the trophic level of the producer (the plant) to that of the consumer; $\delta^{15}N$ values of animal tissues are 3-5‰ more positive than those of their diet. Consequently, $\delta^{15}N$ values of human bone collagen that fed on marine food sources should thus be higher than those of peoples subsisting on terrestrial food sources. In short, stable nitrogen isotopes can be used for reconstructing the relative amounts of marine and terrestrial food sources in historical human diets (Schoeninger, et al., 1983; DeNiro, 1987; Mays, 1998).

Therefore, there is an increase in $\delta^{15}N$ as one ascends a food chain from plants to animals (fig. 11). A low ratio of ^{15}N to ^{14}N points to an agricultural subsistence, while a high ratio points to a marine diet. However, there is an anomaly caused by coral reef resources such as shellfish, which give a low nitrogen value because of the way nitrogen is fixed by plants in reefs. Thus, in cases where a seafood diet seems likely, the carbon isotope method needs to be employed for confirmation (Renfrew & Bahn, 2012; Mays, 1998).

Elevated $\delta^{15}N$ values recorded in human bone may be attributed to the consumption of marine and freshwater foods; however, it may also be an indicator of cultural practices surrounding animal grazing and crop fertilization. Elevated nitrogen levels in humans may indicate consumption of grazing animals raised on plants grown in salt marsh environments or may be a byproduct of manuring. High $\delta^{15}N$ values in animal manure are the result of the preferential loss of ^{14}N as volatile gaseous ammonia that leaves behind manure relatively enriched in ^{15}N; this ammonium is subsequently converted to nitrate with high $\delta^{15}N$, which is then taken up by plants that use it as a source of nitrogen for the biosynthesis of plant amino acids, that eventually will end up in the bone collagen of the consumer (Bogaard, et al., 2007; MacKinnon, 2015).

The combination of $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen separates marine feeders from terrestrial ones. In addition, $\delta^{15}N$ values show an increase of 3-5‰ at each trophic step in both the marine and the terrestrial environment; while the $\delta^{13}C$ values of marine animals are about 5‰ more positive than those of terrestrial animals living in temperate habitats (DeNiro, 1987).

4.23 Sulfur stable isotopes

As discussed for carbon and nitrogen, sulfur isotope signatures of animal or human tissue can be understood as a reflection of the sulfur isotopic composition of their consumed diet. Sulphur has four stable isotopes: ^{32}S (95.02%), ^{33}S (0.75%), ^{34}S (4.21%), and ^{36}S (0.02%). The ratio between the two most abundant isotopes, ^{32}S and ^{34}S is defined as the $\delta^{34}S$ value which is measured relative to the meteorite standard Canyon Diablo Troilite (FeS) found in a meteor crater near Flagstaff, Arizona (now is used the Vienna CDT, VCDT) (Meier-Augenstein, 2010; Richards, et al., 2003).

Plants receive most of their sulfur through their roots as sulphate, which is derived from the weathering of local geological formations (bedrock); other source of sulfur is microbiological activity. Plants can also obtain sulfur from the atmosphere by wet deposition (the incorporation of sulfur falling to earth in water droplets from sea spray or acid rain (H_2SO_4)) or dry deposition (the uptake of SO_2 gas). Once sulfur is obtained by the plant, most of it is stored in organic molecules such as amino acids and sulphate esters. The $\delta^{34}S$ value of plants is variable depending upon location and geology, with values falling between the extremes of −22 to +22‰ (Richards, et al., 2003). (see fig. 12)

In modern and archaeological bone, sulfur is distributed throughout the inorganic matrix as calcium sulphate ($CaSO_4$) and within the protein collagen as methionine with a frequency of five residues per 1000 (Richards, et al., 2003).

The $\delta^{34}S$ values of plant and animals from freshwater environments and marine environments are significantly different; marine organisms have $\delta^{34}S$ values close to +20‰ whereas freshwater organisms can have a wide range of $\delta^{34}S$ values, between −22 to +22‰. Terrestrial animals and birds have values less than +10‰ whereas mammals from more marine environments have values ranging between +16 and +18‰. Given the aforementioned differences between marine, freshwater and terrestrial $\delta^{34}S$ values, with the help of sulfur isotope analysis of animal or human tissue it is potentially possible to distinguish between freshwater/terrestrial or marine dietary sources (Richards, et al., 2003; Meier-Augenstein, 2010).

$\delta^{34}S$ values do not necessarily reflect consumption of marine protein, as they can also register the proximity of the dietary protein source to the sea. This is a result of the so-called 'sea spray effect', which can carry sulfur particles inland and cause the coastal soil $\delta^{34}S$ values to be similar to those of the ocean (Richards, et al., 2003).

In order to help distinguish between the consumption of marine resources and proximity to the ocean in an archaeological population, $\delta^{13}C$ and $\delta^{15}N$ measurements must be made in conjunction with $\delta^{34}S$ values (Richards, et al., 2003).

Sulfur stable isotope analysis was not as common as the nitrogen and carbon stable isotope analysis because it used to require a relatively large sample amount (due to its low relative abundance in organic compounds), but now the analysis can be made with 10mg (Meier-Augenstein, 2010).

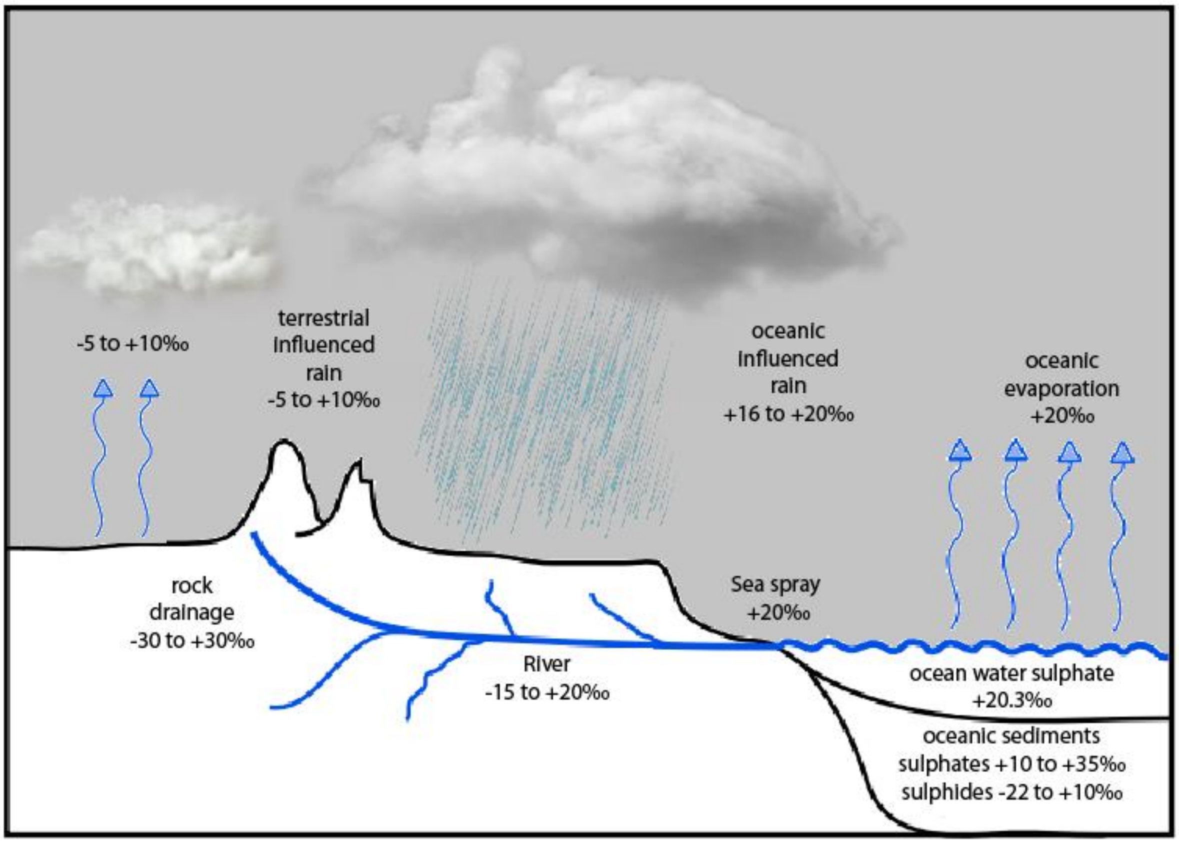


Figure 12. Schematic overview of the cycling of sulphur and its expected sulphur isotope values within the environment. Adapted from (Nehlich, 2015)

Chapter 5. MATERIALS AND METHODS

5.1 Materials

Stable isotope analysis of faunal remains from the same region and same period of the human bone samples is valuable for establishing a baseline to compare with human values and to explore animal husbandry practices. Faunal samples from the trash pits of Oficina do Senhor Carrilho (Loulé) dating from the Almohad period, previously studied by the zooarcheologists Patricia Aleixo and Maria João Valente from the University of Algarve were analyzed for establishing a dietary baseline. The faunal remains found inside these pits were characterized by the presence of skeletal parts with high meat value and anthropic cut-marks, which denounce the eminently alimentary nature of the content. The most common species in the pits were rabbit (*Oryctolagus cuniculus*), followed by red deer (*Cervus elaphus*) and ovicaprids (goat, *Capra hircus* and sheep, *Ovis aries*); other identified taxa in order of abundance were equines (*Equus sp.*) and pig or wild boar (*Sus sp*.) (Aleixo, et al., in press).

3 chickens (*Gallus gallus)*, 1 pig or wild boar (*Sus sp.)*, 6 rabbits (*Oryctolagus cuniculus)*, 2 equines (*Equus sp*.), 5 red deer (*Cervus elaphus)*, 3 sheep/goat (*Ovis aries/Capra hircus)* from the 5 and 7 stratigraphic unit were collected for analysis. All specimens were mature. The bones samples were from long bones (femur and humerus) and phalanges (all samples can be seen in *Table 1*). Photos from the samples can be found in Appendix 2.

Table 1. Faunal samples from Oficina do Senhor Carrilho (OSC)

Faunal samples. Oficina do Senhor Carrilho (OSC)		
SAMPLE NUMBER	**TAXONOMY**	**ELEMENT**
OSC 8	Oryctolagus cuniculus	Femur
OSC 9	Gallus gallus dom.	Humerus
OSC 10	Gallus gallus dom.	Humerus
OSC 13	Gallus gallus dom.	Femur
OSC 14	Ovis aries/Capra hircus	phalanx 3
OSC 16	Ovis aries/Capra hircus	phalanx 1
OSC 17	Ovis aries/Capra hircus	phalanx 1
OSC 21	Cervus elaphus	phalanx 3
OSC 22	Cervus elaphus	phalanx 3
OSC 23	Cervus elaphus	phalanx 1
OSC 24	Cervus elaphus	phalanx 2
OSC 25	Cervus elaphus	Metatarsus
OSC 26	Oryctolagus cuniculus	Femur
OSC 27	Oryctolagus cuniculus	Femur
OSC 28	Oryctolagus cuniculus	Femur
OSC 29	Oryctolagus cuniculus	Humerus
OSC 30	Oryctolagus cuniculus	Humerus
OSC 31	Equus sp.	Metacarpus
OSC 32	Equus sp.	Metatarsus
OSC 33	Sus sp.	Phalanx

Human bone samples derived from adult and sub-adult individuals from the Islamic necropolises of Quinta da Boavista (appendix 2) and Hospital da Misericordia (fig. 24, appendix 2), in Loulé; from the Almohad period (12^{th}-13^{th} CE). 42 individuals from Quinta da Boavista were sampled (*table 2*), and 23 individuals from Hospital da Misericordia (*table 3*). Samples were made preferentially from long bones (femur, humerus, tibia, and ulna) because of its high proportion of cortical bone.

Table 2. Human bone samples from the cemetery of Quinta da Boavista, Loulé

Human bone samples. Loulé Quinta da Boavista (LQB)			
SAMPLE NUMBER	**SEX**	**AGE GROUP**	**ELEMENT**
LQB 1	Male	Adult	Humerus
LQB 2	Female	Adult	Femur
LQB 3	Male	Adult	Femur
LQB 4	Male	Adult	Femur
LQB 5	Male	Adult	Femur
LQB 6	Male	?	Tibia
LQB 7	Male	?	Femur
LQB 8	Female	Adult	Fémur
LQB 9	Female	Adult	Fémur
LQB 10	Female	Adult	Fémur
LQB 11	?	Subadult	Fémur
LQB 12	Male	Adult	Fémur
LQB 13	Female	Adult	Fémur
LQB 14	Male	Adult	Fémur
LQB 15	?	Adult	Fémur
LQB 16	Female	Adult	humerus
LQB 17	Female	Adult	Fémur
LQB 18	Male	Adult	Fémur
LQB 19	?	Adult	Fémur
LQB 20	?	Subadult	Fémur
LQB 20ª	?	Adult	Fémur
LQB 21	Male	Adult	Fémur
LQB 22	?	Adult	humerus
LQB 23	Female	Adult	humerus
LQB 24	Male	Subadult	Fémur
LQB 25	?	?	Fémur
LQB 26	Male	?	Fémur
LQB 27	Female	?	Fémur
LQB 28	Female	Adult	Fémur
LQB 29	Male	Adult	Fémur
LQB 30	Male	Adult	Tibia
LQB 31	Female	Adult	Fémur
LQB 32	Male	Adult	Fémur
LQB 33	Female	Adult	Fémur
LQB 34	Female	Adult	Fémur
LQB 35	Female	Adult	Fémur
LQB 36	Female	?	Fémur
LQB 37	Female	Adult	Fémur
LQB 38	Male	Adult	Fémur

LQB 39	Female	Adult	Fémur
LQB 40	Male	Subadult	Fémur
LQB 41	?	Subadult	Fémur

Table 3. Human bone samples from the cemetery of Hospital da Misericordia, Loulé

Human bone samples. Loulé Hospital da Misericordia (LHM)			
SAMPLE NUMBER	**SEX**	**AGE GROUP**	**ELEMENT**
LHM 1	Male?	Adult	Femur
LHM 2	?	Subadult	Femur
LHM 4	Male	Adult	Femur
LHM 5	Female?	Adult	Femur
LHM 6	Male	Adult	Femur
LHM 7	Female	Adult	Femur
LHM 9	?	Adult	Tibia
LHM 12	Male	Adult	Femur
LHM 13	?	Adult	Femur
LHM 14	?	Adult	Tibia
LHM 15	?	Adult	Humerus
LHM 16	?	Adult	Femur
LHM 17	Male	Adult	Tibia
LHM 18	Male	Adult	Femur
LHM 20	?	Adult	Femur
LHM 22	?	Subadult	Femur
LHM 25	Male?	Adult	Femur
LHM 27	?	Adult	Tibia
LHM 29	?	Subadult	Ulna
LHM 30	Male	Adult	Femur
LHM 31	Female	Adult	Femur
LHM 32	?	Adult	Femur
LHM 33	?	Adult	Femur
LHM 34	Female	Adult	Femur
LHM 36	?	Adult	Tibia
LHM 37	Female	Adult	Femur

Infants were not included because there is a significant difference in $\delta^{13}C$ and $\delta^{15}N$ values between infant individuals and adults; for example, a sample with infants and adults from the same family would appear to suggest different diets when, in fact, the difference is due to the different age distributions within. Also, children would reflect a residual nursing effect with higher $\delta^{15}N$ values (Katzenberg, 1993). However, Quinta da Boavista's samples included some non-adults, because they were previously analyzed before having the anthropological report.

It is important to mention that only 38 samples were analyzed for sulfur stable isotope at the Stable Isotopes Laboratory from the University of Lisbon (SIIAF) because there were some technical problems with the EA-IRMS at HERCULES laboratory. The rest of the samples will be analyzed for sulfur stable isotope after the submission of this thesis. The 38 analyzed samples were OSC 9, OSC 10, OSC 14, OSC 17, OSC 21, OSC 22, OSC 23, OSC 25, OSC 26, OSC 31, OSC 33 from faunal bone collagen; LQB 1, LQB 4, LQB 9, LQB 12, LQB 13, LQB 16, LQB 18, LQB 19, LQB 21, LQB 22, LQB 26, LQB 27, LQB 30, LQB 31, LQB 32, LQB 35, LQB 38 from Quinta da Boavista; and LHM 5, LHM 13, LHM 14, LHM 15, LHM 16, LHM 29, LHM 30, LHM 32, LHM 36 from Hospital da Misericordia.

5.2 Collagen extraction

To extract collagen from bone, the Longin method (Longin, 1971) was followed with modifications (Brown, et al., 1988).

A small piece of bone, from each sample, of approximately 0.5-0.6 g was cut and surface-cleaned with a DREMEL®3000 to remove superficial contamination and trabecular bone (fig. 13). Trabecular bone remodels 18% per year, while cortical bone remodels 3% per year; trabecular bone would yield enriched ^{15}N and ^{13}C values of the diet if it is combined with cortical bone (García-Collado, 2016). The cleaned pieces were weighed, and then placed in 16mm Ezee plastic tubes (Elkay Laboratory Products) (fig. 13) in 10 ml of 0.5 M HCl at room temperature for two weeks to eliminate the carbonates, phosphates, fulvic acids and organic contaminants soluble in acid (Longin, 1971; Ambrose, 1990); the samples were vortexed 3 to 4 times per day; the acid was changed once during this time and was removed until demineralization was complete.

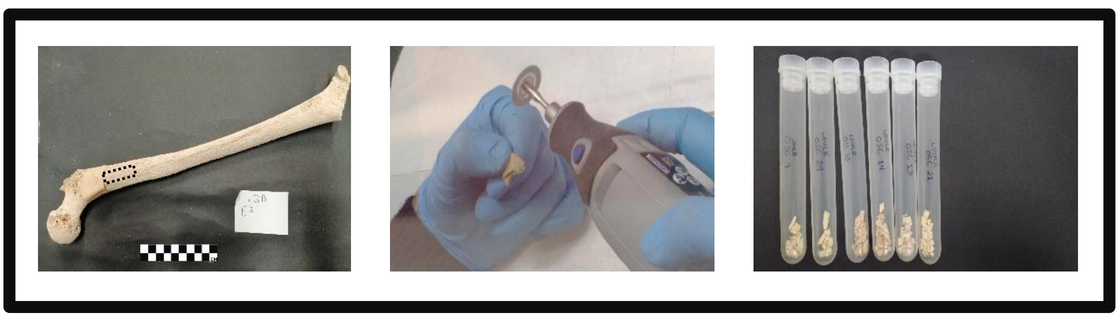


Figure 13. Bone sample preparation for collagen extraction.

Samples were rinsed seven times with milli-Q water and using a centrifuge CompactStar CS4 (VWR™) for 5 minutes at 6.0 (x1000 RPM) until neutral pH, then treated for 20 h in 0.125 M NaOH at room temperature to remove base-soluble contaminants such as humic acids and some lipids (Sealy, et al., 2014). Next, samples were rinsed five times in milli-Q water until the pH of the water remained neutral and then they were put in 0.01 M HCl for 48 hours in an oven at 70°C. The samples were vortexed during the process of digestion/gelatinization; if there was presence of big chunks of not demineralized bone, 100 to 400 µl of 0.5 M HCl were added to the sample (in some extraordinary cases 500-600 µl were put). The result after 2 days was a transparent gelatinized residue that was subsequently filtered with a 9ml Ezee-Filter™ (Elkay Laboratory Products).

The filtered gelatin (collagen) was placed in vials for later freezing with liquid nitrogen. The frozen gelatinized samples were placed inside a Telstar LyoQuest freeze dryer in vacuum at 10.000 mBar with a condenser at -71°C, for 48 hours. The resulting product was lyophilized collagen that was weighed in order to know the collagen yield of bones.

Approximately 0.50 mg of lyophilized collagen of each sample was weighed into tin capsules, closed, folded and pressed to a small size for carbon (C) and nitrogen (N) stable isotopic analysis. For sulfur (S) stable isotope analysis, ~8mg of lyophilized collagen were weighed into the tin capsules with additional V_2O_5 for each sample in order to enhance combustion.

5.3 EA-IR-MS Analysis

The tin capsules were loaded in a MAS 200R (Thermo Scientific) and were combusted to N_2 and CO_2 in an Organic Elemental Analyzer (EA ThermoScientific FLASH 2000) coupled with a continuous-flow (Conflo IV) to an isotope ratio mass spectrometer (Delta V Advantage Isotope Ratio Mass Spectrometer) for Carbon and Nitrogen stable isotope analysis. Carbon and nitrogen isotope analysis used helium as a carrier gas at a flow rate of 95 mL/min. On the other hand, sulfur stable isotopes analysis was done at SIIAF (University of Lisbon), using an IsoPrime mass spectrometer with a pulse of oxygen.

The calibration of $\delta^{13}C$ and $\delta^{15}N$ was made by using IAEA-CH-6 (sucrose, $\delta^{13}C$: −10.449‰ VPDB) and IAEA-N-2 (ammonium sulphate, $\delta^{15}N$: +20.3‰ air N_2). As in-house standards IAEA-600 (caffeine, $\delta^{13}C$: -27.771‰ VPDB, $\delta^{15}N$: +1.0‰ air N_2) and L-Alanine ($\delta^{13}C$: -19.17‰ VPDB, $\delta^{15}N$: +4.26‰ air N2) were used. The standard deviation of $\delta^{15}N$ was ±0.2 and the one of $\delta^{13}C$ was ±0.1. The calibration of sulfur was done through the inorganic international standards NBS127 ($\delta^{34}S$: +20.3‰ VCDT), IAEA S1 ($\delta^{34}S$: -0.3‰ VCDT) and casein protein ($\delta^{34}S$: +4.0‰ VCDT); the standard deviation of $\delta^{34}S$ was +0.08‰. The standards were weighed into tin capsules.

The standards used were recognized by the International Atomic Energy Agency (IAEA).

After each run, calibration curves are constructed by plotting the measured values of in-house standards (in this study is L-Alanine and IAEA-600) against the expected values of IAEA-CH-6 relative to Vienna Pee Dee Belemnite (VPDB) for carbon, IAEA-N-2 relative to atmospheric nitrogen (AIR) for nitrogen, and Vienna Canyon Diablo Troilite (VCDT) for sulfur stable isotopes. These calibrations are applied to the isotopic measurements obtained for the samples, in order to express them relative to the international standards (Sealy, et al., 2014, p. 66).

Carbon and Nitrogen EA-IRMS analyses were performed in the HERCULES Laboratory (Évora, Portugal). Sulphur stable isotopes were analysed at the Faculdade de Ciências da Universidade de Lisboa (Lisbon, Portugal).

Chapter 6. RESULTS AND DISCUSSION

6.1 Collagen yield, C/N and bone collagen preservation

When collagen extraction was completed, the collagen yield was calculated over the raw bone weight. Collagen yield from faunal samples (n=20) (*Table 4 & 5*) ranged from 2.2 to 20.9%, with an average yield of 13.3 ± 4.75%. While human samples from Quinta da Boavista (n=42) ranged from 4.4 to 12.4%, with an average yield of 7.3 ± 2.0%. Hospital da Misericordia's human samples (n=23) ranged from 1.5 to 14.1%, with an average yield of 7.8 ±3.73% (*Table 6 & 7*). DeNiro and Weiner (1988) proposed that collagen yields below 2% would be a sign of potentially problematic samples for isotopic analysis; because of postmortem alteration of their collagen (DeNiro & Weiner, 1988); for these reasons, samples LHM 1 (collagen yield: 1.51%) and LHM 9 (collagen yield: 1.94%) were excluded for the IR-MS analysis and further interpretation. Nevertheless, Sealy, et al. (Sealy, et al., 2014) mention that collagen yields are not the only useful indicator of the preservation of collagen.

In order to demonstrate that the material extracted is well preserved collagen, DeNiro and Weiner (DeNiro & Weiner, 1988) proposed that the material extracted with a carbon-to-nitrogen (C/N) ratio in the range of 2.9 to 3.6 should preserve reasonable stable isotope ratios to those from the lifetime of the organism. Since the ratio of carbon to nitrogen in modern (not buried) bone collagen averages 3.2, this range was suggested to take into consideration analytical error and some slight alteration over long periods of time. If the collagen was not well isolated from the bone mineral and contaminants from the burial environment, the ratio will not be inside the range proposed by DeNiro; if it contained lipids, which contain carbon, the C/N ratio will be lower. If the collagen is degraded, it will present a low nitrogen content, which would be reflected in a higher C/N ratio. All of that may impact C and N isotopic composition.

The average C/N ratio of the faunal samples (OSC) was 3.23 ± 0.05, while the average from the human samples of Quinta da Boavista (LQB) was 3.22 ± 0.15; and the ones from Hospital da Misericordia had an average C/N ratio of 3.13 ± 0.03. The resultant ratios, in combination with the collagen yields, show that the samples yielded well-preserved collagen with a ratio close to the one of modern unburied bone samples. However, sample LQB 23, from Quinta da Boavista, did not have a ratio inside the range (C/N: 2.34), but it provided reasonable content of carbon and nitrogen inside the criteria (C%: 32.3; N%: 16.1), that is between 15.3 and 47.0% for carbon content and between 5.5 and 17.3% for nitrogen content (Ambrose, 1990), and was considered for the analysis. The rest of the samples from Quinta da Boavista (C% mean: 39.8 ± 3.1; N% mean: 14.4 ± 0.9), the samples from Hospital da Misericordia (C% mean: 40.7 ± 3.7; N% mean: 15.2 ± 1.4), and the faunal samples (C% mean: 42.9 ± 1.2; N% mean: 15.5 ± 0.5) provided C% and N% content inside the range mentioned by Ambrose (1990).

Regarding sulfur content, faunal samples (n=12) (Table 5) had a mean S% of 0.20± 0.03, while Quinta da Boavista (n=17) and Hospital da Misericordia (n=9) had a mean S% of 0.28± 0.05% and 0.20 ±0.02%, respectively (see Table 7). These resulting values agree with the calculated amount of sulfur for mammalian collagen of 0.2% mentioned by Nehlich & Richards (2009); if the sulfur amount is below 0.15% and above 0.35% this would mean that the sulfur is heavily altered, which is not the case for the bone collagen from this study. The calculated atomic C/S ratio and N/S ratio for mammalian and bird collagen should be 600± 300 and 200± 100, respectively (Nehlich & Richards, 2009); the ratios obtained for faunal bone collagen were C/S: 616± 108 and N/S: 192 ± 34, which are inside the quoted range. Quinta da Boavista had a mean C/S ratio of 428 ± 78 and a mean N/S ratio of 133 ± 25, while Hospital da Misericordia had an average C/S ratio of 563± 52 and an average N/S ratio of 180 ± 17; the obtained ratios agree with the suggested ratio by Nehlich & Richards (2009).

6.2 Isotopic Composition

6.21 Baseline for human dietary investigation. Carbon, Nitrogen and Sulfur isotopic composition of faunal bone collagen

The $\delta^{13}C$ value for faunal bone collagen samples from Oficina do Senhor Carrilho ranges between -22.8‰ and -18.7‰ with a mean value of -20.8 ± 1.08‰, and $\delta^{15}N$ value ranges between 3.1 and 11.7‰ with a mean value of 6.3 ± 2.56‰. $\delta^{34}S$ mean value for faunal bone collagen was 12.4 ± 3.6‰.

Carbon, nitrogen and sulfur values are shown in the table 4 and a summary in table 5.

Table 4. Full $\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$ results for medieval animal bone collagen from Oficina do Senhor Carrilho, Loulé

Sample OSC	SPECIES	ELEMENT	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)	C(%)	N(%)	S(%)	C/N	C/S	N/S	%Col.
8	Rabbit	Femur	-22.1	4.2		42.1	15.2		3.2			12.5
9	Chicken	Humerus	-18.7	10.7	15.9	41.5	15.0	0.24	3.2	497	154	15.8
10	Chicken	Humerus	-19.1	10.4	12.5	43.8	15.5	0.23	3.3	549	167	14.7
13	Chicken	Femur	-19.2	11.7		39.8	14.2		3.3			2.2
14	Sheep/goat	Phalanx 3	-20.9	6.5	10.6	43.7	15.7	0.19	3.2	658	203	14.1
16	Sheep/goat	Phalanx 1	-19.9	6.9		42.5	15.3		3.2			5.7
17	Sheep/goat	Phalanx 1	-20.4	7.2	10.8	41.3	15.2	0.20	3.2	587	185	12.5
21	Red deer	Phalanx 3	-20.4	3.9	15.2	44.2	16.0	0.16	3.2	790	245	20.9
22	Red deer	Phalanx 3	-20.5	8.7	15.6	44.1	16.2	0.16	3.2	805	253	17.0
23	Red deer	Phalanx 1	-20.7	7.9	12.9	43.5	15.9	0.20	3.2	621	195	19.4
24	Red deer	Phalanx 2	-20.6	8.1		43.9	15.9		3.2			19.0
25	Red deer	Metatarsus	-20.6	6.3	13.4	43.3	15.5	0.20	3.3	621	190	18.2
26	Rabbit	Femur	-21.5	3.1	17.0	43.7	15.7	0.26	3.2	485	149	14.3
27	Rabbit	Femur	-21.8	4.9		44.5	16.2		3.2			11.2
28	Rabbit	Femur	-22.8	4.7		43.4	15.6		3.2			11.8
29	Rabbit	Humerus	-22.0	3.5	12.8	42.8	15.4	0.24	3.2	505	156	15.3
30	Rabbit	Humerus	-22.2	5.2		43.2	15.4		3.3			14.3
31	Equus sp.	Metacarpus	-21.2	4.1	6.3	43.0	15.4	0.17	3.3	712	218	9.1
32	Equus sp.	Metatarsus	-21.1	4.2		42.9	15.5		3.2			7.4
33	Sus sp.	Phalanx	-20.3	4.4	5.3	41.8	15.8	0.21	3.1	566	184	11.0

Table 5. Summary of δ13C, δ15N, δ34S results for medieval animal bone collagen from Oficina do Senhor Carrilho, Loulé

CARBON AND NITROGEN STABLE ISOTOPE SUMMARY TABLE									
Species	N	$\delta^{13}C_{VPDB}$(‰)				$\delta^{15}N_{AIR}$(‰)			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Rabbit	6	-22.8	-21.5	1.3	-22.1 ± 0.44	3.1	5.2	2.1	4.3 ± 0.83
Red deer	5	-20.7	-20.4	0.3	-20.6 ± 0.11	3.9	8.7	4.8	7.0 ± 1.94
Sheep/goat	3	-20.9	-19.9	1.0	-20.4 ± 0.5	6.5	7.2	0.7	6.9 ± 0.35
Equus sp.	2	-21.2	-21.1	0.1	-21.2 ± 0.07	4.1	4.2	0.1	4.2 ± 0.11
Sus sp.	1				-20.3				4.4
Chicken	3	-19.2	-18.7	0.5	-19.0 ± 0.26	10.4	11.7	1.3	10.9 ± 0.68

SULFUR STABLE ISOTOPE SUMMARY TABLE					
Species	N	$\delta^{34}S_{VCDT}$(‰)			
		Min	Max	Range	Mean ± 1σ
Rabbit	2	12.8	17.0	4.2	14.9 ± 3.0
Red deer	4	12.9	15.6	2.7	14.3 ± 1.3
Sheep/goat	2	10.6	10.8	0.2	10.7 ± 0.1
Equus sp.	1				6.3
Sus sp.	1				5.3
Chicken	2	12.5	15.9	3.4	14.2 ± 2.4

Rabbits *(Oryctolagus cuniculus*) have the lowest δ^{13}C and second lowest δ^{15}N values, with a mean δ^{13}C value of −22.1 ± 0.44‰ and a mean δ^{15}N value of 4.3 ± 0.83‰. Rabbits are followed by medium–large herbivores: equines (*Equus sp.)*, red deer (*Cervus elaphus*) and ovicaprids (*Ovis aries* /*Capra hircus*), with average δ^{13}C values of -21.2 ± 0.07‰, -20.6 ±0.11‰, and -20.4 ± 0.5‰, respectively. Equines have δ^{13}C values closer to the ones of rabbits, while red deer and ovicaprids show similar mean δ^{13}C values which are less negative than the ones from rabbits and equids. Regarding their δ^{15}N mean values, equines have the lowest δ^{15}N mean value: 4.2 ±0.11‰; red deer have an average δ^{15}N value 7.0 ±1.94‰ and ovicaprids δ^{15}N mean value was 6.9 ±0.35‰. The isotopic variability in δ^{15}N is wide for red deer: 4.8‰. A summary with all the mean values is found in table 5 and a faunal carbon and nitrogen stable isotopes graph can be found in fig. 14.

Bone collagen $\delta^{15}N$ and $\delta^{13}C$ values of the faunal samples show three differentiated groups: 1) rabbits and equines, 2) red deer and ovicaprids, and 3) chickens (see fig. 13 and 15). The observed isotopic composition of each faunal group seems to demonstrate: wild (1) and domesticated (2 and 3). Generally wild herbivore animals have lower $\delta^{13}C$ values than the domesticated herbivores (Fraser, et al., 2013) probably because of the canopy effect: in forests, where biogenic CO_2 has a $\delta^{13}C$ value around-26‰, the forest canopy prevents rapid mixing of atmospheric and biogenic CO_2. This "canopy effect" lowers the $\delta^{13}C$ value of atmospheric CO_2 near the forest floor. Leaves fixing this ^{13}C-depleted CO_2 have lower $\delta^{13}C$ values than those higher up in the canopy. Since the canopy effect is reflected at higher trophic levels, animals feeding on the forest floor should have the most negative $\delta^{13}C$ values among terrestrial ecosystems (Ambrose, 1993), while animals grazing far from the forest would have slightly higher $\delta^{13}C$ values. In the Medieval time in the Ossonoba (Faro) district mainly of pine trees (Catarino, 1997/1998); these forests could have been where the wild animals foddered.

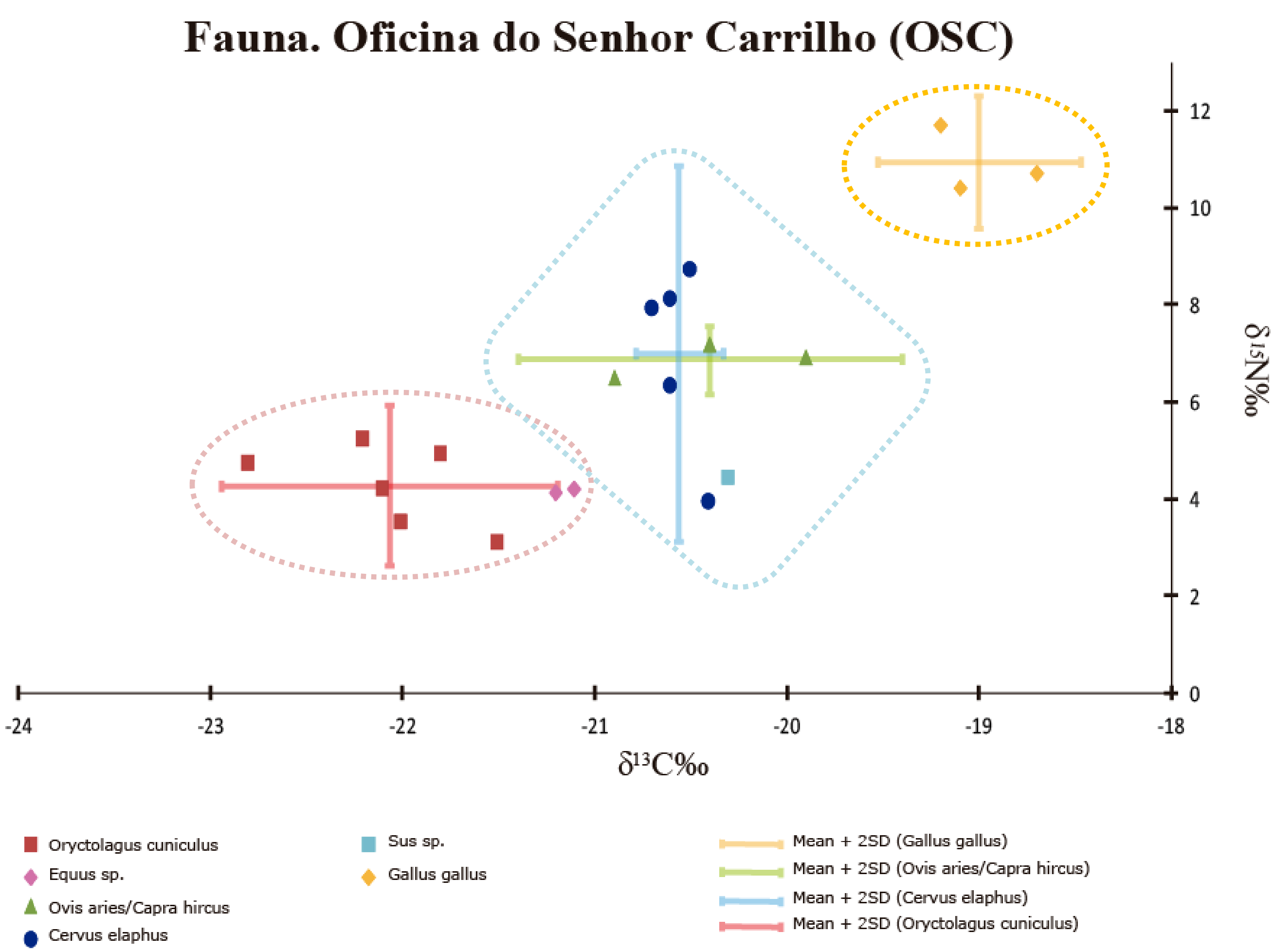


Figure 14. Carbon and Nitrogen stable isotope from faunal bone collagen of Oficina do Senhor Carrilho

Another explanation for the differences in $\delta^{13}C$ values between wild and domesticated herbivores is manuring; manuring was one of the a agricultural techniques utilized by the Muslims in the Iberian Peninsula (Guede, et al., 2017); cord grass (*Spartina maritima*), sapeira (*Salicornia*), and eelgrass (*Zostera marine*) were some of the plants known to be used as manure in Islamic Algarve (Botão, 2009; Feio, 1983), ashes and straw were also utilized (Pickard, et al., 2017), and dung from equines and ovicaprids to manure gardens and orchards (Catarino, 1997/1998). Manured plants present a $\delta^{13}C$ increase of around +1‰ in response to nitrogen fertilization (Treasure, et al., 2016); the mean $\delta^{13}C$ value of the wild herbivores bone samples was -21.84 ± 0.56‰, while the $\delta^{13}C$ value of domesticated herbivores was -20.5 ± 0.29‰ showing an increase of +1.34 in domesticated herbivores $\delta^{13}C$ values, that would agree with Treasure et al (2016).

On the other hand, manured chaff and grains would also present enriched ^{15}N values (Fraser, et al., 2011) by 2.6 to 8.0‰, depending on the intensity of the process (Dury, et al., 2018). Animals fed with manured grains (in this study, ovicaprids and red deer) would then yield higher $\delta^{15}N$ values than wild herbivore animals (rabbits and equines) that would eat herbivore forage (with a $\delta^{15}N$ value that ranges between 1-3‰) (Bogaard, et al., 2013). Grazing grains, herbs and forbs would be reflected in higher $\delta^{15}N$ in comparison to browsing trees and shrubs (Hofman-Kaminska, et al., 2018).

Besides, elevated $\delta^{15}N$ values in plants can also be the result of natural environmental conditions such as salinity and aridity (which are characteristic for the Algarve region, mainly in the Littoral subregion) and, subsequently, animals grazing near coastal areas and salt marshes would have enriched $\delta^{15}N$ values (Alexander, et al., 2015; Alexander, et al., 2019). Plowed soil is also relatively enriched in ^{15}N and would increase the $\delta^{15}N$ values in plants cultivated in this type of soil, these enrichment would be also evident in the consumers of these plants (Bogaard, et al., 2013).

Red deer is considered a wild animal and is one of the most common wild species found in medieval Islamic contexts, but often is poorly represented (Aleixo, et al., in press; Grau-Sologestoa, 2017); however, it is the second most common species found in the trash pits from Oficina do Senhor Carrilho (Aleixo, et al., in press) and they present mean $\delta^{15}N$ and $\delta^{13}C$ values closer to the mean values of ovicaprids than those of the rabbits. These values together with their variability in the $\delta^{15}N$ values would evidence a possible domestication of red deer for dietary consumption and that deer were not only fed with manured chaff or grains but may also have grazed in open areas.

Rabbit is a common species in medieval Islamic contexts in Portugal (Aleixo, et al., in press), its presence can be related to hunting practices or to captivity for later consumption. But according to their isotopic values, they come from hunting rather than captivity.

Equines were mainly used as riding and transportation animals, and its presence is common in urban settlements (Aleixo, et al., in press); their carcasses were processed for consumption, which may suggest an episode of food shortage (Telles Antunes, 1996). Sheep and goat were two most appreciated animals in al-Andalus not just because of their meat, but also because of their milk (Catarino, 1997/1998; García Sánchez, 1986). Therefore, their presence in the trash pits of Oficina do Senhor Carrilho is not out of the ordinary. Also, ovicaprids are the most frequent taxon in medieval sites from the Iberian Peninsula (Grau-Sologestoa, 2017).

The resultant $\delta^{13}C$ and $\delta^{15}N$ values for the pig or wild boar (*Sus sp.*) sample were -20.3‰ and 4.4‰, respectively. Even though *Sus sp.* is considered and omnivorous animal, its $\delta^{15}N$ value is lower than the one of the domesticated herbivores; and is closer to the one of wild herbivores, i.e. all rabbits and equines. However, its carbon isotopic signature is also closer to the domestic herbivores, which could indicate that the pig was roaming, or grazing plants close to the urban settlement but also in open areas. The presence of *Sus sp.* (specially with cutmarks) most certainly indicates that it was consumed. Although pig is considered *haram* (forbidden) food by the Qur'an, it is also known that in case of need this animal could be consumed (Quran 2:173):

> He has only forbidden to you dead animals, blood, the flesh of swine, and that which has been dedicated to other than Allah. But whoever is forced [by necessity], neither desiring [it] nor transgressing [its limit], there is no sin upon him. Indeed, Allah is Forgiving and Merciful (The Noble Qur'an, 2016).

Alexander et al. (2015) mention that the presence of pigs is not unusual for Muslim sites of this period and that the remains that are recovered are usually attributed to the presence of a small number of Christians (Mozarab) on site or to hunting of wild boar (Alexander, et al., 2015). The isotopic signal of the *Sus* may indicate that it was a wild boar and not a domesticated pig.

Chickens (*Gallus gallus*) have the highest $\delta^{15}N$ mean values between the faunal bone samples (10.9‰ ±0.68), as expected for domesticated omnivores, and their $\delta^{13}C$ mean value is -19.0‰ ±0.26, being more ^{13}C enriched than the rest of the faunal bone samples. Chicken isotopic signatures are closer to the ones of human individuals (fig. 16) which may indicate that they were fed on domestic food scraps and/or insects that have both enriched ^{15}N values.

The absence of cattle in the collection of Oficina do Senhor Carrilho makes this context unique when compared with other contemporary contexts in the Algarve (Aleixo, et al., in press); cattle breeding is mentioned in the chronicle made by Ibne Rasis, where he mentioned that the mountains near to Ossonoba (Faro) were good to raise cattle (Catarino, 1997/1998), however because of the ecological conditions in the Barrocal and the lack of uniformity of the terrains, cattle farming was probably limited. Bos taurus was more appreciated as labor provider, than for its meat and milk (Telles Antunes, 1996). It is important to mention that cattle tended to be most numerous in areas of northwestern Europe where the climate favored extensive natural pasture, whereas sheep assumed importance in the dry zones around the Mediterranean (Ross, 1987).

Fish remains of pink dentex (*Dentex gibbosus*), houndshark (*Triakidae*), hake (*Merluccius merluccius*), meagre (*Argyrosomus regius*) and sea bream (*Sparidae*) were abundant also in Oficina do Senhor Carrilho; however, they were not analyzed.

Overall, faunal samples have $\delta^{13}C$ values indicative of a C_3-plant based diet. If C_3-plants have a mean $\delta^{13}C$ value of -26‰ and the trophic shift in $\delta^{13}C$ is around +5‰ from plants to consumers, the $\delta^{13}C$ of a pure C_3-plant eater would be around -21‰ (Ambrose & Norr, 1993), a value that is close to the ones obtained for the faunal bone samples. The C_3-plant diet would have been probably composed by weeds, carob, hulled barley, bitter vetch, straw and alfalfa (Peña-Chocarro, et al., 2019).

C_4 plants inputs would have included *sapeira*, which is mentioned in historical sources for feeding animals such as equines and sheep (Botão, 2009; Feio, 1983). Another C_4 plant present would be millets, such as *Panicum miliaceum*, which is found in the western part of the Iberian Peninsula and is commonly related to Islamic sites (like Convento de S. Francisco, Santarém) and were consumed by humans, animals and fowl (Peña-Chocarro, et al., 2019); another C_4-plant is cord grass (*Spartina maritima*) which is recorded to be given for cattle mixed with straw (Botão, 2009) which could also have been used to feed sheep, goats and even red deer. The enrichment in ^{13}C in domestic animals could be explained by the sporadic consumption of these C_4 plants.

To have a better understanding of the baseline from medieval Loulé, $\delta^{34}S$ of some faunal bone collagen samples (and human) were analyzed (see table 4 and 5 and fig. 15). Two distinct groups are visible: one (1) conformed by the rabbits (mean $\delta^{34}S$ value: 14.9 ± 3.0‰), chickens (mean $\delta^{34}S$ value: 14.2± 2.4‰), ovicaprids (mean $\delta^{34}S$ value: 10.7 ± 0.1‰) and red deer (mean $\delta^{34}S$ value: 14.3 ± 1.3‰); and the other group (2) conformed by the equine ($\delta^{34}S$ value: 6.3‰) and the sus ($\delta^{34}S$ value: 5.3‰). This differentiation can be caused by diverse reasons. First, group 1 is integrated by the domestic herbivores and the rabbits, that were considered wild because of their $\delta^{13}C$ and $\delta^{15}N$ values; this group were under influence of anthropogenic factors, such as manuring or bedding. Sapeira, eelgrass and cordgrass were used for both of these practices (Feio, 1983; Botão, 2009), and are plants that grow in marine environments, rich in ^{34}S, which would explain the high $\delta^{34}S$ values of this group (1) in comparison with the other. The equine and the pig could be wild and from other area different to the one of the group 1.

Another possibility for the distinct groups could be the geochemistry of the area, which is conformed mainly by evaporites such as limestone, marls, dolomites (see chapter 2.2). Geological sulphate samples from islands, coastal sites and oceanic sediments have higher $\delta^{34}S$ (Nehlich, 2015) that would increase $\delta^{34}S$ values in the food webs of the site. Group 2 is integrated by wild animals that probably fed far from Loulé, which were not influenced by the geochemistry of the place in their foodwebs.

One more possibility could be the sea spray effect, which can carry marine sulphates particles inland, reaching up to 30 km inland and cause the coastal soil $\delta^{34}S$ values to be similar to those of the ocean (Richards, et al., 2003; Nehlich, 2015). Loulé is 11 km from the coast, which is inside the range of effect of the sea spray. However, group 2 shows no influence from the sea spray, that could be related to these animals not living in the vicinities and probably coming from the Serra Algarvia or through trade with an area with low $\delta^{34}S$ values.

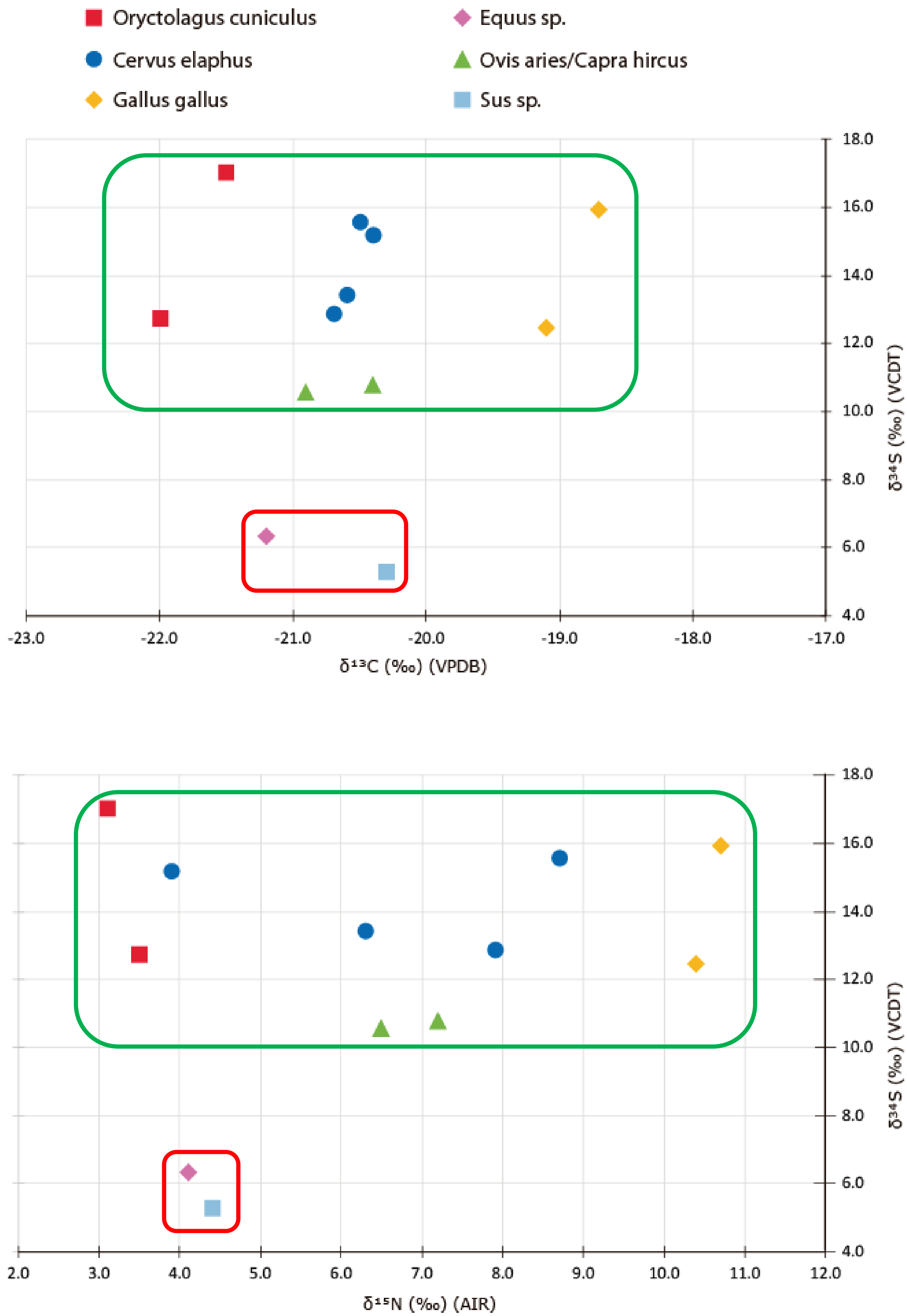


Figure 15. Graphs showing δ^{34}S, δ^{13}C and δ^{15}N from the faunal bone collagen. Group 1 is enclosed in green; group 2 in red.

6.22 Dietary reconstruction of the Islamic individuals from the two cemeteries of Loulé. Carbon, Nitrogen and Sulfur isotopic composition of human bone collagen

The $\delta^{13}C$ values of human bone collagen from Quinta da Boavista range between -19.5‰ and -17.4‰ with a mean value of -18.53 ± 0.50‰, and $\delta^{15}N$ values range between 9.3‰ and 13.8‰ with a mean value of 12.0 ± 0.88‰. While the $\delta^{13}C$ values from Hospital da Misericordia human samples ranges between -18.9‰ and -16.9‰ with a mean value of -17.99 ± 0.65‰; the $\delta^{15}N$ values range between 9.4‰ and 12.2‰ with a mean value of 10.60 ± 0.79‰. All results are shown in table 5. The $\delta^{34}S$ values of some of the individuals bone collagen from Quinta da Boavista range between 9.0‰ and 13.6‰ with a mean value of 11.5 ± 1.3‰; Hospital da Misericordia bone collagen, on the other hand, had $\delta^{34}S$ values ranging from 8.9‰ to 11.7‰ with a mean value of 10.6 ±0.9‰.

Table 6. Stable carbon, nitrogen and sulfur isotope data for human bone collagen from Quinta da Boavista and Hospital da Misericordia, Loulé (Period: Almohad 12th-13th CE).

SAMPLE NUMBER	SITE	ELEMENT	SEX	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)	C (%)	N (%)	S (%)	C/N	C/S	N/S	%Col.
LQB 1	QUINTA DA BOAVISTA	Humerus	M	-18.0	12.6	12.5	38.2	13.7	0.29	3.2	379	116	4.9
LQB 2		Femur	F	-18.5	12.3		37.1	13.4		3.2			8.0
LQB 3		Femur	M	-19.2	10.9		41.6	14.8		3.3			5.9
LQB 4		Femur	M	-18.5	9.3	9.0	40.1	15.0	0.24	3.1	476	152	5.7
LQB 5		Femur	M	-19.0	12.2		44.1	15.6		3.3			7.5
LQB 6		Tibia	M	-18.4	12.8		42.8	15.4		3.2			9.6
LQB 7		Femur	M	-17.9	11.3		41.5	15.4		3.1			4.5
LQB 8		Femur	F	-18.9	11.3		40.0	14.2		3.3			8.1
LQB 9		Femur	F	-17.6	10.9	9.2	42.3	15.8	0.23	3.1	511	164	8.4
LQB 10		Femur	F	-18.8	11.9		38.8	13.6		3.3			7.5
LQB 11		Femur	?	-18.8	12.4		35.9	13.2		3.2			5.1
LQB 12		Femur	M	-18.2	11.4	10.1	43.1	15.5	0.24	3.2	505	156	4.4
LQB 13		Femur	F	-19.2	12.1	11.2	43.6	15.7	0.24	3.2	508	157	4.7
LQB 14		Femur	M	-18.9	12.4		45.1	15.0		3.5			5.0
LQB 15		Femur	?	-18.1	12.5		32.9	12.3		3.1			6.6
LQB 16		Humerus	F	-18.7	12.7	11.8	37.6	13.4	0.30	3.3	360	110	7.4
LQB 17		Femur	F	-18.6	12.4		40.5	14.6		3.2			10.1
LQB 18		Femur	M	-18.0	13.1	12.5	41.4	14.9	0.24	3.2	492	152	9.4
LQB 19		Femur	?	-18.4	13.0	12.7	41.5	14.4	0.34	3.3	346	103	9.0
LQB 20		Femur	?	-18.1	12.0		44.4	15.9		3.3			5.4
LQB 20a		Femur	?	-18.0	12.8		39.1	13.9		3.3			7.8
LQB 21		Femur	M	-18.5	12.1	12.8	36.0	12.9	0.37	3.2	273	84	6.0
LQB 22		Humerus	?	-18.1	13.8	13.6	41.3	14.6	0.27	3.3	431	131	5.4
LQB 23		Humerus	F	-18.9	11.1		32.3	16.1		2.3			7.2
LQB 24		Femur	M	-19.0	10.3		39.7	14.5		3.2			5.6
LQB 25		Femur	?	-18.5	12.2		37.2	13.5		3.2			5.5
LQB 26		Femur	M	-17.4	11.9	9.7	43.2	15.7	0.28	3.2	432	134	8.5

LQB 27		Femur	F	-19.5	10.8	10.8	35.7	13.0	0.25	3.2	407	127	6.1
LQB 28		Femur	F	-18.7	12.5		35.7	12.8		3.2			5.9
LQB 29		Femur	M	-19.0	11.7		41.4	15.0		3.2			7.6
LQB 30		Femur	M	-17.5	11.2	11.5	43.2	15.5	0.25	3.2	481	148	9.6
LQB 31		Femur	F	-18.3	12.4	12.1	39.2	14.0	0.37	3.3	298	91	5.1
LQB 32		Femur	M	-18.5	11.5	12.6	43.3	15.5	0.23	3.3	526	161	11.2
LQB 33		Femur	F	-18.9	11.1		42.6	15.1		3.3			5.9
LQB 34		Femur	F	-18.9	12.0		39.8	14.3		3.2			9.8
LQB 35		Femur	F	-19.3	12.0	11.5	40.9	14.7	0.24	3.2	478	147	10.2
LQB 36		Femur	F	-18.2	13.2		38.1	14.0		3.2			8.0
LQB 37		Femur	F	-19.0	11.3		41.3	14.9		3.2			12.4
LQB 38		Femur	M	-18.0	13.2	11.8	40.8	15.0	0.31	3.2	379	119	6.2
LQB 39		Femur	F	-18.4	12.0		35.9	13.1		3.2			6.6
LQB 40		Femur	M	-19.3	10.9		36.3	13.2		3.2			10.5
LQB 41		Femur	?	-18.4	12.6		37.6	13.8		3.2			9.3
LHM 1	HOSPITAL DA MISERICORDIA	Femur	?	-	-		-	-		-			1.5
LHM 4		Femur	M	-18.7	10.1		41.8	15.6		3.1			11.4
LHM 5		Femur	?	-17.2	10.5	8.9	42.5	15.8	0.20	3.1	616	197	4.5
LHM 6		Femur	M	-17.5	10.5		40.9	15.3		3.1			6.6
LHM 7		Femur	F	-18.1	10.4		41.7	15.5		3.1			7.7
LHM 9		Tibia	?	-	-		-	-		-			1.9
LHM 12		Femur	M	-18.1	10.5		41.5	15.6		3.1			14.1
LHM 13		Femur	?	-17.0	12.0		39.2	14.7		3.1			7.4
LHM 14		Tibia	?	-18.5	11.2	11.7	41.6	15.5	0.21	3.1	552	176	8.3
LHM 15		Humerus	?	-17.1	12.2	10.5	42.1	15.8	0.22	3.1	548	176	7.1
LHM 16		Femur	?	-18.9	11.0	11.4	41.0	15.3	0.20	3.1	570	182	10.5
LHM 17		Tibia	M	-18.2	9.8		41.2	15.4		3.1			8.0
LHM 18		Femur	M	-18.5	9.8		41.7	15.6		3.1			13.2
LHM 22		Femur	?	-17.9	11.3		41.6	15.3		3.2			2.7
LHM 25		Femur	?	-17.6	10.9		41.6	15.7		3.1			8.0
LHM 29		Ulna	?	-18.8	9.4	11.7	41.0	15.5	0.18	3.1	653	211	11.9
LHM 30		Femur	M	-18.9	9.5	10.7	24.7	9.09	0.15	3.2	479	151	4.5
LHM 31		Femur	F	-17.6	10.7		41.7	15.5		3.1			3.1
LHM 32		Femur	?	-16.9	11.5	11.2	41.9	15.6	0.23	3.1	579	185	9.9
LHM 33		Femur	?	-17.3	10.8		41.0	15.3		3.1			9.8
LHM 34		Femur	F	-18.3	10.8		42.0	15.6		3.1			5.3
LHM 36		Tibia	?	-18.0	9.8	9.7	41.7	15.6	0.21	3.1	562	181	14.0
LHM 37		Femur	F	-18.6	10.0		41.9	15.4		3.2			7.7

Table 7. Summary of stable carbon, nitrogen and sulfur isotope data for human bone collagen from Quinta da Boavista and Hospital da Misericordia, Loulé (Period: Almohad 12th-13th CE).

SUMMARY OF CARBON AND NITROGEN STABLE ISOTOPE									
Site	N	**$\delta^{13}C_{VPDB}$(‰)**				**$\delta^{15}N_{AIR}$(‰)**			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Quinta da Boavista	42	-19.5	-17.4	2.1	-18.5 ± 0.50	9.3	13.8	4.5	12.0 ± 0.88
Hospital da Misericordia	21	-18.9	-16.9	2.0	-18.0 ± 0.65	9.4	12.2	2.8	10.6 ± 0.79
Both cemeteries	63	-19.5	-16.9	2.6	-18.35 ±0.60	9.3	13.8	4.5	11.50 ±1.06

SULFUR STABLE ISOTOPE SUMMARY TABLE					
Species	N	**$\delta^{34}S_{VCDT}$(‰)**			
		Min	Max	Range	Mean ± 1σ
Quinta da Boavista	17	9.0	13.6	4.6	11.5 ± 1.3
Hospital da Misericordia	9	8.9	11.7	2.8	10.6 ± 0.9
Both cemeteries	26	8.9	13.6	4.7	11.2 ± 1.2

The trophic level offset between humans and domesticated herbivores is close to the commonly quoted range for enrichment values of 3–5‰ for δ^{15}N, and 0-2‰ for δ^{13}C (see fig. 16) (Bocherens & Drucker, 2003; Alexander, et al., 2015). Quinta da Boavista values are on average 2.0‰ higher in δ^{13}C and 5.1‰ in δ^{15}N compared to the domesticated herbivores, while Hospital da Misericordia's values are 2.5‰ higher in δ^{13}C and 3.7‰ higher in δ^{15}N than domesticated herbivores. Quinta da Boavista human bone samples exhibited a wide range in δ^{15}N values of 4.5‰, ranging from 9.3‰ to 13.8‰ (table 7).

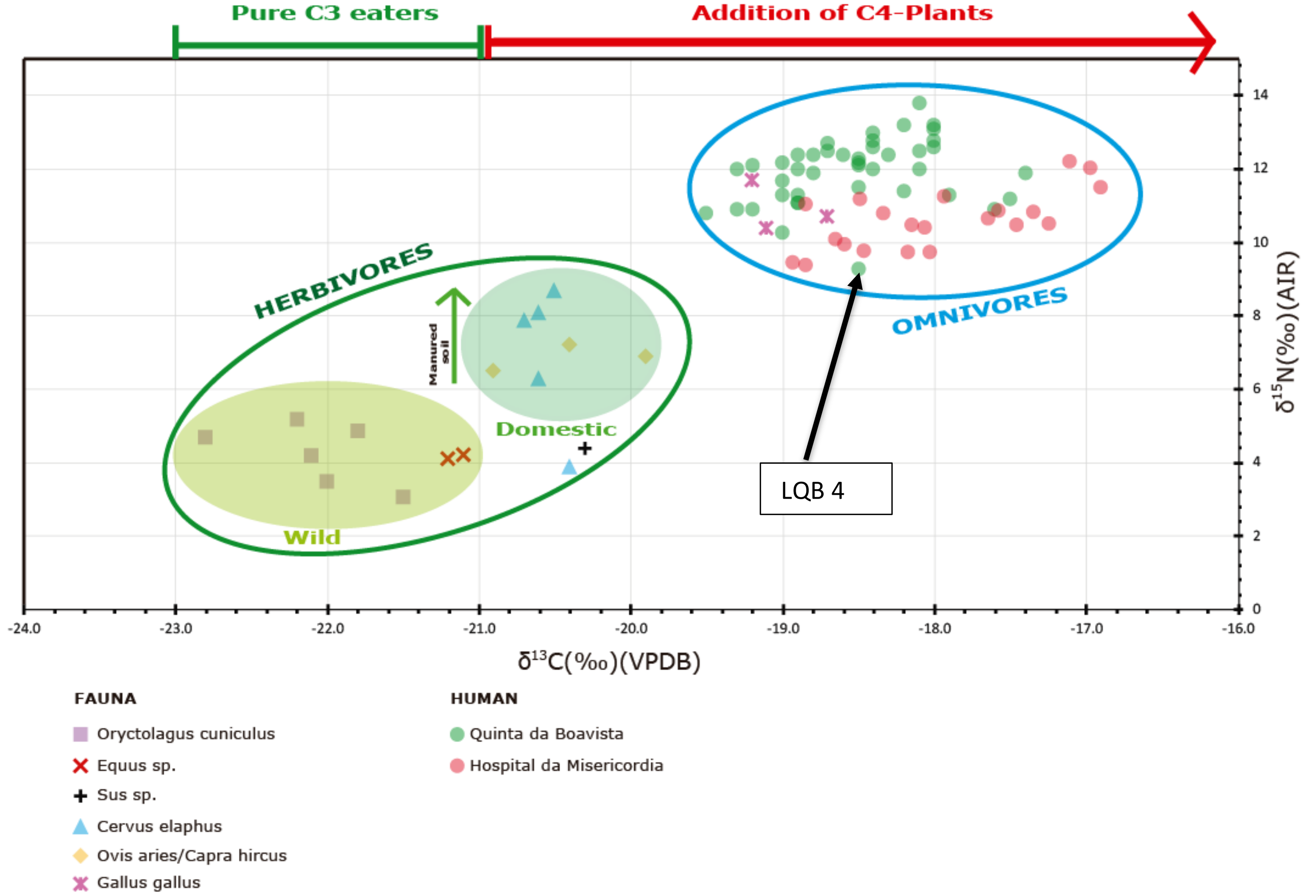


Figure 16. Carbon and Nitrogen stable isotope data from humans and animal bone collagen. Plotted by species and separated by herbivores and omnivores. LQB 4 is an outlier highlightened for the following discussion.

Plant intake

The $\delta^{13}C$ mean value from Quinta da Boavista is barely inside the range of trophic enrichment (trophic offset: 2.0‰, the quoted range is from 0 to 2‰); the mean $\delta^{13}C$ value of -18.5 ± 0.50‰ would suggest that the plant intake was mainly of terrestrial C_3 plants protein with an occasional minor input of C_4 plants or through the indirect consumption of animals foddered on C_4 plants. On the other hand, Hospital da Misericordia surpasses the quoted range of 0-2‰ enrichment, with a mean value of 2.5‰ higher than the mean $\delta^{13}C$ of domesticated animals. This would suggest that Hospital da Misericordia's individuals had a higher C_4 plants input than the ones from Quinta da Boavista (fig. 17). C_4 plants such as sorghum and millet are thought to be appreciated by Muslims because they were cultivated together with wheat and barley (Alexander, et al., 2015); however, sorghum and millet were considered grains for lower classes from rural areas and were only consumed by the higher classes when wheat and barley were scarce (in winter, for example) (García Sánchez, 1995; García Sánchez, 1983). Sorghum was considered the food base for the inhabitants of rural areas, but in humoral treatises it was considered as a cold and dry food stuff, a poor source of nourishment and that constipates (Nasrallah, 2007); probably individuals from higher classes would try to follow a humoral treaty and discriminate between food stuffs, while individuals from lower classes would consume what is available.

Millet (*Panicum miliaceum*) consumption was related to rural areas (García Sánchez, 1995) but its presence in medieval Islamic sites in the Peninsula stands out, mainly in the west; like in the case of the Convento de S. Francisco in Santarém (Peña-Chocarro, et al., 2019).

Wheat (*Triticum durum*) occupied a prominent position in the diet of al-Andalus, as mentioned in the "Religion and Diet" chapter, and was mainly prepared and consumed as bread (García Sánchez, 1983). The market of cereals was the most important in the souks, where wheat, barley, rye, and sorghum were sold. These is supported by the carpological remains found in medieval Islamic sites, where cereals are generally the most abundant plant remains; naked wheats (*Triticum durum/aestivum*) and hulled barley (*H. vulgare sp. vulgare*) are the main cereal species, followed by hulled wheats, millet, rye and oats (Peña-Chocarro, et al., 2019). Both wheat and barley are C_3 plants and were consumed mostly as bread; wheat was the preferred grain, although barley was considered also a substitution grain (such as sorghum and millet) related to lower classes, it was consumed mostly by animals. For example, in the agricultural Calendar of Cordoba it is said that horses feed on barley most of the year (Catarino, 1997/1998).

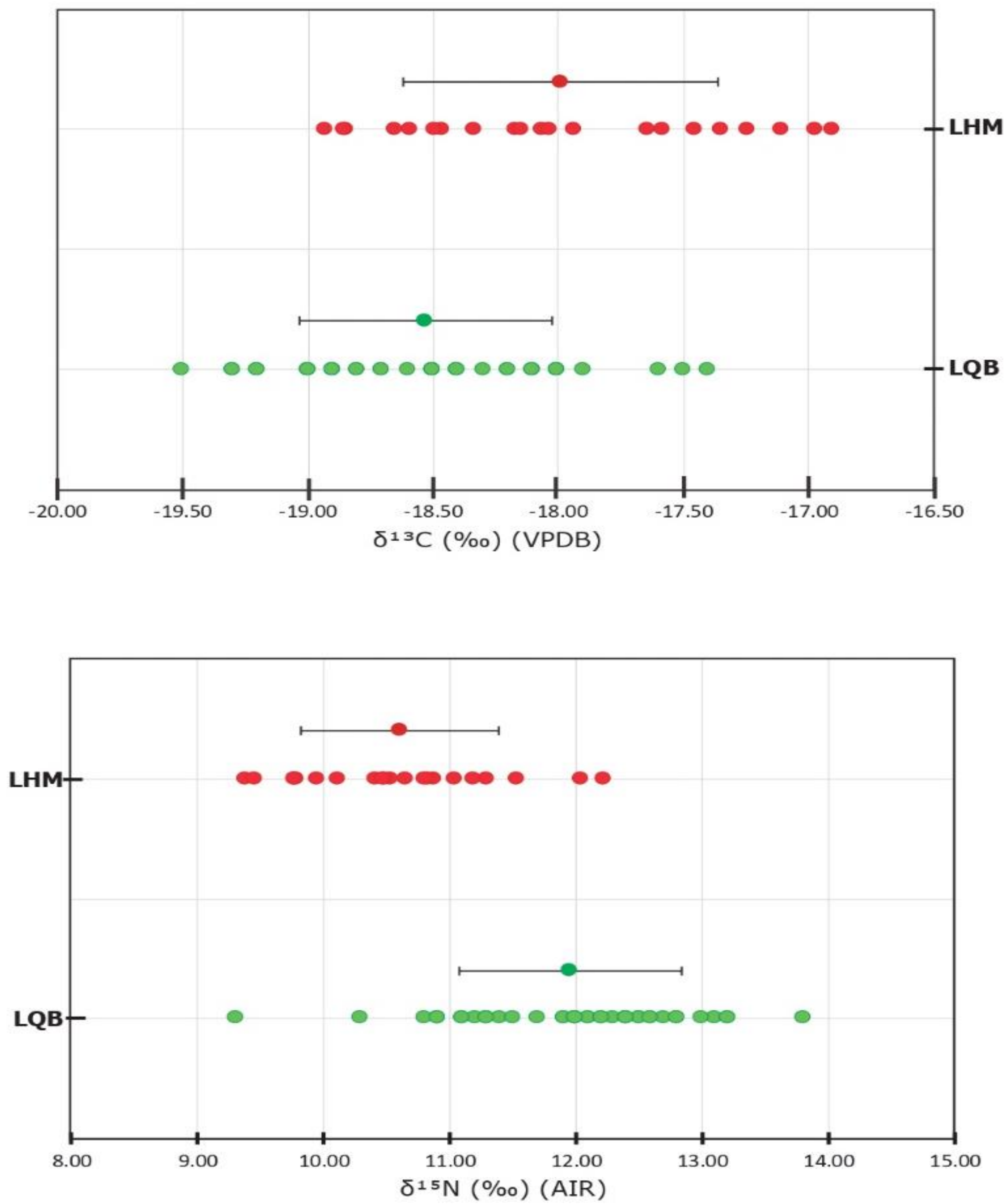


Figure 17. Carbon and Nitrogen stable isotope data for human bone samples. Comparison between LHM and LQB

Besides wheat and barley, fruits, legumes and other plants -which are also C_3 plants- were majorly consumed in al-Andalus. Fruits like grapes, figs, olives, carob, almonds, oranges, apricot; legumes such as chickpeas, peas and lentils; and plants cultivated in the *almuinhas,* like onion, leek, coriander, mint, thyme, marjoram, carrots, cabbages and spinach (Botão, 2009; García Sánchez, 1983). The presence of cultivated fruits is significant in places under medieval Islamic rule, mainly of grape and fig; apricot appears for the first time in the Iberian peninsula in Mértola dating to the 11th and 12th centuries (Peña-Chocarro, et al., 2019). Olive consumption was widely distributed in al-Andalus and its oil was used in the preparation of most of meals (Catarino, 1997/1998). It is important to mention that the Lower Algarve is an important fruit region (Lautensach, 1967).

Legumes played an important role as food for animals (bitter vetch and common vetch) and humans (peas, lentils, broad bean, chickpeas) and also as a fertilizer (Peña-Chocarro, et al., 2019).

The major presence of C_3 plants and minor of C_4 plants in medieval Islamic sites, along with the resultant $\delta^{13}C$ values of Hospital da Misericordia and Quinta da Boavista, would help us assume that the plant protein intake was mainly of C_3 plants with occasional inputs of C_4 plants. In the case of Hospital da Misericordia, the C_4 plant consumption could have been a little bit more constant than in Quinta da Boavista.

Meat intake

Regarding the mean $\delta^{15}N$ values, Quinta da Boavista values are 5.1‰ higher than domesticated herbivores and 3.7‰ higher in the case of Hospital da Misericordia (fig. 16). Quinta da Boavista human bone samples exhibited a wide range in $\delta^{15}N$ values of 4.5‰, ranging from 9.3‰ to 13.8‰ (see Table 7). Its human-domesticated herbivore dietary spacing is 0.1‰ higher than the commonly quoted range (3 to 5‰) which probably suggests that the protein consumption was not only based on domestic herbivores animal protein, but also in other enriched sources of ^{15}N like eggs, chicken or marine animals. Hospital da Misericordia $\delta^{15}N$ mean value is inside the trophic level offset range.

As previously mentioned lamb was the most appreciated meat during al-Andalus and was reserved mostly for the wealthy classes (Marín, 2008; García Sánchez, 1986). Lamb was followed by goat, then cattle and chicken. Chicken sometimes was considered better for consumption than cattle; Averroes, a philosopher and physician living under Almohad rule in al-Andalus, puts it before all the meats, including cattle (García Sánchez, 1986). The meats were followed by milk of goat, sheep and cow and other derivatives, which were also consumed (like eggs). Game meat of rabbits, partridge and red deer were also eaten. All these species appeared in the zooarchaeological record from medieval Islamic sites; also, in the case of Loulé, except for cattle. There is zooarchaeological evidence of the consumption of these animals during the Islamic period in the Iberian Peninsula, which tell us about consumption of individual food stuffs. Stable isotopes can reveal the relative importance of these food resources to the overall diet of individuals. The data obtained related to the protein consumption in Islamic Loulé agrees with a terrestrial animal protein intake, but the variability in $\delta^{15}N$ values obtained in Quinta da Boavista could agree with a marine animal protein intake.

Fish intake

Fish were quite consumed by the popular classes of the Algarve (see fig. 18), thanks to its abundance on the littoral and, it is important to mention, that fish remains were found in Oficina do Senhor Carrilho. But, to which extent was fish consumption important in the diet of medieval Islamic Loulé?

Figure 18. Illumination showing moors fishing in Faro. From the Cantiga 183 in the Cantigas de Santa Maria of Alfonso X, from the Biblioteca del Escorial, Madrid. F. 241v © Biblioteca del Escorial

In the Algarve (with a wide coastal strip) one of the dominant economic activities was and is fishing; fresh fish was the most consumed, as can be seen from the textual registers, salting, especially of sardines and tuna, should have been practiced during this period (Catarino, 1997/1998). However, fish was a food stuff that did not enjoy great esteem among the upper classes in the medieval Muslim world. This was influenced by factors of very different kinds: socio-economic, religious, cultural and dietary, among others (García Sánchez, 1995; Jiménez-Brobeil, et al., 2016). In coastal populations, fish was a popular constituent of diet; it was consumed as a substitute for the "luxury proteins" of meat (for example, lamb), as opposed to the upper classes, who considered it as a complement to meat, not an element of substitution (García Sánchez, 1996). It might be the case that fish, being so available near the coast, could be considered as a common element in diet, and in order to differentiate from the common population, high classes would not consume it. This choice would be influenced by socio-economical dynamics rather than availability. In some cases, even populations living near the sea would not have fish as a major constituent of their diet, as it happened with the Roman population of Can Reinés (García, et al., 2004).

Fish consumption can be perceived through stable isotopes; $\delta^{15}N$ values tend to be higher in aquatic ecosystems due to the longer length of food chains (Alexander, et al., 2019; García-Collado, et al., 2018). The flesh of marine mammals and fish has a $\delta^{13}C$ value of about -17 to -18‰ and $\delta^{15}N$ values ranging from 11 to 23‰ (Mays, 1998). The $\delta^{15}N$ values from Quinta da Boavista would probably point to an occasional marine animal protein consumption, or consumption of fish from lower trophic levels (like sardines) or in form of fish sauce, like *almorí*. *Almorí* was one of the basic condiments in al-Andalus cuisine and was very similar to the Roman garum, it was the resulting liquid from the maceration of the intestines of certain fish with salt (García Sánchez, 1995). In Hospital da Misericordia, the $\delta^{15}N$ values might point to a minimal intake of marine protein and a primarily terrestrial animal protein consumption.

There is 1 outlier from Quinta da Boavista (LQB): LQB 4 with a $\delta^{15}N$ value of 9.30‰, which is the lowest $\delta^{15}N$ value of all the human samples, and the lowest compared with the other omnivorous (*Gallus gallus*). LQB 4 has a $\delta^{13}C$ value of -18.5‰, inside the mean for Quinta da Boavista, but not inside the mean for $\delta^{15}N$ values. This could be explained with a diet entirely restricted to C_3 plants and terrestrial animal protein, with almost no consumption of marine animal protein.

In fig. 19 there are two tendency lines showing a small correlation: it seems that while there is less negative $\delta^{13}C$ values, the $\delta^{15}N$ values are higher, and vice versa. This could be related with aquatic protein consumption and will be discussed further with the $\delta^{34}S$ resultant values.

To sum up, it can be implied that human bone data reflects a C_3 plant based diet, with C_4 plant inputs (that are higher in the case of Hospital da Misericordia) and terrestrial animal protein consumption with a small intake of aquatic animal protein (which is higher for the humans from Quinta da Boavista).

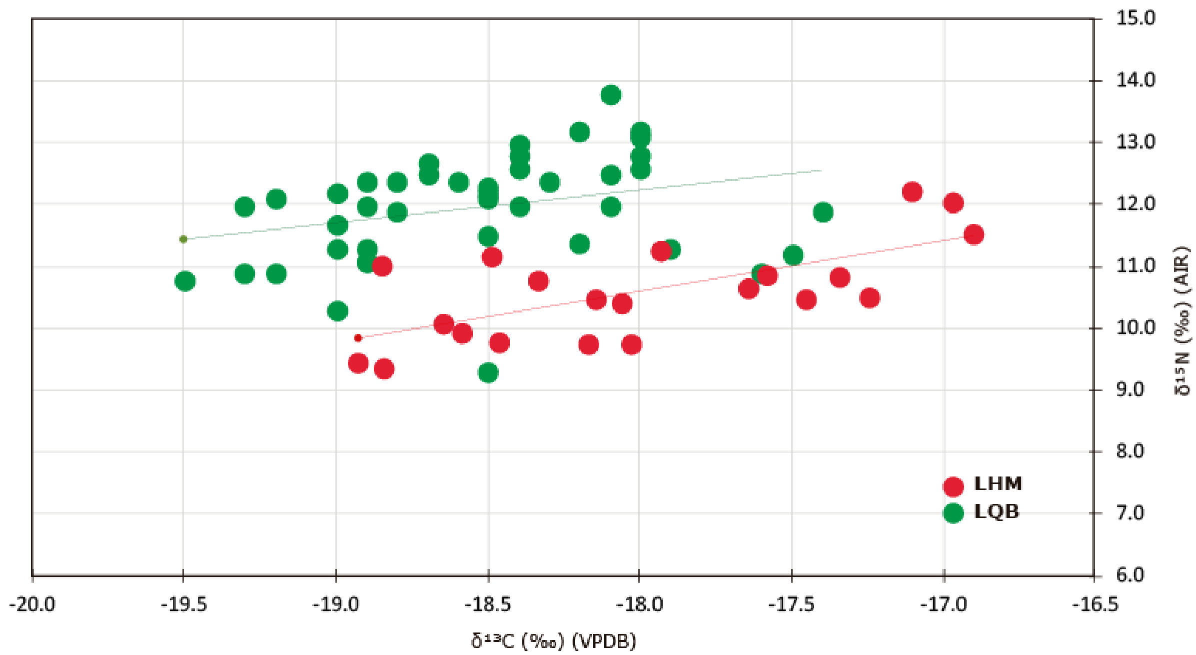


Figure 19. Carbon and Nitrogen stable isotope from human bone collagen of LQB and LHM. Tendency lines are shown to depict correlation between $\delta^{15}N$ and $\delta^{13}C$.

The $\delta^{34}S$ values from human bone collagen from both cemeteries (table 6 and 7, fig. 20) showed that the positive correlation seen between $\delta^{13}C$ and $\delta^{15}N$ values, was also present between $\delta^{34}S$ and $\delta^{15}N$ (green line in fig. 20) which can be interpreted as while $\delta^{15}N$ increase, $\delta^{34}S$ increase too. This could mean that there is a possible consumption of marine protein by the individuals from Quinta da Boavista. The number of individuals analyzed from Hospital da Misericordia (n=9) is small to observe any type of correlation.

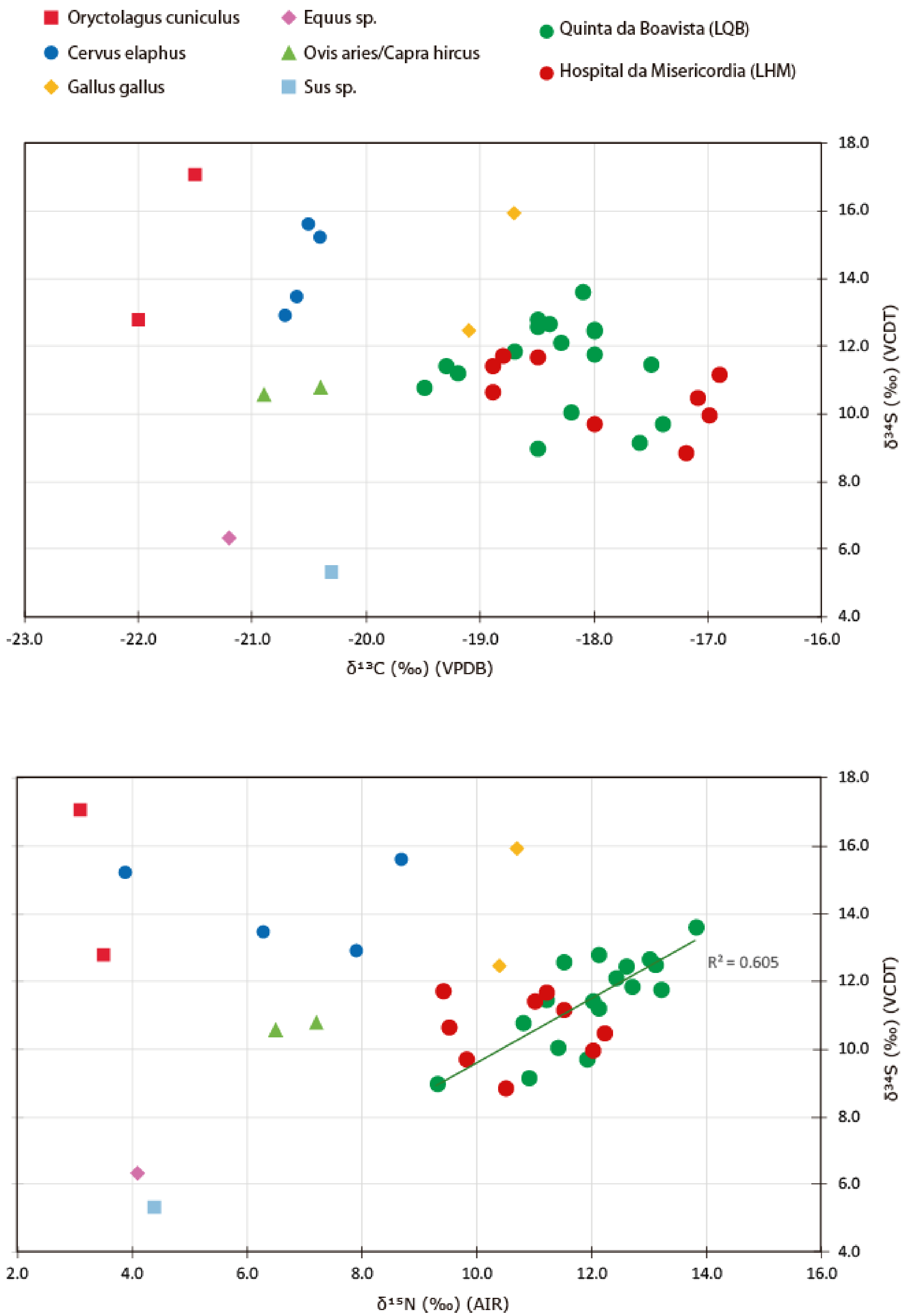


Figure 20. Graphs showing $\delta^{34}S$, $\delta^{13}C$ and $\delta^{15}N$ from the faunal and human bone collagen. A tendency line is present for discussion.

Bone collagen from both cemeteries show lower $\delta^{34}S$ values compared to the faunal group 1 (fig. 20). This could be the reflection of an average value of the consumption of both faunal groups (1 & 2); in order to know this, the consumer-diet spacing can be calculated. Nevertheless, is important to mention that there is no standard average sulfur isotopic spacing between humans (consumers) and their diet; there is one obtained from published archaeological studies of +0.8 ± 2.5‰ (Nehlich, 2015), which has a large standard deviation.

The difference between the faunal bone collagen (possible diet) and the human bone collagen (consumer) from both cemeteries is -1.2‰, that agrees with the referential range made with archaeological studies mentioned by Nehlich (2015). However, it is important to mention that equines and pigs (group 2) were animals that were not consumed as often as other terrestrial animals according to the historical sources; horse was not normally consumed and would evidence an episode of food shortage (Telles Antunes, 1996), while pig was a prohibited foodstuff in the religious norm (*haram*). To have a spacing closer to the "daily diet" of the populations, the faunal group 1 $\delta^{34}S$ mean value (chickens, rabbits, red deer and ovicaprids) was compared with the $\delta^{34}S$ mean value of both cemeteries. A consumer-diet spacing of -2.3‰ was obtained, that is outside the proposed range. If Quinta da Boavista individuals seem to have consumed marine animal protein and terrestrial protein, why a lower $\delta^{34}S$ mean value is obtained in contrast with the fauna? Individuals who lived in Loulé would had also experienced the sea spray effect and the influence of marine grasses in manure and later in their food web, why humans have a lower $\delta^{34}S$ than the fauna?

A possibility could be that part of the foodstuffs consumed by the individuals were not from Loulé, but from a place where the $\delta^{34}S$ value was lower. Cereals were a central foodstuff in al-Andalus cuisine, for the elaboration of bread e.g.; however, the Algarve does not have suitable terrains for major cereal cultivation (Catarino, 1997/1998), which would create a demand that would had been fulfilled through trade with places that had wheat, barley, millet, etc., for example the Alentejo: where Beja, Serpa and Mértola exported wheat to the Algarve in the Islamic medieval period, as mentioned by the historical sources (Oliveira Marques, 1968). Other foodstuffs could have been also brought to Loulé, like meat or freshwater fish, that would influence their $\delta^{34}S$ value. All these elements could have been obtained from souks and through trade.

Humans having lower $\delta^{34}S$ than fauna also occurred in the studies made from Es Soto, Spain (Nehlich, et al., 2012) and Tomar, Portugal (Curto, et al., 2019); in Es Soto the individuals living under Islamic rule seemed to have consumed food that did not come from the locality, and that came from other places through trade (Nehlich, et al., 2012). Trading routes during al-Andalus were sophisticated and enabled commerce between Europe and the north of Africa, and the results could be an evidence of it.

Some considerations about dietary differences between Quinta da Boavista and Hospital da Misericordia

Differences between sample groups were analyzed by applying the two-tailed Mann-Whitney U test; this test was selected because of the small sample size of each group; and is used to compare differences between 2 groups. A critical p value of p=0.05 was used. If the p-value obtained from the Mann-Whitney U test is greater than the critical one, it means that the mean values of each group do not differ with a significance level of 5%, while if the value obtained is lower than the critical p-value, the groups mean values differ by a significance level of 5%. Statistical analysis was done using SPSS.

There is a statistically significant difference between the $\delta^{13}C$ mean values from Quinta da Boavista and Hospital da Misericordia (p= 0.003), (see fig. 16) and between the $\delta^{15}N$ mean values (p= <0.001). There are not statistically significant differences between the $\delta^{34}S$ values from these cemeteries (p= 0.058). These would suggest that both contemporary groups conforming the 2 cemeteries had different diets or different access to foodstuffs, but were local to Loulé. Maybe they were part of two different socio-economical groups or two different families. Perhaps one of the cemeteries was used only by Arabs and Berbers, while the other by *Muladi* (people from the Iberian Peninsula who converted to Islam and lived under Islamic rule or children from a marriage between a Christian and a Muslim). It is important to mention that medieval Islamic society stratification was mainly by ethnic division (Guede, et al., 2017), where Arabs were the upper class minority, followed by the Berbers, then the Muladi, then Mozarabs (Christians living under Islamic rule) and Jews and finally the slaves. Because Arabs, Berbers and Muladi were Muslim, it could explain why both Loule's contemporary cemeteries followed the Islamic rite but were separated possibly by ethnic adscription.

Additionally, García-Collado (2016) mentions that small standard deviations are characteristic of societies with homogeneous diets, where there are no internal differences, or at least they are not materialized through food, while, on the contrary, large standard deviations are typical of heterogeneous communities where there are different levels of access to food resources, a reflection of the existence of internal social inequalities. In order to check this affirmation, the mean $\delta^{13}C$ and $\delta^{15}N$ values was calculated of the 2 groups together. The mean $\delta^{13}C$ value was

-18.35 ± 0.60‰ (with a range of 2.6‰) and the $\delta^{15}N$ value was 11.50 ± 1.06‰ (with a range of 4.5‰).

What do the differences between Quinta da Boavista and Hospital da Misericordia say about these two groups? Should we consider these differences as a reflection of social status and socio-economic inequalities?

Grau-Sologestoa (2017) mentions that there are some zooarchaeological markers to help us assume a high-status consumption: high number and variety of species, presence of game and wild birds, presence of rare/expensive species, high proportion of young animals and a high proportion of selected meaty body parts; some of these markers are present in the trash pits from Oficina do Senhor Carrilho, but we could not infer that these zooarchaeological remains are representative of the entire consumption of the population or just from a part of it.

Moreover, it is presupposed that the higher the trophic level, the higher the status (García-Collado, 2016); but, is it possible to affirm that in the case of both cemeteries? A higher consumption of fish would reflect a higher trophic level, but for medieval Islamic high classes, fish was not part of their tables as a principal dish. Consumption of sorghum and millet would reflect an enrichment of ^{13}C that would probably mean reduced-wheat period or a low-class adscription, but it could also reflect consumption of fish from lower trophic levels or shellfish, which have $\delta^{15}N$ values ranging between 7 and 8‰ (Mays, 1998). In this case the cultural context influenced food choices, instead of availability; the question now would be if this was indeed a cultural influenced choice or socio-economical dependent. In the following sections the identification of a possible conditioned food choice by other variables, such as sex, age or specific characteristics is revised.

6.23 Discussion by sex

From the human remains from Quinta da Boavista, female and male values do not show significant statistical differences of δ^{13}C values (p=0.161), δ^{15}N values (p=0.730), and δ^{34}S values (p=0.441). The difference in δ^{13}C is of 0.3‰ and 0.2‰ in δ^{15}N. Females have a slightly higher δ^{15}N, a slightly more negative δ^{13}C value and a lower δ^{34}S value than males (table 8 and 9, fig. 21).

Table 8. Carbon, Nitrogen and Sulfur stable isotope data from Quinta da Boavista. By sex

Carbon and Nitrogen stable isotope data from Quinta da Boavista. By sex									
Sex	N	δ^{13}C$_{VPDB}$(‰)				δ^{15}N$_{AIR}$(‰)			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Female	17	-19.5	-17.6	1.9	-18.7± 0.45	10.8	13.2	2.4	11.9± 0.69
Male	17	-19.3	-17.4	1.9	-18.4± 0.58	9.3	13.2	3.9	11.7± 1.02
Undetermined	8	-18.8	-18.0	0.8	-18.3± 0.27	12.0	13.8	1.8	12.7± 0.56
Sex	N	δ^{34}S$_{VCDT}$(‰)							
		Min	Max	Range	Mean ± 1σ				
Female	6	9.2	12.1	2.9	11.1± 1.0				
Male	9	9.0	12.8	3.8	11.4± 1.4				

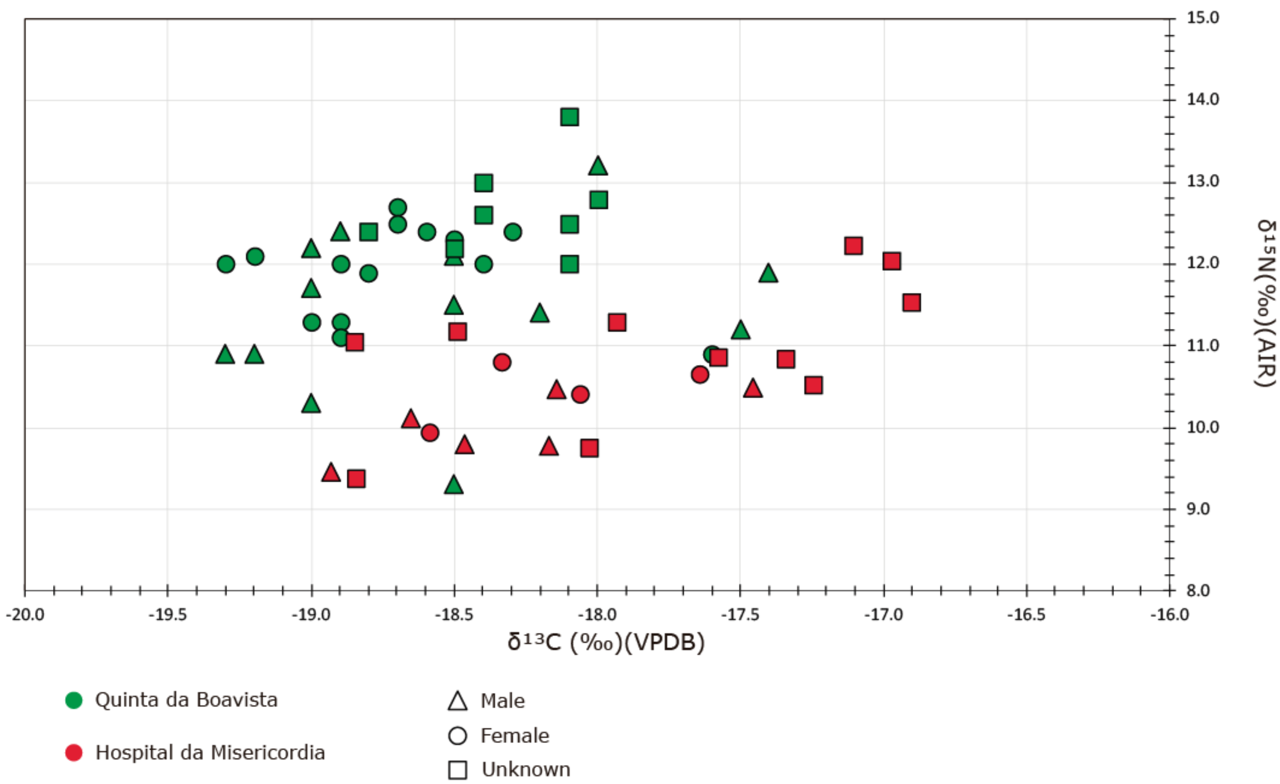


Figure 21. Carbon and Nitrogen stable isotope data from human bone collagen. Plotted by site and sex.

There are no significant statistical differences as well between female and male bone collagen $\delta^{13}C$ (p=0.522) and $\delta^{15}N$ (p=0.133) mean values from Hospital da Misericordia (table 9). As in Quinta da Boavista, females have a higher $\delta^{15}N$ mean value than males one, with a difference of +0.5‰. The $\delta^{13}C$ mean value of males is 0.1‰ more negative than the one of females.

There is no written evidence to suggest that Muslim females and males had a different diet, only special arrangements were made for women during pregnancy or lactation periods (Alexander, et al., 2015). Guede et al. (2017) mentioned that adult males were the most privileged members of society in the medieval Muslim world, however, the carbon and nitrogen stable isotopic data reflected no evident differences in the case of the cemeteries of Loulé. Toso et al. (2019) study agrees that sex difference in diet is not a consistent trend among isotopic datasets for Muslim populations. If males were privileged in the medieval Muslim period, these differences were not shown through diet.

Later a comparison between females from both cemeteries and males was done (fig. 22). Females mean $\delta^{13}C$ (p=0.031) and $\delta^{15}N$ (p=0.003) values were significantly different compared to each other; while males mean $\delta^{13}C$ (p=0.623) and $\delta^{15}N$ (p=0.003) compared between LQB and LHM showed to be different in $\delta^{15}N$ values, but not for $\delta^{13}C$ mean values. Males from Quinta da Boavista have higher $\delta^{15}N$ mean values than Hospital da Misericordia's males. This difference could mean that males and females from LQB consumed food stuffs enriched in ^{15}N than males from LHM like chicken or eggs, as discussed previously.

The difference in bone collagen $\delta^{13}C$ between females could be due to a higher input of C_4 plants and lower consumption of animal protein from females from Hospital da Misericordia. These differences could relate to social class, where the lower class would have a higher C_4 plants consumption than the higher class; however, the number of women compared from Hospital is significantly low (n=4), which may bias the true representativity of this sex in the cemetery.

Table 9. Carbon and Nitrogen stable isotope data from Hospital da Misericordia. By sex

Carbon and Nitrogen stable isotope data from Hospital da Misericordia. By sex									
Sex	n	**$\delta^{13}C_{VPDB}$(‰)**				**$\delta^{15}N_{AIR}$(‰)**			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Female	4	-18.6	-17.6	1.0	-18.2± 0.40	10.0	10.8	0.8	10.5± 0.37
Male	6	-18.9	-17.5	1.4	-18.3± 0.51	9.5	10.5	1.0	10.0± 0.42
Undetermined	11	-18.9	-16.9	2.0	-17.8± 0.72	9.4	12.2	2.8	11.0± 0.86

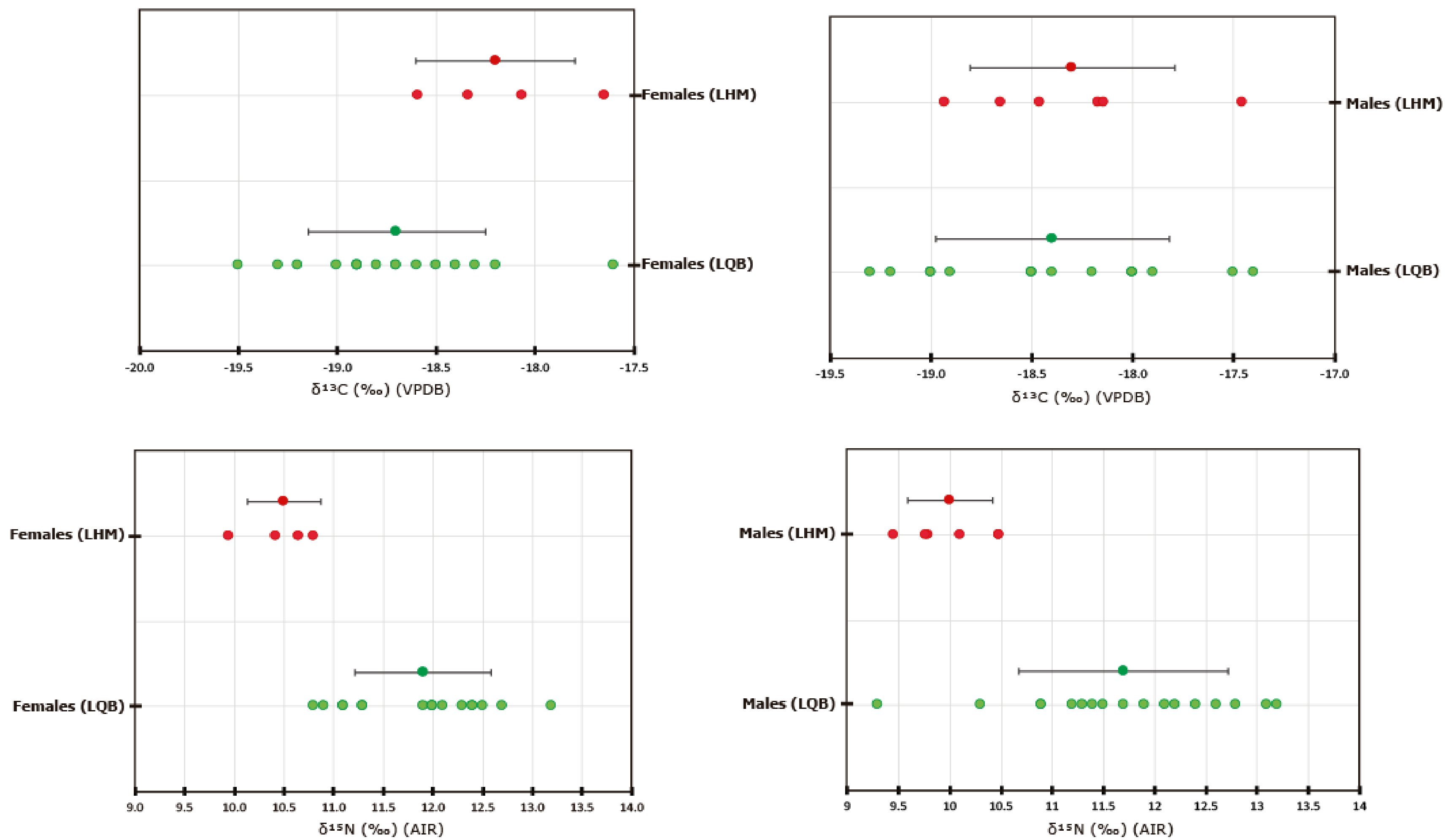


Figure 22. Figure depicting a comparison between male and female carbon and nitrogen stable isotopes from Quinta da Boavista (LQB) and Hospital da Misericordia (LHM)

6.24 Discussion by Age

The samples from Quinta da Boavista were divided into 3 age groups: children (0-12 years old), sub-adults (13-17 years old) and adults (>18 years old) (table 10).

Table 10. Age groups from the cemetery of Quinta da Boavista (LQB)

Age groups from the cemetery of Quinta da Boavista (LQB)		
Age group	**N**	**Samples number (LQB)**
Children (0-12 years old)	1	LQB 11
Sub-adults (13-17 years old)	4	LQB 20, LQB 24, LQB 40, LQB 41
Adults (>18 years old)	28	LQB 1, LQB 2, LQB 3, LQB 4, LQB 5, LQB 8, LQB 9, LQB 10, LQB 12, LQB 13, LQB 14, LQB 15, LQB 16, LQB 17, LQB 19, LQB 20a, LQB 21, LQB 28, LQB 29, LQB 30, LQB 31, LQB 32, LQB 33, LQB 34, LQB 35, LQB 37, LQB 38, LQB 39
Undetermined	9	LQB 6, LQB, 7, LQB 18, LQB 22, LQB 23, LQB 25, LQB 26, LQB 27, LQB 36

Bone collagen from the child from Quinta da Boavista (n=1) yields a $\delta^{15}N$ value of 12.4‰, which is higher by ~1.0‰ than the mean ones of adults and sub-adults. These could be resulting from a nursing effect in which elevations of 2-3‰ in $\delta^{15}N$ above the adult mean for individuals up to the age of two can be observed (Nitsch, et al., 2011).

Later, the values obtained for adults and sub-adults were compared (table 11), and there were no significant statistical differences between the both: $\delta^{13}C$ (p=0.587) and $\delta^{15}N$ (p=0.332). The difference between both groups ranged between 0.1‰ and 0.5‰, respectively. This suggests that diet did not vary between adults and sub-adults, nonetheless, the sub-adult group is small (n=4) in comparison to the adult group (n=28), which may not be truly representative of this age group.

Table 11. Carbon, Nitrogen and Sulfur stable isotope data from Quinta da Boavista. By age groups.

Carbon and Nitrogen stable isotope data from Quinta da Boavista. By age groups.									
Age group	N	**$\delta^{13}C_{VPDB}$(‰)**				**$\delta^{15}N_{AIR}$(‰)**			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Children	1	-	-	-	-18.8	-	-	-	12.4
Sub-adults	4	-19.3	-18.1	1.2	-18.7± 0.55	10.3	12.6	2.3	11.45± 1.04
Adults	28	-19.2	-17.5	1.7	-18.6± 0.47	9.3	13.2	3.9	11.92± 0.81
Undetermined	9	-19.5	-17.4	2.1	-18.3± 0.61	10.8	13.8	3	12.24± 1.05
Sex	N	**$\delta^{34}S_{VCDT}$(‰)**							
		Min	Max	Range	Mean ± 1σ				
Adult	14	9.0	12.8	3.8	11.5± 1.2				

Similarly, samples from Hospital da Misericordia were separated into 3 age groups: children (0-12 years old), sub-adults (13-17 years old), and adults (>18 years old) (table 12).

Table 12. Age groups from the cemetery of Hospital da Misericordia (LHM)

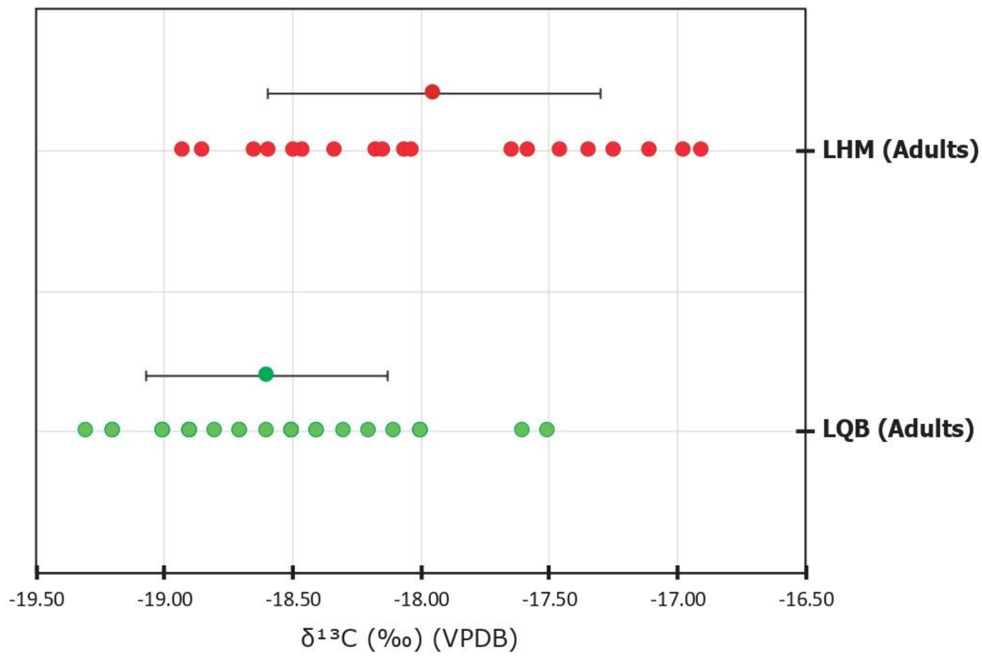
Age groups from the cemetery of Hospital da Misericordia (LHM)		
Age group	**n**	**Samples number (LHM)**
Children (0-12 years old)	1	LHM 22
Sub-adults (12-17 years old)	1	LHM 29
Adults (>18 years old)	19	LHM 4, LHM 5, LHM 6, LHM 7, LHM 12, LHM 13, LHM 14, LHM 15, LHM 16, LHM 17, LHM 18, LHM 25, LHM 30, LHM 31, LHM 32, LHM 33, LHM 34, LHM 36, LHM 37

The child and sub-adult groups are composed by a single individual. Further statistical analysis was therefore not possible.

Table 13. Carbon, Nitrogen and Sulfur stable isotope data from Hospital da Misericordia. By age groups.

Carbon and Nitrogen stable isotope data from Hospital da Misericordia. By age groups.									
Age group	N	$\delta^{13}C_{VPDB}$(‰)				$\delta^{15}N_{AIR}$(‰)			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Child	1	-	-	-	-17.90	-	-	-	11.3
Sub-adult	1	-	-	-	-18.80	-	-	-	9.4
Adult	19	-18.9	-16.9	2.0	-17.95 ± 0.65	9.5	12.2	2.7	10.63 ± 0.76
Sex	N	$\delta^{34}S_{VCDT}$(‰)							
		Min	Max	Range	Mean ± 1σ				
Adult	8	8.9	11.7	2.8	10.5± 0.9				

Adult groups stable isotopic data, belonging to both cemeteries, was compared (fig. 23). Adults $\delta^{13}C$ mean values were significantly different (p=0.002), with a difference between groups of ~0.7‰, while $\delta^{15}N$ mean values were also significantly different (p=<0.001) with a difference between groups of 1.2‰. As with the comparison between the entire data of both cemeteries, it seems that both groups had different access to foodstuffs or different diets. The comparison of $\delta^{34}S$ of adults group (fig. 24) showed that their sulfur stable isotope values were significantly different (p=0.029), which would evidence a higher input of a foodstuff rich in sulfur (probably marine protein) by the individuals from Quinta da Boavista.



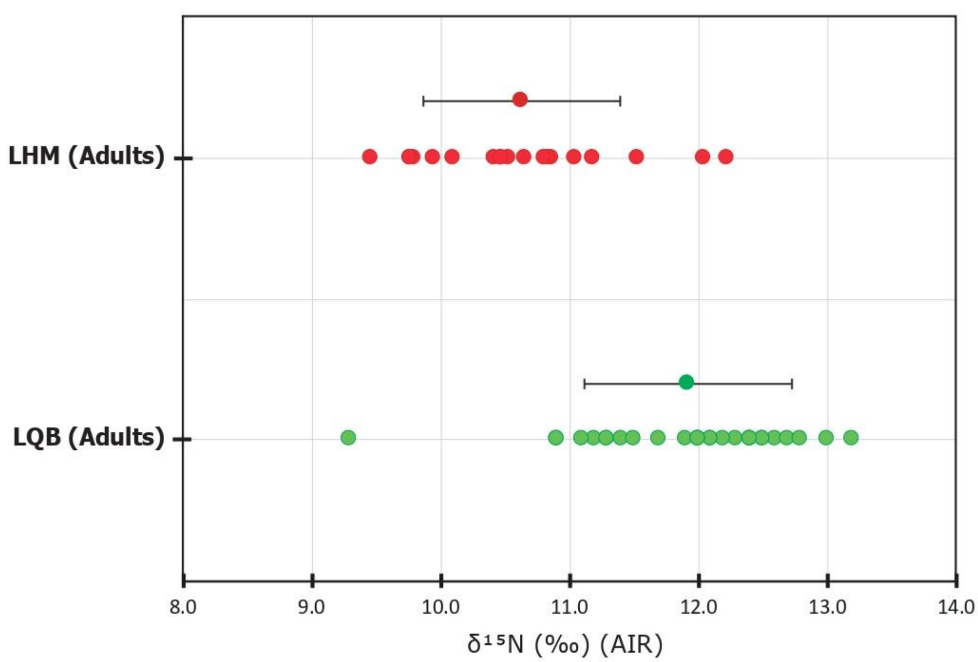


Figure 23. Carbon and Nitrogen stable isotope data for human bone samples, plotted by age. Adults.

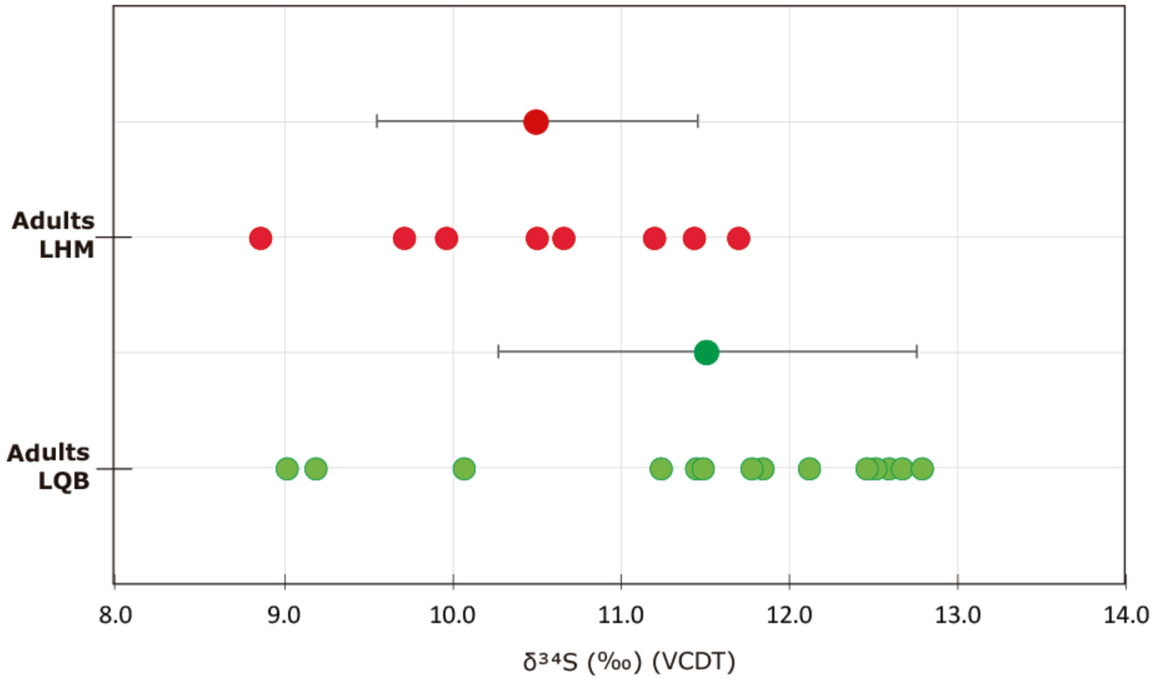


Figure 24. Sulfur stable isotope data for human bone samples, plotted by age. Adults

6.25 Discussion by discrete traits and pathologies

In Quinta da Boavista human bone remains had a high incidence of certain traits: the septal opening of the humerus and the absence of fusion of the first vertebrae of the sacrum in individuals older than 30 years old (see chapter 3.1). The individuals also possessed predominantly elongated skulls (dolichocephalic) and a series of unusual features, like posterior flattening, narrow front and great robustness in certain areas of cranial muscle insertion (Cunha, et al., 2001; Departamento de Antropologia, 2000). These peculiar incident characters may suggest a high level of endogamy in this population, as thought by the anthropologist Cunha (2001). It would have been a relatively "closed" population (Departamento de Antropologia, 2000).

In Hospital da Misericordia, the septal opening of the humerus is also present in a significant percentage of the individuals (Benisse, 2009), however, the anthropological report does not specify which individuals had this character. Comparison between individuals from both cemeteries with this same discrete character was therefore not possible.

Guede et al. (2017) mentions that in the medieval Islamic period, endogamous marriages were viewed as the ideal system in an ethnically stratified society. If each of the cemeteries was used by two different ethnic groups (probably one cemetery for Arabs and Berbers, and the other for Muladi), this high level of endogamy would be compatible to this hypothesis.

The samples with each of these characters were separated to look for any tendency between groups. The first one is that the individuals who had the septal opening of the humerus, do not have the first sacral vertebra fused after 30 years old (table 14 and 15; fig. 25).

Three other individuals were also separated (LQB 30 and LQB 31), with "Sindrome do Cavaleiro" and Porotic hyperostosis, respectively. The "Sindrome do Cavaleiro" (Knight's syndrome) comprehends all the non-articular degenerative lesions of the proximal end of the femurs underlining the strong commitment of the extensor and rotatory muscles that participate in a horse rider's posture. Porotic hyperostosis is a pathological condition that affects bones of the cranial vault. It manifests with localized porosity on the outer surface of the cranial vault and it appears as consequence to the increased production of blood cells. This is a compensation mechanism followed by a reduction in red blood cells or hemoglobin in the blood, caused essentially by different forms of anemia (Minozzi & Canci, 2015).

Table 14. Groups divided by discrete traits or pathologies from the cemetery of Quinta da Boavista (LQB)

Groups divided by incident character or disease from the cemetery of Quinta da Boavista (LQB)		
Pathology or discrete trait	**N**	**Samples number (LQB)**
1st sacral vertebra is not fused after 30 years old	6	LQB 4, LQB 18, LQB 28, LQB 29, LQB 38, LQB 39
Septal opening in humerus	5	LQB 1, LQB 12, LQB 13, LQB 17, LQB 37
Sindrome do Cavaleiro	1	LQB 30
Porotic hyperostosis	2	LQB 31, LQB 32

Table 15. Carbon and Nitrogen stable isotope data from Quinta da Boavista. By incident character or disease

Carbon and Nitrogen stable isotope data from Quinta da Boavista. By pathology or discrete trait									
Pathology or discrete trait	n	$\delta^{13}C_{VPDB}$(‰)				$\delta^{15}N_{AIR}$(‰)			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
1st sacral vertebra is not fused after 30 years old	6	-19.0	-18.0	1.0	-18.44± 0.36	9.3	13.2	3.9	11.90± 1.32
Septal opening in humerus	5	-19.2	-18.0	1.2	-18.60± 0.51	11.3	12.6	1.3	11.96± 0.59
Sindrome do Cavaleiro	1	-	-	-	-17.5	-	-	-	11.2
Porotic hyperostosis	2	-18.5	-18.3	0.2	-18.4± 0.14	11.5	12.4	0.9	11.95± 0.64
Without any of these	29	-19.5	-17.4	2.1	-18.58± 0.51	10.3	13.8	3.5	11.96± 0.83

First, the group without sacral fusion was compared with the group with the septal opening in humerus, $\delta^{13}C$ and $\delta^{15}N$ mean values were not significantly different (p=0.518, p=0.584, respectively). The same situation occurred when comparing these two groups with the group that did not present any character. The group with the 1st sacral vertebra not fused compared to the group without the character were also not significantly different; and the septal opening in humerus group compared to the group which did not present characters were not significantly different either in their $\delta^{13}C$ mean values and their $\delta^{15}N$ mean values.

It could be inferred that these two groups had a similar diet like the individuals without the characters or had similar access to foodstuffs; it is more likely that these individuals shared space and food. In the case of the individuals with porotic hyperostosis, they had similar $\delta^{13}C$ and $\delta^{15}N$ values to the mean values of Quinta da Boavista. Anemia seemed not to affect the stable isotopic values of both individuals' bone collagen.

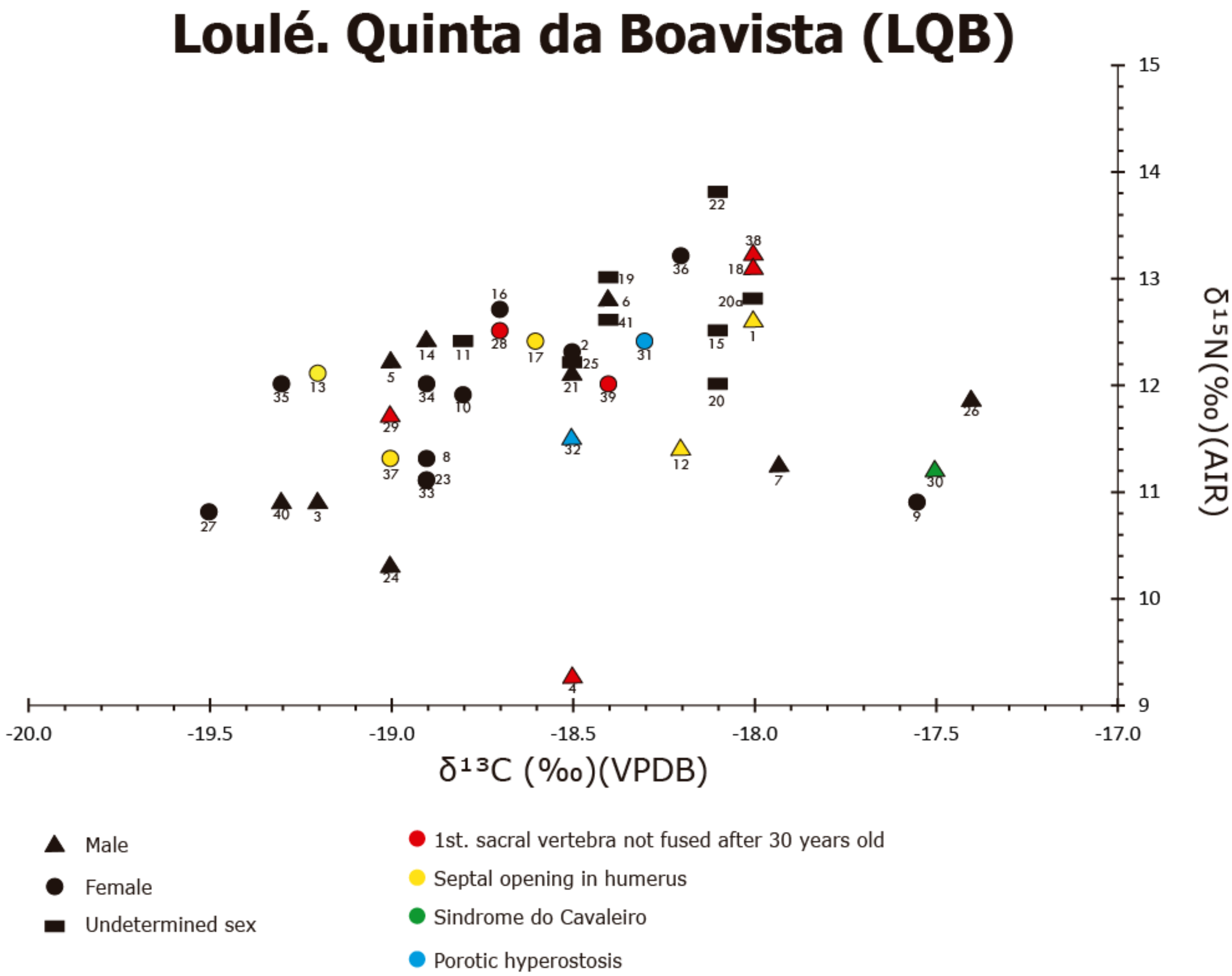


Figure 25. Groups divided by incident character or disease from the cemetery of Quinta da Boavista (LQB)

While the individual with Sindrome do Cavaleiro (LHM 30) has a difference of +1‰ in $\delta^{13}C$ values against the group without characters, the Mann-Whitney test showed that the group with no characters mean values do not differ by a significance level of 5% (p=0.117).

It would be interesting, in the future, to compare individuals with the septal opening of the humerus of both cemeteries, when more anthropological data from Hospital da Misericordia will be available.

6.26 Discussion of individuals found with goods

The presence of iron nails and crossbows bolts related to some of the burials from the cemetery of Quinta da Boavista was noticed. In the burial 32, 14 iron nails were collected; the nails were perfectly aligned along the skeleton, which may suggest that a wooden cover was used to cover it. Cases, like this one, were found in Andalusia in the *Yabal Faruh* cemetery in Malaga, for example. The wooden cover and nails would possibly be attributed to the Christian pressure or influence towards the Muslim populations. Also, in the same burial, 2 crossbow bolts were found associated to the superior part of the skeleton; in burial 38, 3 crossbow bolts were found also associated to the superior part of the skeleton (Luzia, 1999/2000). Iron nails were also found in burials 12 (1 nail), 25 (3 nails), and 34 (5 nails).

Presence of any goods related to the burials from Hospital da Misericordia were not reported. Comparison of stable isotopic data from bone collagen between groups (table 16 and 17; fig. 26) with iron nails, crossbow bolts and individuals with no materials found was done.

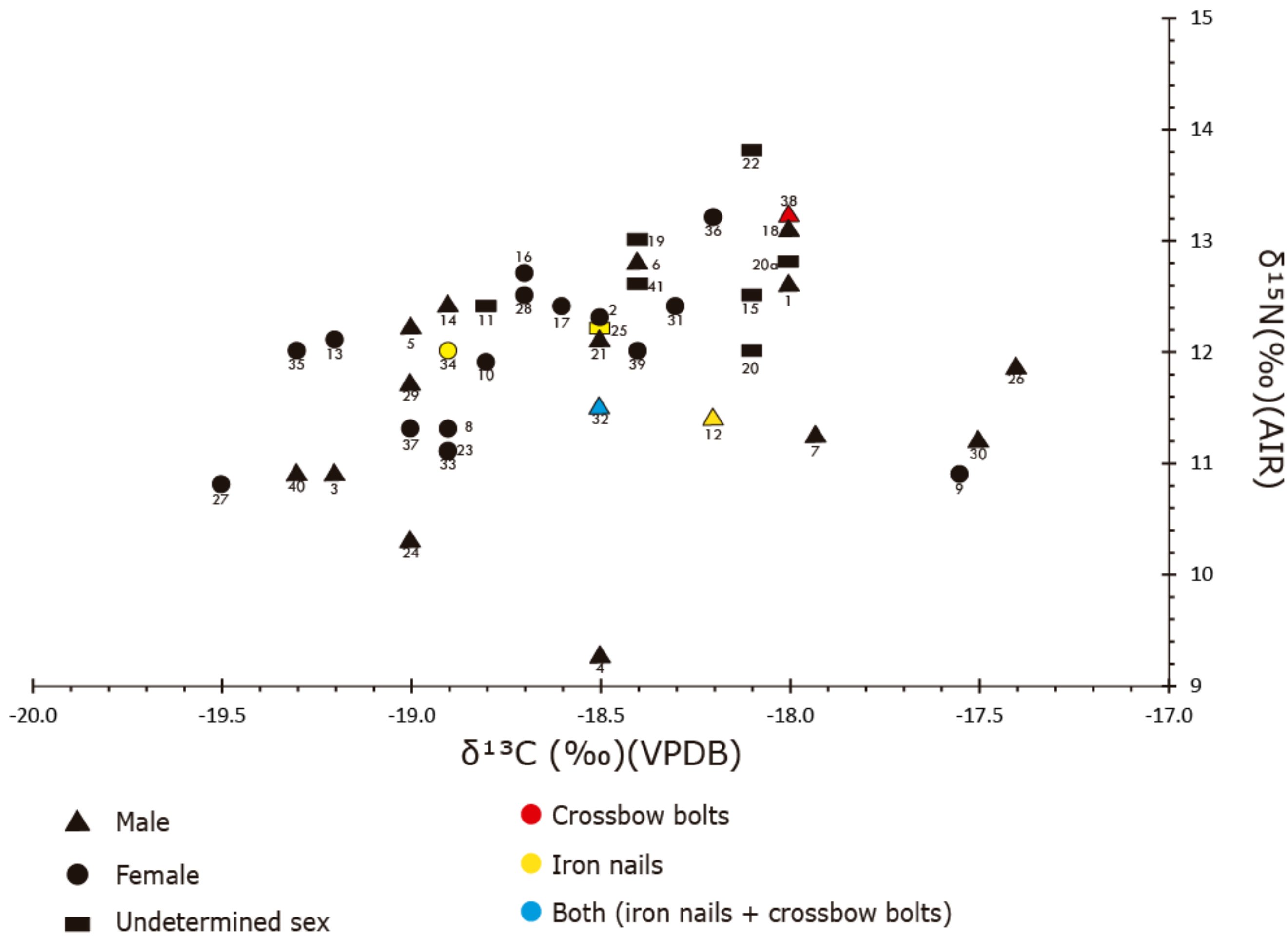


Figure 26. Groups divided by materials found in burial (LQB)

Table 16. Groups divided by materials found in burials

Groups divided by materials found in burials		
Material found	**N**	**Samples number (LQB)**
Iron nails	3	LQB 12, LQB 25, LQB 34
Crossbow bolts	1	LQB 38
Both (iron nails and crossbow bolts)	1	LQB 32

Table 17. Carbon and Nitrogen stable isotope data from burials with materials found

Carbon and Nitrogen stable isotope data from burials with materials found									
Disease or discrete character	N	$\delta^{13}C_{VPDB}$(‰)				$\delta^{15}N_{AIR}$(‰)			
		Min	Max	Range	Mean ± 1σ	Min	Max	Range	Mean ± 1σ
Iron nails	3	-18.9	-18.2	0.7	-18.5± 0.35	11.4	12.2	0.8	11.9± 0.42
Crossbow bolts	1	-	-	-	-18.0	-	-	-	13.2
Both (iron nails and crossbow bolts)	1	-	-	-	-18.5	-	-	-	11.5
LQB without materials	37	-19.5	-17.4	2.1	-18.5± 0.52	9.3	13.8	4.50	11.9± 0.91

Individual LQB 32, who had iron nails and crossbow bolts related in burial, also had porotic hyperostosis. This individual had a similar diet to the individuals with no associated materials in their burials from Quinta da Boavista. The same situation can be seen with the individuals with iron nails associated to their burials. Individual LQB 38, with crossbow bolts associated to the burial, showed enrichment in ^{13}C and ^{15}N in comparison to the mean of the individuals without materials found in association to the burial.

Another hypothesis for the presence of iron nails is that a wooden board could have been used to protect the walls of the pit, preventing ground from touching the deceased. While the presence of the crossbow bolts could be related to an individual who died in battle or in a confrontation. The Islamic tradition mentions that the faithful killed during a warlike confrontation for the defense of Islam will not be subjected to ritual washing and will be buried with the wounds and blood remains that cover their body. Neither will any type of martyr, such as those killed by drowning, women who died while giving birth, those who died of an abdominal illness, who died on the way on their pilgrimage to Mecca, etc. would be subjected to the ritual washing (Chávet Lozoya, 2015). The individuals with crossbow bolts found within the burial could have died in a battle.

6.27 Comparison with other coetaneous sites

Individuals from Loulé (LQB and LHM) were compared with broadly coetaneous Muslim populations at several locations in the Iberian Peninsula (fig. 27) to characterize the Iberian medieval Islamic diet and to find differences between coetaneous sites under Muslim rule. In order to know if the human bone collagen isotopic composition would be comparable with the one of Loulé, the faunal baselines used by the authors in their studies were compared with the faunal remains of Oficina do Senhor Carrilho, that was used for this thesis.

The species chosen for the comparison were *Ovis aries/Capra hircus*, *Bos taurus*, *Gallus gallus* and *Sus sp*. Cattle (*Bos taurus*) was not present in Oficina do Senhor Carrilho, however, it was chosen for comparison in-between sites (table 18, fig. 28).

Figure 27. Map showing the coteaneous Islamic medieval sites for comparison. Adapted from d-maps.com

Table 18. Carbon and Nitrogen stable isotope data from coetaneous Islamic medieval faunal bone remains

Carbon and Nitrogen stable isotope data from coetaneous Islamic medieval faunal bone remains					
Site and Period	**Taxonomy**	**N**	**$\delta^{13}C_{VPDB}$(‰)** Mean ± 1σ	**$\delta^{15}N_{AIR}$(‰)** Mean ± 1σ	**Reference**
São Jorge Castle, Portugal (11th-12th CE)	Ovis aries	5	-20.80 ±0.6	6.60 ±2.4	(Toso, et al., 2019)
	Capra hircus	3	-20.20 ±0.6	6.50 ±3.6	(Toso, et al., 2019)
Benipeixcar, Spain (13th-16th CE)	Ovis aries/ Capra hircus	9	-19.30 ±0.2	4.00 ±0.8	(Alexander, et al., 2015)
Western Mediterranean		32	-19.70 ±0.7	5.50 ±2.0	(Dury, et al., 2018)
Valencia, Spain (11th-13th CE)		8	-19.50 ±0.6	6.50 ±2.6	(Alexander, et al., 2019)
Es Soto, Spain (10th-13th CE)		14	-19.80 ±0.7	6.50 ±2.3	(Fuller, et al., 2010)
Écija, Spain (9th-13th CE)		5	-20.30 ±0.7	7.60 ±1.3	(Inskip, et al., 2018)
Oficina do Senhor Carrilho, Portugal (12th-13th CE)		3	-20.40 ±0.5	6.87 ±0.3	This study
São Jorge Castle, Portugal (11th-12th CE)	Bos Taurus	10	-21.10 ±0.5	6.30 ±1.9	(Toso, et al., 2019)
Benipeixcar, Spain (13th-16th CE)		5	-17.80 ±2.8	7.00 ±1.2	(Alexander, et al., 2015)
Western Mediterranean		12	-19.30 ±2.2	7.20 ±1.2	(Dury, et al., 2018)
Valencia, Spain (11th-13th CE)		5	-18.00 ±1.7	6.20 ±2.3	(Alexander, et al., 2019)
Es Soto, Spain (10th-13th CE)		4	-20.30 ±0.1	8.10 ±0.3	(Fuller, et al., 2010)
Écija, Spain (9th-13th CE)		6	-19.20 ±1.1	6.90 ±2.2	(Inskip, et al., 2018)
São Jorge Castle, Portugal (11th-12th CE)	Gallus gallus	5	-19.00 ±0.6	9.40 ±1.3	(Toso, et al., 2019)
Benipeixcar, Spain (13th-16th CE)		4	-15.80 ±2.1	9.30 ±1.8	(Alexander, et al., 2015)
Valencia, Spain (11th-13th CE)		2	-13.95	11.40	(Alexander, et al., 2019)
Oficina do Senhor Carrilho, Portugal (12th-13th CE)		3	-19.00 ±0.2	10.93 ±0.6	This study
São Jorge Castle, Portugal (11th-12th CE)	Sus sp.	6	-20.0 ±0.8	6.60 ±1.0	(Toso, et al., 2019)
Benipeixcar, Spain (13th-16th CE)		1	-17.80	6.60	(Alexander, et al., 2015)
Western Mediterranean		4	-19.80 ±1.4	5.80 ±0.7	(Dury, et al., 2018)
Valencia, Spain (11th-13th CE)		1	-19.50	7.70	(Alexander, et al., 2019)
Es Soto, Spain (10th-13th CE)		1	-19.70	5.10	(Fuller, et al., 2010)
Écija, Spain (9th-13th CE)		1	-19.30	8.10	(Inskip, et al., 2018)
Oficina do Senhor Carrilho, Portugal (12th-13th CE)		1	-20.30	4.40	This study

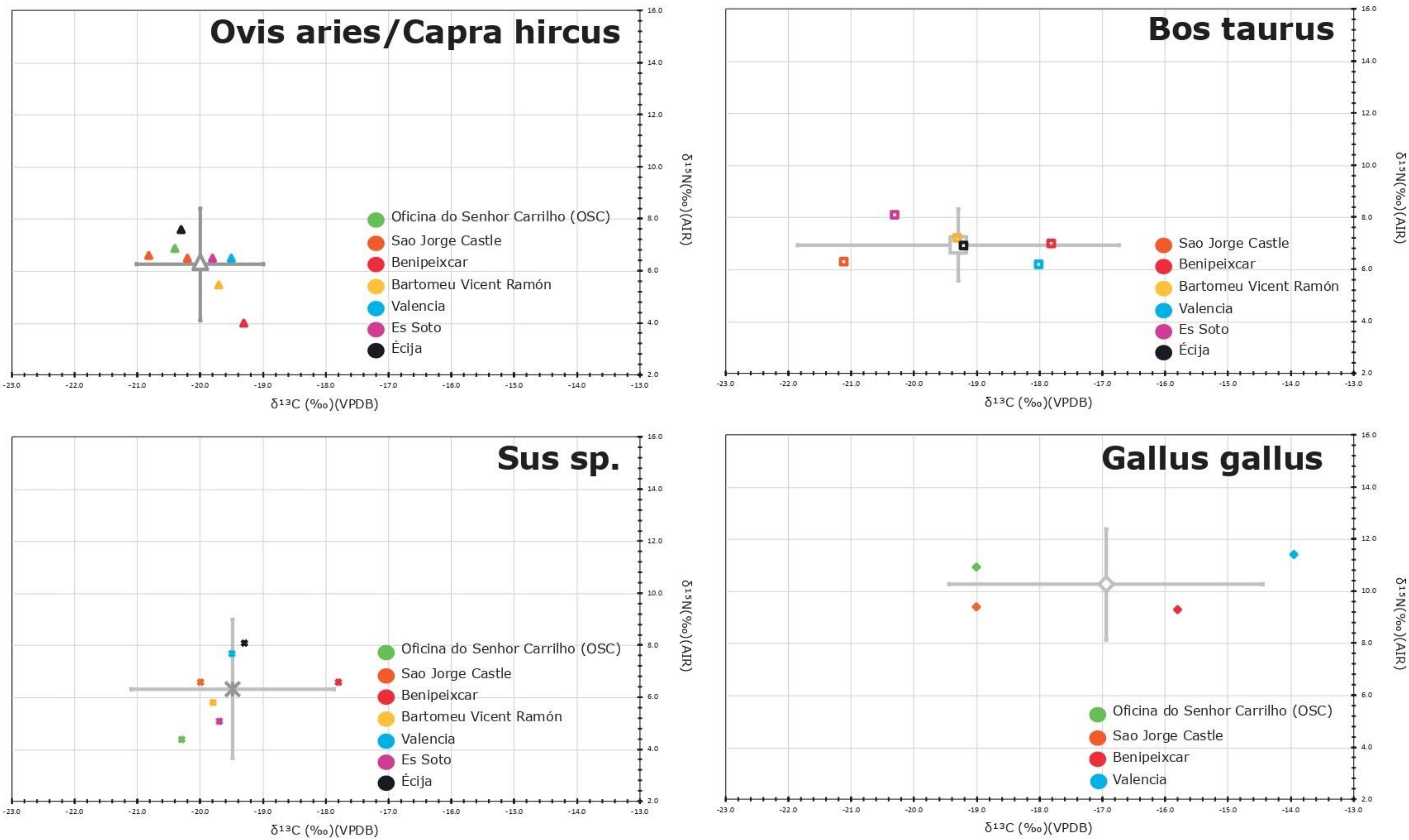


Figure 28. Carbon and Nitrogen stable isotope data from coetaneous Islamic medieval faunal bone remains

The differences between mean values of $\delta^{13}C$ and $\delta^{15}N$ from the sites per species ranged from 1.9‰ (difference of the maximum $\delta^{15}N$ value and the minimum $\delta^{15}N$ value of *Bos taurus*) to 5.05‰ (difference of the maximum $\delta^{13}C$ value against the minimum $\delta^{13}C$ value of *Gallus gallus*). The site that had the most similar faunal baseline compared to Oficina do Senhor Carrilho was the one from São Jorge Castle, Lisbon, Portugal. Summing up, most of the faunal baselines have similar stable isotopic values like the ones from Oficina do Senhor Carrilho (fig. 28).

Later the comparison between human values from the different medieval Islamic sites in the Iberian Peninsula was done (table 19). Some of the sites used the faunal baseline from other studies, because they lacked faunal remains related to their sites. Pickard et al. (2017), in the study of Can Fonoll human remains, used as baseline the faunal data from Es Soto (Fuller, et al., 2010); while Guede et al. (2017) and Jiménez-Brobeil et al. (2016) used as baseline the faunal data from Benipeixcar (Alexander, et al., 2015).

Table 19. Carbon and Nitrogen stable isotope data from coetaneous Islamic medieval faunal bone remains

Carbon and Nitrogen stable isotope data from coetaneous Islamic medieval faunal bone remains				
Site and Period	**N**	**$\delta^{13}C_{VPDB}$(‰)**	**$\delta^{15}N_{AIR}$(‰)**	**Reference**
		Mean ± 1σ	Mean ± 1σ	
São Jorge Castle, Portugal (11th-12th CE)	10	-18.90 ±0.3	9.90 ±0.8	(Toso, et al., 2019)
Benipeixcar, Spain (15th-16th CE)	20	-16.40 ±1.0	10.70 ±0.6	(Alexander, et al., 2015)
Bartomeu Vicent Ramón (10th-12th CE)	42	-18.60 ±0.8	10.80 ±0.8	(Dury, et al., 2018)
Valencia, Spain (11th-13th CE)	38	-17.70 ±1.3	11.50 ±1.4	(Alexander, et al., 2019)
Es Soto, Spain (10th-13th CE)	21	-18.10 ±1.3	10.90 ±1.0	(Fuller, et al., 2010)
Écija, Spain (9th-13th CE)	38	-19.10 ±0.3	10.00 ±1.0	(Inskip, et al., 2018)
Can Fonoll, Spain (10th-13th CE)	112	-19.00 ±1.3	10.30 ±0.8	(Pickard, et al., 2017)
Tauste, Spain (8th-10th CE)	31	-19.10 ±0.5	15.00 ±1.7	(Guede, et al., 2017)
La Torrecilla, Spain (13th-15th CE)	5	-14.40 ±2.1	10.20 ±0.9	(Jiménez-Brobeil, et al., 2016)
Quinta da Boavista, Portugal (12th-13th CE)	42	-18.53 ±0.5	11.95 ±0.9	This study
Hospital da Misericordia, Portugal (12th-13th CE)	21	-17.99 ±0.6	10.60 ±0.8	This study
Total	380	-17.98 ±1.4	11.08 ±1.4	

Overall, all the sites (table 19, fig. 29) compared depicted $\delta^{13}C$ mean values ranging from -19.10‰ to -14.40‰ (La Torrecilla). If La Torrecilla and Benipeixcar are excluded, the rest of the sites present $\delta^{13}C$ values between -19.10‰ to -17.70‰, which would suggest a diet based mainly on C_3 plants or domestic herbivores that foddered on C_3 plants. On the other hand, $\delta^{15}N$ values ranged from 9.90‰ to 15.00‰, which comprehends a range of 5.10‰. If we remove Tauste from the consideration ($\delta^{15}N$ mean value: 15.00 ± 1.7‰), the remaining sites $\delta^{15}N$ mean values would be in a range between 9.90‰ and 11.95‰. This suggests a mainly terrestrial animal protein and pulses consumption, with potentially small inputs of aquatic animal protein. Interestingly, LQB is amongst the highest in nitrogen isotopic values.

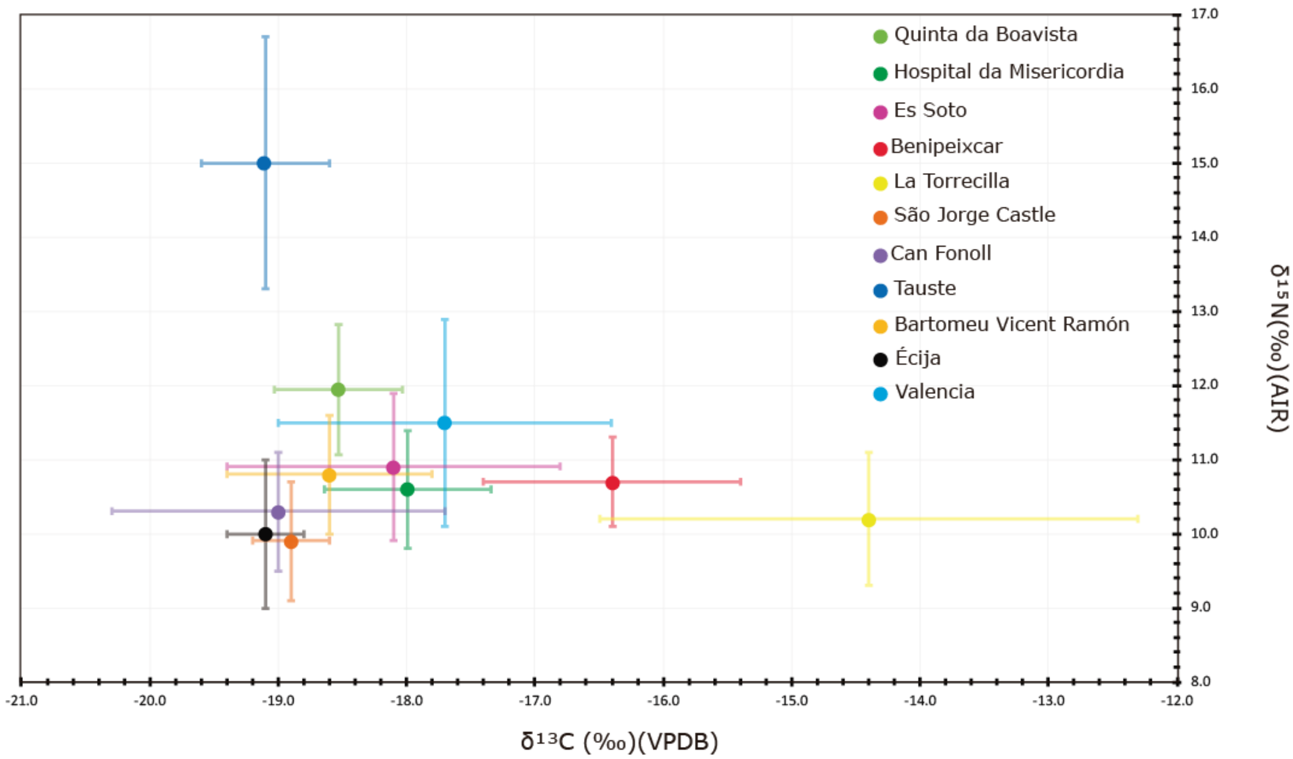


Figure 29. Carbon and Nitrogen stable isotope data from coetaneous Islamic medieval sites (mean+1SD)

Most of the Islamic medieval sites compared are close to the coast and consequently, to marine resources (with exception of Écija and Tauste). However, the stable isotopic signature shows that the individuals from these sites did not rely mainly on marine protein resources. It could be the case that the populations consumed marine fish from lower trophic levels (like sardines), hence the $\delta^{15}N$ value would reflect it and give an isotopic signature similar to the one of terrestrial animals.

The human remains data from Quinta da Boavista has the second highest $\delta^{15}N$ mean value, which would suggest a stronger input of marine animals or omnivorous animals, like chicken in their diet. On the contrary, Hospital da Misericordia presents values close to the mean ones of all the Islamic medieval sites.

Then, the sites which have stable isotopic values similar to both cemeteries from Loulé were compared; through applying the two-tailed Mann-Whitney U test. The closest sites were Valencia, Es Soto and Bartomeu Vicent Ramón; São Jorge Castle was chosen too, because of the similarity between faunal baseline with Loulé (table 20).

Table 20. p- values obtained from two-tailed Mann-Whitney U test

Site	Comparing Site	$\delta^{13}C$ p=value	$\delta^{15}N$ p=value
Quinta da Boavista	São Jorge Castle	0.047	< 0.001
	Valencia	0.002	0.021
	Es Soto	0.251	< 0.001
	Bartomeu Vicent Ramón	0.081	< 0.001
Hospital da Misericordia	São Jorge Castle	< 0.001	0.007
	Valencia	0.442	0.004
	Es Soto	0.148	0.203
	Bartomeu Vicent Ramón	< 0.001	0.251

Both cemeteries from Loulé's mean values were statistically different than São Jorge Castle mean value (5%, level of significance). Valencia and Quinta da Boavista $\delta^{13}C$ and $\delta^{15}N$ mean values were significantly different, while the $\delta^{13}C$ mean values from Valencia and Hospital da Misericordia were not significantly different (p=0.442), but their $\delta^{15}N$ mean values were.

The comparison between Es Soto and Hospital da Misericordia $\delta^{13}C$ and $\delta^{15}N$ mean values showed that they were not significantly different (p=0.148 and p=0.203, respectively). Quinta da Boavista compared to Es Soto demonstrate significantly different $\delta^{15}N$ mean values, but not different $\delta^{13}C$ mean values.

$\delta^{13}C$ and $\delta^{15}N$ mean values from Bartomeu Vicent Ramón compared to Loule's cemeteries showed that Quinta da Boavista $\delta^{13}C$ mean values and Hospital da Misericordia $\delta^{15}N$ values were not statistically different to Bartomeu Vicent Ramón mean values, but the others were significantly different.

In brief, the sites compared through the Mann-Whitney U test showed more similarities between $\delta^{13}C$ mean values than $\delta^{15}N$ mean values.

Individuals from the different Islamic medieval populations here compared exhibit similar values with small variations in $\delta^{13}C$ and $\delta^{15}N$ mean values. The range in variations in $\delta^{13}C$ can be explained by the introduction (sugar cane) and use (millet and sorghum) of distinct C_4 plants in the diet of these individuals, maybe influence from the Berber groups who came to the Peninsula; the diversity in $\delta^{15}N$ values reflects a variety of animal protein choices from low terrestrial protein consumption to aquatic protein consumption. These differences can be influenced by the local environment availability of certain foodstuffs, where the climate and soil can influence which foodstuffs can be produced and in which amount. The local lack of some foodstuffs could be fulfilled by trade, but this does not mean that everyone could manage to get them. The purchasing power to obtain certain foodstuffs that were not available locally would have been influenced by socio-cultural factors, such as ethnic adscription or fulfillment of religious norms (eating just halal foodstuffs). Data from other coetaneous Islamic sites in Portugal would be necessary for comparison to look if there are any trends observable, or if foodstuffs were something conditioned by the local availability.

Chapter 7. CONCLUSION

Stable isotopic analyses were used to provide part of the picture related to the diet of animals and individuals coming from two Islamic cemeteries in Loulé. The other part of the picture, identifying specific foodstuffs, can be done through other type of approaches, like mentioned in historical sources, in zooarchaeological and archaeobotanical remains present in the site. Carbon and nitrogen stable isotopes data from bone collagen helped to identify certain tendencies in protein intake, and the relative importance of certain food groups (C_3 and/or C_4 plants consumption, terrestrial animals and/or aquatic protein consumption).

The faunal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values obtained led to understand some of the husbandry practices during medieval times. Stable isotopic data from animals from Oficina do Senhor Carrilho allowed to distinguish between domesticated and wild animals, where red deer (*Cervus elaphus*) was part of the domesticated ones. The absence of cattle (*Bos taurus*) in the trash pits from OSC could be explained possibly by the use of red deer as a substitute of it. Animals studied indicate a C_3-plants based diet; they differed between each other probably because of agricultural practices, such as manuring and plowing that enriched the consumed plants with ^{15}N and ^{13}C. Differences were also observed through faunal bone collagen $\delta^{34}S$ values, were manuring practices with marine grasses, the geochemistry of the area and the sea spray effect showed 2 different groups: one influenced by these variables and one without.

The human bone collagen stable isotopic results presented here indicate also a mainly C_3-plants based diet with occasional C_4-plants inputs. There is a considerable degree of environmental and socio-economic influence in foodstuffs choice that could not only be obtained from historical sources alone. The isotopic data has indicated that there was a subtle diversity in diet in Islamic medieval Loulé, shown by the different results obtained for each of the cemeteries: Quinta da Boavista and Hospital da Misericordia. Individuals from each of the cemeteries differed in access to foodstuffs or differed in local preference of food choices. Individuals from Hospital da Misericordia's cemetery seemed to consume more C_4-plants (sorghum and millet), while Quinta da Boavista's cemetery individuals appear to consume more ^{15}N enriched foodstuffs or aquatic animals' protein. This was supported by Quinta da Boavista $\delta^{34}S$ obtained values, where a positive correlation between nitrogen and sulfur stable isotopes was observed.

Individuals from the two cemeteries do not appear to have consumed fish as a major foodstuff in their diets, which is interesting, because Loulé is close to the Littoral sub-region in the

Algarve. This choice seems to be more influenced by cultural or socio-economical aspects, rather than availability of the product. Sex or age-based differences were not found in each cemetery; however, when compared against each other, females from both cemeteries showed different diets. A conclusion cannot be drawn about it, because the female group from Hospital da Misericordia had a small size (n=4).

$\delta^{34}S$ values showed that local foodstuffs were not the only input in Loule's medieval population diet, but that a high number of ingredients or food were brought from other sites far from the coast, that would evidence sophisticated trading routes during the al-Andalus period.

The individuals from both cemeteries may be part of two ethnically distinct groups, because homogeneous diets were shown in the 2 cemeteries; individuals from each of the cemeteries had similar access to foodstuffs within the cemetery but differed in comparison to the other maqbara. The hypothesis is that probably Quinta da Boavista's individuals were part of an Arab or Berber group, while the individuals from Hospital da Misericordia were from a Muladi group (Islam converts). This hypothesis would benefit from the use of complementary stable isotope analysis, like strontium stable isotope, to identify migrations; DNA analysis to look for differences between individuals from both cemeteries to examine if the hypothesis would be plausible.

Archaeobotanical remains study would also help in this research to know about the major carpological remains found in Loulé and in the Algarve during the Islamic period, to help identify specific foodstuffs.

In conclusion, this study has provided a better understanding of the relative importance of foodstuffs in medieval Islamic diet from Loulé. The combined multidisciplinary approach used here offers an insight into the lifeways of an Islamic population from nowadays Portugal. Isotopic data from more al-Andalus Portugal medieval sites is necessary to extend the understanding of how diet influences and is influenced by cultural, socio-economic and religious factors.

REFERENCES

Aleixo, P., Valente, M. J. & Luzia, I., in press. Zooarchaeological study of Oficina do Senhor Carrilho, an urban Medieval Islamic site (Loulé, Portugal). In: M. J. Valente, C. Costa & C. Detry, eds. *New Trends in Iberian Zooarchaeology.* Oxford: Archaeopress Publishing.

Alexander, M. M., Gerrard, C. M., Gutiérrez, A. & Millard, A. R., 2015. Diet, Society and Economy in Late Medieval Spain: Stable Isotope Evidence From Muslims and Christians From Gandía, Valencia. *American Journal of Physical Anthropology,* 156(2), pp. 263-273.

Alexander, M. M. et al., 2019. Economic and socio-cultural consequences of changing political rule on human and faunal diets in medieval Valencia (c. fifth-fifteenth century AD) as evidenced by stable isotopes. *Archaeological and Anthropological Sciences.*

Alfonso X, 1280. Cantiga 183: The Moors of Faro who Threw a Statue of the Virgin into the Sea. In: *Cantigas de Santa Maria.* Madrid: Biblioteca del Escorial.

Ambrose, S. H., 1990. Preparation and Characterization of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science,* Issue 17, pp. 431-451.

Ambrose, S. H., 1993. Chapter 2. Isotopic Analysis of Paleodiets: Methodological and Interpretive Considerations. In: M. K. Sandford, ed. *Investigations of Ancient Human Tissue. Chemical Analyses in Anthropology.* USA: Gordon and Breach Science Publishers, pp. 59-130.

Ambrose, S. H. & Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: J. B. Lambert & G. Grupe, eds. *Prehistoric Human Bone. Archaeology at the Molecular Level.* Berlin: Springer, pp. 1-37.

Benisse, V., 2009. *Relatório dos Trabalhos de Antropología Física realizados no Hospital da Misericórdia, em Loulé.* Loulé: s.n.

Bocherens, H. & Drucker, D., 2003. Trophic Level Isotopic Enrichmnet of Carbon and Nitrogen in Bone Collagen: Case Studies from Recent and Ancient Terrestrial Ecosystems. *International Journal of Osteoarchaeology,* Volume 13, pp. 46-53.

Bogaard, A. et al., 2013. Crop manuring and intensive land management by Europe's first farmers. *Proceedings of the National Academy of Sciences,* Volume 110, pp. 12589-12594.

Bogaard, A., Heaton, T., Poulton, P. & Merbach, I., 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science,* Issue 34, pp. 335-343.

Botão, M. d. F., 2009. *A construção de uma identidade urbana no Algarve Medieval: O caso de Loulé.* First ed. Lisbon: Caleidoscópio_Edição e Artes Gráficas.

Bou-Gharios, G. & Crombrugghe, B. d., 2008. Type I Collagen Structure, Synthesis, and Regulation. In: J. P. Bilezikian, L. G. Raisz & T. J. Martin, eds. *Principles of Bone Biology.* San Diego: Academic Press Elsevier, pp. 285-318.

Brown, T. & Brown, K., 2011. *Biomolecular Archaeology: An Introduction.* s.l.:Wiley-Blackwell.

Brown, T. A., Nelson, D. E., Vogel, J. S. & Southon, J. R., 1988. Improved collagen extraction by modified Longin Method. *Radiocarbon,* 30(2), pp. 171-177.

Catarino, H., 1997/1998. A Sociedade e a Economia. *AL-ÚLYÁ,* II(6), pp. 662-712.

Catarino, H., 1997/1998. Aproximação ao território em estudo. *AL-ÚLYÁ,* I(6), pp. 31-60.

Catarino, H., 1997/1998. Aspectos sobre a Dieta Alimentar. *AL-ÚLYÁ,* II(6), pp. 739-750.

Catarino, H., 1997/1998. O contexto histórico: o processo de islamização e os territórios do Garbe Al-Andaluz. *AL-ÚLYÁ,* I(6), pp. 61-83.

Catarino, H., 1997/1998. Sinopse sobre a investigação na arqueologia do periodo islâmico. *AL-ÚLYÁ,* I(6), pp. 24-31.

Catarino, H., 1999. O Garbe Al-Andaluz: definição territorial e administrativa. In: *O Algarve da Antiguidade aos nossos dias (elementos para a sua história).* Lisbon: Edições Colibri, pp. 69-74.

Catarino, H., 2017. O atual território de Loulé no período islâmico. In: *Loulé. Territórios, Memórias, Identidades.* Lisbon: Museu Nacional de Arqueologia, pp. 450-462.

Chávet Lozoya, M., 2015. *Los rituales de enterramiento islámicos en al-Andalus (SS. VIII-XVI): las tumbas tipo lahd. Arqueología de la muerte en Madinat Lurqa.* Granada: Universidad de Granada.

Child, A. M., 1995. Microbial Taphonomy of Archaeological Bone. *Studies in Conservation,* 40(1), pp. 19-30.

Cohen, M. N., 1987. The Significance of Long-Term Changes in Human Diet and Food Economy. In: *Food and Evolution. Toward a Theory of Human Food Habits.* Philadelphia: Temple University Press, pp. 261-284.

Cox, G. & Sealy, J., 1997. Investigating Identity and Life Histories: Isotopic Analysis and Historical Documentation of Slave Skeletons Found on the Cape Town Foreshore, South Africa. *International Journal of Historical Archaeology,* 1(3), pp. 207-224.

Cunha, E., Marques, C. & Silva, A. M., 2001. O passado em Al'-Ulyã: Estudo Antropológico de uma população muçulmana. *Al-Ulya,* Issue 8, pp. 35-49.

Curto, A. et al., 2019. Did military orders influence the general population diet? Stable isotope analysis from Medieval Tomar, Portugal. *Archaeological and Anthropological Sciences,* Volume 11, pp. 3797-3809.

DeNiro, M. J., 1987. Stable Isotopy and Archaeology. *American Scientist,* 75(2), pp. 182-191.

DeNiro, M. J. & Weiner, S., 1988. Chemical, enzymatic and spectroscopic characterization of "collagen" and other organic fractions from prehistoric bones. *Geochimica et Cosmochimica Acta,* Volume 52, pp. 2197-2206.

Departamento de Antropologia, 2000. *O Passado em Al-'Ulyã: Estudo Antropológico de um Cemitério Muçulmano.* Coimbra: Universidade de Coimbra.

Dury, G. et al., 2018. The Islamic cemetery at 33 Bartomeu Vicent Ramon, Ibiza: investigating diet and mobility through light stable isotopes in bone collagen and tooth enamel. *Archaeological and Anthropological Sciences,* p. Published online.

Estremoz, P., 1994. A evolução da cidade de Loulé: introdução à História Regional. *AL-ÚLYÁ,* Issue 4, pp. 69-75.

Fahy, G. E. et al., 2017. Bone deep: Variation in stable isotope ratios and histomorphometric measurements of bone remodelling within adult humans. *Journal of Archaeological Science,* Volume 87, pp. 10-16.

Feio, M., 1983. *Le Bas Alentejo et l'Algarve.* Évora: Centro de Ecologia Aplicada da Universidade de Évora.

Fraser, R. A. et al., 2011. Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. *Journal of Archaeological Science,* Volume 38, pp. 2790-2804.

Fraser, R. A. et al., 2013. Integrating botanical, faunal and human stable carbon and nitrogen stable isotope values to reconstruct land use and palaeodiet at LBK Vaihingen an der Enz, Baden-Württemberg. *World Archaeology,* 45(3), pp. 492-517.

Fuller, B. T., Márquez-Grant, N. & Richards, M. P., 2010. Investigation of Diachronic Dietary Patterns on the Islands of Ibiza and Formentera, Spain: Evidence from Carbon and Nitrogen Stable Isotope Ratio Analysis. *American Journal of Physical Anthropology,* Issue 143, pp. 512-522.

García Sánchez, E., 1983. La alimentación en la Andalucía islámica. Estudio Histórico y Bromatológico. I: Cereales y leguminosas. En: *Andalucía Islámica. Textos y estudios, II-III.* Granada: Universidad de Granada, pp. 139-178.

García Sánchez, E., 1986. La alimentación en la Andalucía islámica. Estudio histórico y Bromatológico. II: Carne, pescado, huevos, leche y productos lácteos. In: *Andalucía islámica. Textos y Estudios, IV-V (1983-1986).* Granada: Universidad de Granada, pp. 237-278.

García Sánchez, E., 1995. La gastronomía andalusí. In: *El Zoco. Vida económica y artes tradicionales en Al-Andalus y Marruecos.* Barcelona: Lunwerg Editores, pp. 49-57.

García Sánchez, E., 1996. La alimentación popular urbana en el al-Andalus. *Arqueología Medieval,* Issue 4, pp. 219-235.

García-Collado, M. I., 2016. Food consumption patterns and social inequality in an early medieval rural community in the centre of the Iberian Peninsula. In: J. A. Quirós Castillo, ed. *Social complexity in Early Medieval rural communities. The north-western Iberia archaeological record.* Oxford: Archaeopress Publishing Ltd, pp. 59-78.

García-Collado, M. I. et al., 2018. Palaeodietary reconstruction as an alternative approach to poorly preserved early medieval human bone assemblages: the case of Boadilla (Toledo, Spain). *Archaeological and Anthropological Sciences.*

García, E., Subirá, M. E. & Richards, M. P., 2004. Régime et société d'après l'analyse des isotopes stables: l'exemple de la population de <<Can Reinés>> (Mallorca, Espagne, 600 ap. J. C.). *Antropo,* Issue 7, pp. 171-176.

Gonzaga, A. R., 2018. *Arqueologia da Morte no Gharb "português" Almocavares e outros registos funerários.* Coimbra: Universidade de Coimbra.

Grau-Sologestoa, I., 2017. Socio-economic status and religious identity in medieval Iberia: The zooarchaeological evidence. *Environmental Archaeology. The Journal of Human Palaeoecology,* 22(2), pp. 189-199.

Guede, I. et al., 2017. Isotope analyses to explore diet and mobility in a medieval Muslim population at Tauste (NE Spain). *PLoS ONE,* 5(12), pp. 1-27.

Guichard, P., 2000. Tercera Parte: Los siglos XII-XV. In: *De la Expansión Árabe a la Reconquista: Esplendor y Fragilidad de al-Andalus.* Granada: Fundición El Legado Andalusí, pp. 165-252.

Hofman-Kaminska, E. et al., 2018. Stable isotope signatures of large herbivore foraging habitats across Europe. *PLoS One (online),* 13(1).

Inskip, S., Carroll, G., Waters-Rist, A. & López-Costas, O., 2018. Diet and food strategies in a southern al-Andalusian urban environment during Caliphal period, Écija, Sevilla. *Archaeological and Anthropological Sciences,* pp. 1-18.

Jiménez-Brobeil, S. A. et al., 2016. How royals feasted in the court of Pedro I of Castile: A contribution of stable isotope study to medieval history. *Journal of Archaeological Science: Reports ,* Volume 10, pp. 424-430.

Katzenberg, M. A., 1993. Age Differences and Population Variation in Stable Isotope Values from Ontario, Canada. In: J. B. Lambert & G. Grupe, eds. *Prehistoric Human Bone. Archaeology at the Molecular Level.* Berlin: Springer-Verlag Berlin Heidelberg GmbH, pp. 39-62.

Lautensach, H., 1967. *Geografía de España y Portugal.* Barcelona: Hermann Lautensach; Editorial Vicens-Vives.

Lewis, B., 1993. *The Arabs in History.* Sixth ed. Oxford: Oxford University Press.

Longin, R., 1971. New Method of Collagen Extraction for Radiocarbon Dating. *Nature,* Volume 230, pp. 241-242.

Luzia, I., 1999/2000. A excavação arqueológica de emergência do cemitério muçulmano da <<Quinta da Boavista>> / Loulé. *Al-úlyá,* Issue 7, pp. 129-185.

MacKinnon, A. T., 2015. *Dietary Reconstruction of Medieval and Early Modern Spanish Populations using Stable Isotopes of Carbon and Nitrogen.* Chico: California State University.

Marín, M., 2008. Los textos árabes como fuente para la historia de la alimentación. In: *Xelb 9. Actas do 6° Encontro de Arqueologia do Algarve.* Silves: Camara Municipal de Silves; Museu Municipal de Arqueologia, pp. 161-173.

Mays, S., 1998. *The Archaeology of Human Bones.* First ed. London: Routledge.

Meier-Augenstein, W., 2010. *Stable Isotope Forensics. An introduction to the Forensic Application of Stable Isotope Analysis.* Dundee UK: Wiley-Blackwell.

Minozzi, S. & Canci, A., 2015. *Archeologia dei resti umani. Dallo scavo al laboratorio.* Second ed. Roma: Carocci editore.

Müldner, G. & Richards, M. P., 2007. Stable isotope evidence for 1500 years of human diet at the City of York, UK.. *American Journal of Physical Anthropology,* Volume 133, pp. 682-697.

Mumuni, A. G. et al., 2018. Religious identity, community and religious minorities' search efforts for religiously sanctioned food: The case of halal food in non-Muslim majority markets. *International Journal of Consumer Studies,* Issue 42, pp. 586-598.

Mundee, M. M., 2010. *Exploring Diet and Society in Medieval Spain: New Approaches Using Stable Isotope Analysis.* Durham: Durham University.

Museu Nacional de Arqueologia, et al., 2017. *LOULÉ. Territórios, Memórias e Identidades [Museum exposition].* Lisbon: Museu Nacional de Arqueologia.

Nasrallah, N., 2007. *Annals of the Caliphs' Kitchens. Ibn Sayyār al-Warrāq's Tenth-Century Baghdad Cookbook.* Leiden: Brill.

Nehlich, O., 2015. The application of sulphur isotope analyses in archaeological research: A review. *Earth-Sciences Reviews,* Volume 142, pp. 1-17.

Nehlich, O., Fuller, B. T., Márquez-Grant, N. & Richards, M. P., 2012. Investigation of Diachronic Dietary Patterns on the Islands of Ibiza and Formentera, Spain: Evidence from Sulfur Stable Isotope Ratio Analysis. *American Journal of Physical Anthropology,* Volume 149, pp. 115-124.

Nehlich, O. & Richards, M., 2009. Establishing collagen quality criteria for sulfur stable isotope analysis of archaeological bone collagen. *Archaeological and Anthropological Sciences,* Volume 1, pp. 59-75.

Nitsch, E., Humphrey, L. T. & Hedges, R. E. M., 2011. Using Stable Isotope Analysis to Examine the Effect of Economic Change on Breastfeeding Practices in Spitalfields, London, UK. *American Journal of Physical Anthropology,* 146(4), pp. 619-628.

O'Leary, M. H., 1988. Carbon Isotopes in Photosynthesis. *BioScience,* 38(5), pp. 328-336.

Oliveira Marques, A. H., 1968. *Introdução à História da Agricultura em Portugal.* Lisbon: Edições Cosmos.

Oliveira, J. T., 1992. *Carta Geológica de Portugal. Escala 1/200000. Notícia explicativa da folha 8.* Lisbon: Serviços Geológicos de Portugal.

Palma, J. F. M. d., 2015. *O Desenvolvimento Urbano de Loulé. Do período medieval ao fim da época moderna.* Faro: Universidade do Algarve.

Peña-Chocarro, L. et al., 2019. Roman and medieval crops in the Iberian Peninsula: A first overview of seeds and fruits from archaeological sites. *Quaternary International,* Volume 499, pp. 49-66.

Pereira, C., 2017. Mundo Funerário Romano no Território de Loulé. In: *Loulé. Territórios, memórias, identidades.* Lisbon: Museu Nacional de Arqueologia, pp. 302-311.

Pickard, C. et al., 2017. Isotopic evidence for dietary at the mediaeval Islamic necropolis of Can Fonoll (10th to 13th centuries CE), Ibiza, Spain. *Journal of Archaeological Science: Reports,* Issue 13, pp. 1-10.

Pimenta, C. M., Moreno García, M. & Varela Gomes, R., 2009. *Aves no prato e... não só! A ornitofauna recuperada no Sector Sul do Castelo de Silves.* Silves, XELB 10. 7° Encontro de Arqueologia do Algarve.

Pires, A. & Luzia, I., 2017. As Necrópoles Islâmicas de Loulé. En: *Loulé. Territórios, Memórias, Identidades.* Lisbon: Museu Nacional de Arqueologia, pp. 494-503.

Ramos-Pereira, A., 2017. Territórios de Loulé. En: *Loulé. Territórios, Memórias, Identidades.* Lisbon: Museu Nacional de Arqueologia, pp. 50-57.

Remie Constable, O., 1997. *Medieval Iberia. Readings from Christian, Muslim, and Jewish Sources.* Philadelphia: University of Pennsylvania Press.

Renfrew, C. & Bahn, P., 2012. *Archaeology. Theories, Methods, and Practice.* 6th ed. London: Thames & Hudson.

Ribeiro, O., 1992. *Portugal. O Mediterrâneo e o Atlântico.* Lisbon: Edições João Sá da Costa.

Richards, M. P. y otros, 2003. Sulphur Isotopes in Palaeodietary Studies: a Review and Results from a Controlled Feeding Experiment. *International Journal of Osteoarchaeology,* Issue 13, pp. 37-45.

Ross, E. B., 1987. An Overview of Trends in Dietary Variation from Hunter-Gatherer to Modern Capitalist Societies. In: *Food and Evolution. Toward a theory of human food habits..* Philadelphia: Temple University Press, pp. 7-56.

Saragoça, P. et al., 2016. Stable isotope and multi-analytical investigation of Monte da Cegonha: A Late Antiquity population in southern Portugal. *Journal of Archaeological Science: Reports,* Volume 9, pp. 728-742.

Schoeninger, M. J., DeNiro, M. J. & Tauber, H., 1983. Stable nitrogen isotope radios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science,* 220(4604), pp. 1381-1383.

Sealy, J., Johnson, M., Richards, M. & Nehlich, O., 2014. Comparison of two methods of extracting bone collagen for stable carbon and nitrogen isotope analysis: comparing whole bone demineralization with gelatinization and ultrafiltration. *Journal od Archaeological Science,* Volume 47, pp. 64-69.

Stanislawski, D., 1963. *Portugal's Other Kingdom. The Algarve.* Austin: University of Texas Press.

Telles Antunes, M., 1996. Alimentação de origem animal em regime islâmico - Alcaria Longa e Casa II da Alcaçova de Mértola. *Arqueologia Medieval,* Issue 4, pp. 267-276.

The Noble Qur'an, 2016. *THE NOBLE QUR'AN (2:173).* [Online]
Available at: https://quran.com/2/173
[Accessed 4 July 2019].

Toso, A. y otros, 2019. High status diet and health in Medieval Lisbon: a combined isotopic and osteological analysis of the Islamic population from São Jorge Castle, Portugal. *Archaeological and Anthropological Sciences,* 11(8), pp. 3699-3716.

Treasure, E. R., Church, M. J. & Gröcke, D., 2016. The influence of manuring on stable isotopes (δ13C and δ15N) in Celtic bean (Vicia faba L.): archaeobotanical and palaeodietary implications. *Archaeological and Anthropological Sciences,* Volume 8, pp. 555-562.

Twiss, K. C., 2007. 1. We are what we eat. In: *The Archaeology of Food and Identity.* s.l.:Center for Archaeological Investigations, Southern Illinois University, pp. 1-15.

Varela Gomes, R., 2002. Silves (Xelb), uma cidade do Gharb Al-Andalus: território e cultura. In: *Trabalhos de Arqueologia 23.* Lisbon: Instituto Português de Arqueologia.

White, T. D., Black, M. T. & Folkens, P. A., 2012. *Human Osteology.* Third ed. Burlington: Elsevier Academic Press.

APPENDIX 1. SUPPLEMENTARY TABLES

Table 21. Summary of the anthropological report from Quinta da Boavista. Based on (Cunha, et al., 2001; Departamento de Antropologia, 2000)

SUMMARY OF THE ANTHROPOLOGICAL REPORT FROM QUINTA DA BOAVISTA				
SAMPLE	**SEX**	**ESTIMATED AGE**	**PATHOLOGIES**	**NOTES**
LQB 1	M	34 ±14.29	Fusion of the 5th to 6th cervical vertebra, which may have a congenital, infectious or traumatic etiology. Lamellar spikes of grade 2 in the posterior regions of the thoracic vertebrae (stress at the level of the spine) Deposits of tartar (testimonies of poor habits of oral hygiene) 12 teeth recovered (ante mortem loss of the 1st molar.)	Discrete character: septal opening in the left humerus. Right mandible condyle
LQB 2	F	<30	Lamellar spikes of grade 2 in the spine vertebrae. Cervical caries grade 2, in the 1st lower premolar. Upper left central incisor hypoplasia (stress period between birth and 2 years of age).	6 teeth recovered The anterior dentition is more affected by wear, which is unusual.
LQB 3	M	>30	Lamellar spikes and nodules of Schmorl's (activity that implies spinal movements and a great effort of this, eventually to load weights). 1st sacral vertebra is not fused (which is fused before the 30 years of age)	Height of 160± 5.92 cm. Average robustness
LQB 4	M	>30	Lack of fusion of the first sacral vertebra. Lamellar spikes in the spine vertebrae. Nodules of Schmorl's in vertebrae (activity that implies spinal movements and a great effort of this, eventually to load weights). Spondylolysis in a lumbar vertebra 4 cavities	Height of 163± 6.90 cm. Remarkable robustness at the level of the femur and average in the tibia
LQB 5	M	>40	Laminar spikes and signs of arthrosis in the vertebral bodies. Ante mortem loss of 4 teeth.	Bad state of preservation
LQB 6	M	?	1st sacral vertebra is not fused Laminar spikes in toraxic and cervical regions. Nodules of Schmorl's in some vertebrae.	No age approximation. Height of 170 ± 6.92 cm

			Compression fracture of two thoracic vertebrae. (this fracture occurs when the bones are crushed by an impacting force). This traumatic episode will have occurred long before the individual's death, since the two injured vertebrae are completely fused anteriorly and posteriorly (These fractures are very common in individuals who are struck on the back by heavy objects, or by falling on their back. Another hypothesis suggests tuberculosis as a probable etiology.). Most teeth had traces of tartar. Hypoplasia present in the teeth (stress period between 2 and 6 years of age).	
LQB 7	M	?	Laminar spikes and artrosis present in posterior part of vertebrae. 1 caries The clavicle has an exostosis in the rhomboid fossa (traumatic etiology or excessive stress in the shoulder region). Ante mortem loss of superior 1° premolar	11 teeth present.
LQB 8	F	>40	Arthrosis in the patella, cervical vertebrae and sternal extremity of the clavicle. Entesopathies in the tibia, femur and patella. Laminar spikes in the spine. Ante mortem loss of 2 teeth; post mortem loss of 7 teeth	
LQB 9	F	>60	Laminar spikes and arthrosis in spine and clavicles. Degenerative pathology observed in the hand 1st phalanx 4 cavities	
LQB 10	F	>20	Arthrosis and laminar spikes in spine Cranial sutures are all open. A total ante-mortem loss of mandible teeth.	
LQB 11		12 years ±30 months		11 teeth present without pathologies or wear
LQB 12	M	>25	Right humerus has a depression related to effort. Laminar spikes in spine 2 cavities	167± 6.90 cm. Robustness in the cranial skeleton. Discrete character:

			Ante mortem loss of left premolar (mandible)	septal opening in both humeri. All maxilar teeth are present (including 3° molar) 1 iron nail found in this burial
LQB 13	F	>50	Laminar spikes of grade 1 in spine Arthrogenic lesions in the acetabulum and distal end of the femurs. 2 small cavities Ante mortem loss of 7 teeth	Height: 148± 5.2 cm Discrete character: septal opening in humerus.
LQB 14	M	25-30	1st sacral vertebra is not fused Laminar spikes of grade 2 in spine	Height: 158± 6.90 cm
LQB 15		<30		Incomplete skeleton
LQB 16	F	20-30	Strong mechanical constraint and intense effort at the level of the spine. Schmorl's nodules in 6 thoracic vertebrae. Laminar spikes of grade 2/3 in al vertebrae Superior and inferior canines present hypoplasia (stress period between 2 and 4 years of age). Ante mortem loss of center left incisor, 1 1° molar	
LQB 17	F	18-25	2 small cavities	Height: 150 cm Discrete character: septal opening in right humerus.
LQB 18	M	? (>30)	1st sacral vertebra is not fused Weak arthrosis on a lumbar vertebra and a thoracic vertebra. 2 cavities	
LQB 19		(Adult)	Arthrosis 1 dental abscess 1° premolar (bad oral hygiene)	Incomplete skeleton
LQB 20		15-17		Low preservation of skeleton
LQB 20 a		Adult		Bones of the foot are robust
LQB 21	M	40-50	1 caries In the jaw, posterior dentition was lost ante	Height: 163±6.96 cm

			mortem.	
LQB 22		? Adult (>30)	3 cavities Laminar spikes in some thoracic vertebrae	Bad preservation of the skeleton (not possible sexual and age diagnosis)
LQB 23	F	? (>30)	Laminar spikes in spine 3 cavities Ante mortem loss of 2 pre-molars.	
LQB 24	M	16-20	Central incisor present hypoplasia (stress period between 2 and 3 years of age).	Very high individual
LQB 25				There are only diaphyses of long bones, from which no relevant inference can be drawn. 3 iron nails found in this burial
LQB 26	M	?	1 caries Osteofibroma at the distal end of the right femur diaphysis.	
LQB 27	F	?		Incomplete skeleton. Sexual diagnosis by talus
LQB 28	F	30-50	Characteristics are from the most complete skeleton (28a) 1st sacral vertebra is not fused Jaw has a narrowing in the alveolar region (a kind of ridge).	Burial of 2 women (1 of them is more complete (28a) than the other skeleton (pelvis, sacrum, 1 humerus are the only remains) 28a height: 151± 5.92 cm
LQB 29	M	30-40	1st sacral vertebra is not fused Schmorl's nodules in some vertebrae Temporal-mandibular arthrosis, shoulder and spine arthrosis Accentuated laminar spikes in thoracic region, enthesopathies in patella (grade 2), in biceps brachii and triceps brachii.	Height: 161± 6.90 cm (robust)

			4 cavities (2 of them are severe, which destroyed the crown of the teeth). Several hypoplasias in different teeth (diverse stress periods between 2 and 6 years old)	
LQB 30	M	>40	Temporal-mandibular arthrosis 1 caries DISH – Diffuse idiopathic skeleton hyperostosis (in thoracic vertebrae) [which is associated with diabetes and obesity cases] Secondary arthrosis in C2 and C5 vertebrae "Sindrome do Cavaleiro" (Knight syndrome): Non-articular degenerative lesions. In the distal part of the femur, bony developments can be appreciated that suggest that the individual was on horseback. Ante mortem loss of 5 teeth	Robust clavicles
LQB 31	F	31 (≈30 years) 31ª (fetus or newborn)	31 has porotic hyperostosis in the orbital (related to anemia). Hyperostosis frontalis interna (related to testosterone and estrogen hormonal changes). 4 cavities. Short height	This burial had 3 skeletons present (1 of them is a non-adult, probably a fetus at the end of its gestation or a newborn baby). 31 and 31a would be considered as the woman related to the baby and the baby. The third one was identified as LQB 37
LQB 32	M	Adult	1st sacral vertebra is not fused Porotic hyperostosis in orbital Laminar spikes in thoracic vertebrae	This sepulture have 2 iron crossbow bolts, and 14 iron nails (probable wooden cover).
LQB 33	F	>50	Porous and light bones (because of old age) Temporal-mandibular arthrosis Laminar spikes in vertebrae	Robust skeleton. Height: 143± 5.92 cm

			4 cavities Hypoplasia present in 1 canine (stress period between 4 to 6 years old) Ante mortem loss of 2 teeth	
LQB 34	F	20-30	Laminar spikes grade 1. Depression in the proximal and anterior region of the humerus. Several hypoplasias found in diverse teeth (stress period between 4 to 7 years) Ante mortem loss of mandible's right 2° molar	Height 151± 5.92 cm 5 iron nails found in this burial
LQB 35	F	40-50	The jaw presents a complete alveolar resorption.	
LQB 36	F		Arthrosis temporal-mandibular Complete ante mortem loss of all mandibular teeth	
LQB 37	F	>30	Ante mortem loss of 6 teeth	Found in the same burial as 31 and 31a Short height Discrete character: septal opening in both humerus.
LQB 38	M	30-50	1st sacral vertebra is not fused Arthrosis present in both ulnas and humerus; also present in cervical vertebrae Laminar spikes in vertebrae Hypoplasia in a canine and an incisor (stress period between 2-4 years) Ante mortem loss of posterior mandibular teeth	Found with 3 iron crossbow bolts associated to the superior region of the skeleton.
LQB 39	F	>30	1st sacral vertebra is not fused Laminar spikes in vertebrae. Entesopathies. Spondylosis present in the last lumbar vertebrae 4 cavities	
LQB 40	M	15-18	The right humerus is much smaller (46 mm) and less robust than the left; In addition, the proximal epiphysis of the humerus is destroyed and semi-fused with the metaphysis.	
LQB 41		15± 36	The teeth have small enamel pearls at the root of	Discrete character:

		months	the 3rd molars. Some teeth (incisors and canines) have linear hypoplasias of dental enamel which is indicative of a period of stress that will have occurred between 2 and 6 years. 1st and 2nd left upper molars have small points where the enamel is not formed	septal opening in left humerus.

Table 22. Summary of the anthropological report from Hospital da Misericordia. Based on (Benisse, 2009)

SUMMARY OF THE ANTHROPOLOGICAL REPORT FROM HOSPITAL DA MISERICORDIA				
SAMPLE	**SEX**	**AGE**	**PATHOLOGY**	**NOTES**
LHM 1	M?	Adult		Found in the interior of the building Bad state of preservation In the abdominal region of the skeleton, a secondary deposition was found (OSSARIO 1).
LHM 2		10-12		Found in the interior of the building Badly preserved because the inhumation was disturbed by the construction of a Wall (just coxal and legs found).
LHM 3		18-24 months		This grave had been disturbed during the construction of the hospital in the 19th century, the lower limbs of the skeleton were destroyed.
LHM 4	M	Adult		Found in the interior of the building Badly preserved because of the construction of the Hospital. Just coxal and legs present.
LHM 5	F?	Adult	Total loss of mandibular teeth (Ante mortem)	Found in the interior of the building
LHM 6	M	Adult		Found in the interior of the building The region of the skeleton above the T10 vertebra had been destroyed by the action of a machine in the course of the present work and the distal portion of the lower limbs when constructing an old wall. Sample “3” for radiocarbon dating (left tibia, right femur and left ulna were used)
LHM 7	F	Adult		Found in the interior of the building The grave had been partially affected by the placement of a sewer, having been destroyed the portion of the skeleton below the femurs. This grave had been opened on a pre-existing grave (burial 11), of smaller width.
LHM 8		7-8 years		Found in the interior of the building Only the thoracic and cranial regions were conserved. The remains were submerged by rainwater before being exhumed.
LHM 9	?	Adult		Found in the interior of the building The entire portion between the thoracic region and the knees has been destroyed by the machines. Badly preserved because of the rain.

LHM 10		5-7 years		Found in the interior of the building The grave had been partially destroyed by the same sewage that affected graves 7 and 11 and the skeleton had been cut in half, the pelvic region absent
LHM 11-OSSARIO				Found in the interior of the building OSSARIO
LHM 12	M	Adult		Found in the interior of the building Really fragile. Found complete
LHM 13	?	Adult		Found in the interior patio The grave had been destroyed by the opening of burial 14, and the feet of the individual in the latter were in the place where the skull of the skeleton should have been. Very badly preserved; bones fell apart when by touch
LHM 14	?	Adult		Found in the interior patio Affected by an ancient sewage, having destroyed the whole portion above the knee region of the skeleton.
LHM 15	?	Adult		Found in the interior patio This grave had been affected by several ancient sewage ditches. The skeleton was represented only by the thoracic region and part of the upper limbs.
LHM 16	?	Adult		Found in the interior patio The grave had been cut off by a wall, keeping only the portion below the middle of the skeletal thighs. On the feet of this skeleton was found a secondary deposition, designated by OSSUARIO 5, consisting of some bones of the upper limb. Sample “2” for radiocarbon dating (left and right tibia, and a fragment of the right femur were used).
LHM 17	M	Adult	Loss of almost all mandibular teeth (ante mortem). Cavities of maximum grade. Presence of osteophytes in vertebrae; as well as bilateral septal opening.	Found in the interior patio This grave was cut by an ancient sewage ditch below the region corresponding to the skeletal knees Sample “1” for radiocarbon dating (right and left femur used).
LHM 18	M	Adult		Found in the interior patio

				This grave had been cut in half by an ancient sewage ditch
LHM 19		≈10 years		The skeleton was poorly preserved.
LHM 20	?	Adult		Found in the interior patio This skeleton was represented only by the proximal half of the right femur.
LHM 21	?	Adult		Found in the interior patio From this skeleton only part of the right half of the skull was found.
LHM 22	?	10		Found in the interior patio The existence of bilateral septal opening was observed. Under this burial, there was an ossuary (OSSARIO 8), deposed in a band excavated along the right side of the grave, and made up of virtually all bones of the skeleton.
LHM 23		Newborn or stillbirth.		Found in the interior patio
LHM 24		Newborn or stillbirth.		Found in the interior patio
LHM 25	M?	Adult		Found in the interior patio This grave had been disturbed by an old box and a sewage ditch, the skeleton having been affected in the region below the proximal third of the femurs and in part of the thoracic region, the upper limbs and the skull. The bones were quite fragile.
LHM 26		18-24 months		Found in the interior patio This grave was oriented with the head to the south and the feet to the north.
LHM 27	?	Adult		Found in the interior patio This grave had been quite disturbed, with only the distal part of the right lower limb of the skeleton
LHM 28		Non-adult		Found in the interior patio Only part of the ribs and right upper limb were recovered, the bones being very fragile.
LHM 29		Teenager		Found in the interior patio This grave was greatly affected by ancient works, with only a small portion of the thoracic and pelvic regions of the skeleton
LHM 30	M	Adult		Found in the interior patio The grave had been greatly affected by an old sewage

				box and other works
LHM 31	F	Adult		Found in the interior patio
LHM 32	?	Adult	The individual had septal opening in the right humerus, and it was not possible to observe the character in the left humerus because the bone was absent.	Found in the interior patio
LHM 33	?	Adult		Found in the interior patio This grave was affected by an old sewage ditch, the skeleton being represented only by the lower limbs.
LHM 34	F	Adult	The individual had septal opening in the right humerus, and it was not possible to observe the character in the left humerus	Found in the interior patio This grave was oriented with the head to the south and the region of the feet to the north. Nails were found in the burial.
LHM 35	?	Adult		Found in the interior patio From this grave, only the head was preserved, the rest being destroyed by a sewage ditch. Only part of the skull was recovered from the skeleton.
LHM 36	?	Adult		Found in the interior patio The grave had virtually disappeared, only the distal part of the right lower limb of the skeleton
LHM 37	F	Adult		Found in the interior patio
OSSARIO 3				Found in the interior patio It was composed essentially of long bones, skull and a hand.

APPENDIX 2. SUPPLEMENTARY FIGURES

Figure 30. Faunal bone samples from Oficina do Senhor Carrilho (OSC)

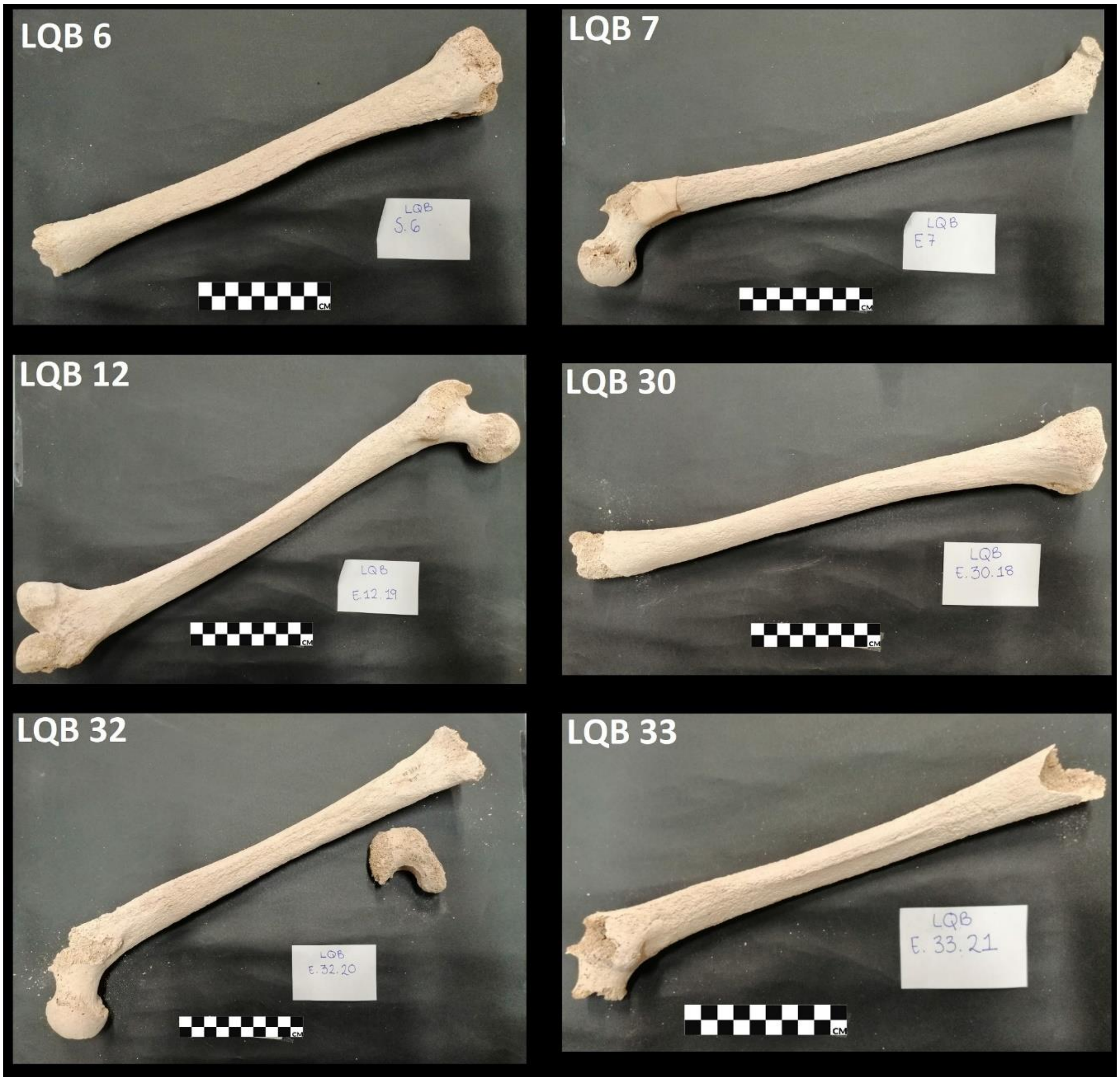


Figure 31. Human bone samples from the cemetery of Quinta da Boavista, Loulé

Figure 32. Human bone samples from the cemetery of Hospital da Misericordia, Loulé