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“There is no point in work unless it absorbs you like an absorbing game.
If it doesn’t absorb you, if it’s never any fun, don’t do it.”

Work, 1922 - D.H. Lawrence

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ABSTRACT.

Organic raw materials have been essential for human survival and cultural development throughout history. Despite their critical role, their perishable nature results in poor preservation in the archaeological record, leading to them being known as the 'missing majority' or 'invisible technologies'. While this refers to organic remains in general, the use of plant fibres, in particular, is considered a valuable indicator of technological and cultural traditions, providing insights into the skills and practices of ancient human groups. Examples of plant-based artefacts are extremely rare in the Mesolithic and Neolithic archaeological record in Europe, but some remains have been found in Central and North Europe preserved by waterlogging and/or charring. The record is even scarcer in southern latitudes such as the Iberian Peninsula, where most of the evidence comes from later periods and is preserved by dehydration.

This PhD thesis focuses on the identification of raw materials in plant fibre-based artefacts, making it the first study of its kind in the region. It examines three of the oldest and best-preserved fibre-based assemblages in Iberia: from Cueva de Los Murciélagos (7986-3740 cal BC; Granada), Coves del Fem (ca. 6065-4545 cal BC; Tarragona) and La Draga (5324-4977 cal BC; Girona). The three sites have offered invaluable opportunities to gain insights into the use of natural resources and the development of technologies by Early to Middle Holocene human groups.

The analytical methods employed in this research aim to reconstruct the initial stages of the chaîne opératoire of fibre-based production, related to the selection, acquisition and preparation of raw materials. This reconstruction is achieved through plant identification by microscopic anatomical criteria and the creation of a reference collection supported by ethnographic, traditional and previous archaeobotanical data documented in the sites. An experimental approach has also been developed to test hypotheses about plant processing. Furthermore, this thesis also investigates the potential for plant fibre remains to be preserved in dental calculus and proposes a specific methodology for their recovery and analysis. The materials studied in this part of the research come from the Cova del Pasteral site (ca. 5000-3000 BC; Girona).

The results of this investigation have provided a more comprehensive picture of how these early societies adapted to the environment, exploited natural resources and developed complex technological practices. This research not only enriches our understanding of the past, but also highlights the links between early human innovation and environmental management, providing valuable lessons for the study of human-environment interactions throughout history, as well as posing an important list of questions to be explored in the future for the further development of archaeobotanical research on plant fibres.

RESUM (CAT).

Les matèries primeres orgàniques han estat essencials per a la supervivència humana i el desenvolupament cultural al llarg de la història. Malgrat el seu paper fonamental, la seva naturalesa perible té com a conseqüència una mala preservació en el registre arqueològic, fet que les ha portat a conèixer amb termes com la “majoria desapareguda” o “tecnologies invisibles”. Aquest fet és extrapolable al conjunt de restes orgàniques, tot i això l'ús de fibres vegetals es considera un indicador valuós de tradicions tecnològiques i culturals, proporcionant informació sobre les habilitats i pràctiques dels grups humans antics. Els exemples d'artefactes fets a partir de fibres vegetals plantes són extremadament atípic en el registre arqueològic del Mesolític i el Neolític a Europa, però s'han trobat algunes restes a Europa Central i del Nord, preservades per saturació en aigua o carbonització. El registre és encara més escàs en latituds meridionals com la Península Ibèrica, on la majoria de les evidències provenen de períodes més recents i la seva preservació és principalment per deshidratació.

Aquesta tesi doctoral es centra en la identificació de matèries primeres en artefactes fets en fibres vegetals, sent el primer estudi d'aquest tipus a la regió. Examina tres dels conjunts de fibres més antics i millor conservats de la Península Ibèrica: la Cueva de Los Murciélagos (7986-3740 cal BC; Granada), les Coves del Fem (ca. 6065-4545 cal BC; Tarragona) i La Draga (5324-4977 cal BC; Girona). La conservació excepcional de la matèria orgànica en els tres jaciments ofereix una oportunitat única d'obtenir informació sobre l'ús d'aquests recursos naturals i el desenvolupament tecnològic per part dels grups humans de l'Holocè Inicial i Mitjà.

Els mètodes analítics emprats en aquesta recerca tenen com a objectiu reconstruir les primeres etapes de la cadena operativa de la producció basada en fibra, relacionades amb la selecció, adquisició i preparació de matèries primeres. Aquesta reconstrucció s'aconsegueix mitjançant la identificació de plantes per criteris anatòmics microscòpics i la creació d'una col·lecció de referència basada en dades etnogràfiques, tradicionals i analítiques arqueobotàniques prèvies en els jaciments. També s'ha desenvolupat un protocol experimental per contrastar les hipòtesis relacionades amb el processament de les plantes. Així mateix, aquesta treball investiga el potencial que tenen les restes de fibres vegetals de ser preservades en el càlcul dental i proposa una metodologia específica per a la seva recuperació i anàlisi. Els materials estudiats en aquesta part de la recerca provenen del jaciment neolític de la Cova del Pasteral (ca. 5000-3000 BC; Girona).

Els resultats d'aquesta investigació han proporcionat una imatge més completa de com aquestes primeres societats s'adaptaven a l'entorn, explotaven els recursos naturals i desenvolupaven pràctiques tecnològiques complexes. Aquesta recerca no només enriqueix la nostra comprensió del passat, sinó que també destaca els vincles entre la innovació humana primerenca i la gestió ambiental, oferint informació valuosa per a l'estudi de les interaccions entre humans i el seu entorn en diferents moments de la seva història. Finalment, planteja una seguit de preguntes a explorar en el futur, de gran importància per a desenvolupament de la recerca arqueobotànica sobre fibres vegetals.

RESUMEN (SP).

Las materias primas orgánicas han sido esenciales para la supervivencia humana y el desarrollo cultural a lo largo de la historia. A pesar de su papel fundamental, su naturaleza perecedera tiene como consecuencia una mala preservación en el registro arqueológico, lo que ha llevado conocerlas con términos como la "mayoría desaparecida" o "tecnologías invisibles". Este hecho es extrapolable al conjunto de restos orgánicos; sin embargo, el uso de fibras vegetales se considera un indicador valioso de tradiciones tecnológicas y culturales, proporcionando información sobre las habilidades y prácticas de los grupos humanos antiguos. Los ejemplos de artefactos hechos en fibras vegetales son extremadamente atípicos en el registro arqueológico del Mesolítico y el Neolítico en Europa, pero se han encontrado algunos restos en Europa Central y del Norte, preservados por saturación en agua o carbonización. El registro es aún más escaso en latitudes meridionales como la Península Ibérica, donde la mayoría de las evidencias provienen de períodos más recientes y su preservación es principalmente por deshidratación.

Esta tesis doctoral se centra en la identificación de materias primas en artefactos hechos en fibras vegetales, siendo el primer estudio de este tipo en la región. Examina tres de los conjuntos de fibras más antiguos y mejor conservados de la Península Ibérica: Cueva de Los Murciélagos (7986-3740 cal BC; Granada), Coves del Fem (ca. 6065-4545 cal BC; Tarragona) y La Draga (5324-4977 cal BC; Girona). La conservación excepcional de la materia orgánica en los tres yacimientos ofrece una oportunidad única para obtener información sobre el uso de estos recursos naturales y el desarrollo tecnológico por parte de los grupos humanos del Holoceno Inicial y Medio.

Los métodos analíticos empleados en esta investigación tienen como objetivo reconstruir las primeras etapas de la cadena operativa de la producción en fibra vegetal, relacionadas con la selección, adquisición y preparación de materias primas. Esta reconstrucción se logra mediante la identificación de plantas por criterios anatómicos microscópicos y la creación de una colección de referencia basada en datos etnográficos, tradicionales y analíticos arqueobotánicos previos en los yacimientos. También se ha desarrollado un protocolo experimental para contrastar las hipótesis relacionadas con el procesamiento de las plantas. Asimismo, este trabajo investiga el potencial que tienen los restos de fibras vegetales preservados en el cálculo dental y propone una metodología específica para su recuperación y análisis. Los materiales estudiados en esta parte de la investigación provienen del yacimiento neolítico de la Cova del Pasteral (ca. 5000-3000 BC; Girona).

Los resultados de esta investigación han proporcionado una imagen más completa de cómo estas primeras sociedades se adaptaban al entorno, explotaban los recursos naturales y desarrollaban prácticas tecnológicas complejas. Esta investigación no solo enriquece nuestra comprensión del pasado, sino que también destaca los vínculos entre la innovación humana temprana y la gestión ambiental, ofreciendo información valiosa para el estudio de las interacciones entre humanos y su entorno en diferentes momentos de su historia. Finalmente, plantea una serie de preguntas a explorar en el futuro, de gran importancia para el desarrollo de la investigación arqueobotánica sobre fibras vegetales.

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CHAPTER III

CHAPTER I - INTRODUCTION

1. Introduction.

1.1. Fibre-based prehistoric archaeological remains in southern Europe.

Perishable organic raw materials such as wood, plant fibres and animal skins have been essential to human survival and cultural development throughout history. Despite their critical role in the manufacture of diverse quotidian artefacts, they are often under-represented in the archaeological record. This is due to their perishable nature, which results in poor preservation over time, leading to them being referred to as the 'missing majority' or 'invisible technologies' (Hurcombe 2014). As a result, the importance of these materials to past human groups has often been underestimated, even though they are crucial to understanding human history and technological evolution.

This under-representation of organic materials in archaeological contexts is directly related to their perishability, which limits the ability to study these objects in detail. Consequently, sites where perishable materials are well preserved offer a unique and invaluable opportunity to gain insights into the past. These sites allow researchers to explore aspects of human history that are usually obscured, furnishing a more complete understanding of how ancient communities used their environment, developed technologies and met their daily needs. The earliest direct evidence of perishable organic materials dates from the Middle Pleistocene (Kvadvadze et al. 2009; Wigforss 2014; Hardy et al. 2020), but such examples are both rare and widely dispersed. This scarcity has led to a reliance on durable materials in reconstructions of past societies, often overshadowing the importance of organic materials in these cultures. Thus, organic materials have been somewhat marginalised in traditional archaeological studies. While this refers to organic remains in general, the use of plant fibres in particular is considered a valuable indicator of technological and cultural traditions, providing insights into the skills and practices of ancient peoples.

In this thesis, the word 'plant fibre' has been used in a wide sense referring to the raw materials to produce fibre objects, both monocotyledonous and dicotyledonous fibres, with no distinction about their origin. When a more specific definition is needed, it is detailed. The study of plant fibre materials has developed considerably in Europe in recent decades, despite a longer tradition of such studies in other continents, such as America. However, the Iberian Peninsula stands out for its notable lack of archaeobotanical research in this field.

In terms of the archaeological record of plant fibre-based materials in Europe, well-preserved perishable material from the Mesolithic and Neolithic periods is extremely rare, typically found only at sites where special conditions such as waterlogging (Mineo et al. 2020; Romero-Brugués et al. 2021b), charring (Piqué et al. 2018; Romero-Brugués et al. 2021a, 2021b; Herrero-Otal et al. 2021, 2023; Romero-Brugués 2022), or desiccation (Romero-Brugués et al. 2021a; Martínez-Sevilla et al. 2023) have occurred. This scarcity of a direct archaeological record is even rarer in southern latitudes such as the Iberian Peninsula, where most of the evidence comes from later periods, particularly from the Chalcolithic and Bronze Ages (Gleba et al. 2021). The oldest known remains of fibre-based production in the peninsula are located on the Mediterranean side, such as the charred braid fragments from Coves de Santa Maira (12,900-10,200 cal BC; Alacant) (Aura-Tortosa et al. 2019), the dehydrated cord, basket and sandal assemblage from Cueva de los Murciélagos (7986-3740 cal BC; Granada) (Martínez-Sevilla et al. 2023), the desiccated and charred cord and the basket from Coves del Fem (ca. 6065-4545 cal BC; Tarragona) (Herrero Otal et al. 2021; Romero-Brugués et al. 2021a), and the charred and waterlogged cords and baskets from La Draga (5324-4977 cal BC; Girona) (Romero-Brugués et al. 2021b).

1.2. Motivation and research justification.

As mentioned above, plant fibre objects are rare materials, found only under specific preservation conditions. Despite their critical importance to early human groups, they have not received the research attention they deserve. The absence of an archaeological or archaeobotanical speciality dedicated to their study was a major challenge to consider before embarking on this research. Fortunately, in recent years some researchers have turned their attention to this area of archaeological material culture, both directly and indirectly. In the Iberian Peninsula these studies tend to focus on morphotechnological aspects, such as measurements, technical issues and production methods (Romero-Brugués 2021), or the indirect evidence of plant processing through malacofaunal, wooden and bone-based tools (Clemente and Cuenca 2011; Gibaja 2011; Altamirano 2014; De Diego et al. 2017, 2018; De Diego 2023). In contrast, this work focuses primarily on the raw materials used in fibre-based products, both their identification and processing.

This thesis examines three of the oldest and best-preserved fibre-based production assemblages in Iberia, dating from ca. 8000 to 4000 cal BC, found in both sepulchral and domestic contexts: Cueva de Los Murciélagos, Coves del Fem and La Draga. These finds highlight the complexity of Early to Middle Holocene human groups, particularly in their relationship with the environment. They demonstrate their profound knowledge and exploitation of natural resources, as well as the development of technologies to meet their daily needs. The aim is to emphasise the importance of these apparently simple technologies used by prehistoric human groups, even before the appearance of pottery in the region.

The materials from the Cueva de los Murciélagos site were recovered almost 150 years ago and remained in museum storage until the 1980s and 1990s, when the first technological studies were carried out (Alfaro 1980, 1984; Cacho et al. 1996). The materials from the Coves del Fem site were excavated during recent field seasons, specifically in 2019, and their study is a central part of this work. The materials from the La Draga site were mainly excavated in the 1990s and some other specimens found in the early 2000s. These were also subjected to technological analysis (Romero-Burgués 2021) and preliminary data on the raw materials of certain pieces were also acquired (Piqué et al. 2018). Although previous technological studies of the materials included in this thesis have been carried out by various researchers, this is the first time that a systematic identification of raw materials for each object, fragment and piece has been performed using both optical and electron microscopy.

Furthermore, the lack of evidence for plant fibre materials underlines the need to explore alternative archaeological records that may provide insights into these technological productions. This thesis investigates the potential for plant fibre remains to be preserved in dental calculus (bacterial plaque) and proposes a specific methodology for their recovery and analysis. The materials studied in this part of the research come from the Neolithic site of Cova del Pasteral (ca. 5000-3000 BC; La Cellera de Ter, Girona) (Rosillo et al. 2021a, 2021b, 2023).

This PhD dissertation focuses on the identification of raw materials in a series of rare archaeological artefacts that have been largely overlooked by traditional archaeological research, making it the first study of its kind in the region.

1.3. The research argument: research questions and objectives.

The primary aim of this research is to shed new light on the importance of plants - wild or cultivated, of different families and genera - in the production of fibre-based objects during Mesolithic and Neolithic periods. These objects include cords, but also baskets, mats, bags and even footwear (sandals). However, no textiles (such as clothing) are studied in the current thesis as they have not appeared in the archaeological record of the case studies. The selection, collection, and processing of plant fibres were essential steps in using them as raw materials for handicrafts. The use of these materials reflects the technological and ecological knowledge of past societies, knowledge often passed down through generations. This research examines the *chaîne opératoire* of plant fibre artefacts, from the selection of raw materials in the field to the production of different objects.

To achieve this aim, systematic raw material identification of fibre-based materials has faced some methodological limitations and issues. The identification of archaeological plant fibres presents significant challenges because key diagnostic features, such as the appearance and localisation of vascular bundles in monocotyledonous, and the presence of nodes and cross-marks in bast fibres (dicotyledonous), are often shared by different plant species, genera and even families. This overlap makes it difficult, if not impossible, to distinguish between plant families. In addition, various characteristics of plant fibres, such as the epidermis, are often modified or altered during processing by physical or chemical methods, further complicating accurate identification.

This research is also closely linked to the description of environmental profiles. This involves expanding our understanding of the palaeoenvironmental profiles in the areas of the sites from an archaeobotanical perspective, complementing other archaeobotanical studies. In the case of the Cueva de los Murciélagos site, the study of materials was carried out as part of a project that also focused on the initial characterisation of the past environmental profile in the area, while in the case of Coves del Fem and La Draga, the determination of raw materials completes a long tradition of defining environmental profiles.

The specific objectives can be summarised in two different points, one focused on methodological aspects and the other on the analysis of archaeological materials.

(i) To create a specific reference collection for plant fibre characteristics.

(ii) To establish the diagnostic anatomical characteristics of plant fibre materials for their identification in archaeological remains.

(iii) To propose a methodology for sampling plant fibres considering the specificities of conservation of these remains. This will be divided in two objectives (iii.i) to test the best procedures to sampling and identify plant fibres remains of objects, (iii.ii) to propose and test a methodological approach for recovering evidence of plant fibres from non-perishable materials, such as dental calculus samples, based on the ethnographic practice of using teeth as a 'third hand'.

(iv) To identify the plant fibres used during the Mesolithic and Early/Middle Neolithic on the Mediterranean side of Iberia (from the southeast to the northeast) in plant-fibre production.

(v) To characterise and describe the first stages of the *chaîne opératoire* of fibre-based production, focusing on the selection, acquisition and processing of raw materials.

(vi) To contribute to archaeobotanical research in the study area, with particular emphasis on the potential of macrobotanical studies to deepen our understanding of prehistoric societies' knowledge and management of natural resources through the analysis of materials that are scarce in the archaeological record.

(vii) To situate the material studied within the wider European archaeological context and provide new light on their significance.

1.4. Methodological approach.

From a methodological point of view, this research is significant because it provides unique systematic identification methods for the analysis of raw materials used for fibre-based products in the Iberian Peninsula in the Early and Middle Holocene. In addition, a specific reference collection - the first of its kind in the Archaeobotany Laboratory of the Prehistory Department at the Universitat Autònoma de Barcelona - has been created to support this work and achieve its objectives.

The analytical methods employed in this research aim to reconstruct aspects of the *chaîne opératoire* of fibre-based production, in particular the initial stages related to the selection, acquisition and preparation of raw materials. This reconstruction is achieved by first gathering information from previous archaeological studies at the sites and then interpreting the data through an experimental lens. The experimental approach involved working with traditional fibre artisans from the study areas who continue to work with the identified plants, thereby incorporating ethnobotanical insights into the analysis.

The identification of the raw materials and the processing to which they were subjected is carried out by means of microscopic observations (optical and scanning) of different vegetative tissues such as parenchyma, epidermis and vascular system, among others. The characteristics used for fibre identification are present both in the epidermis and in the transverse section. It is also possible to identify the part of the plant used. These are examined and then compared with the modern reference collection. However, the identifications are also supplemented by previous research, such as vegetal histology publications. This analytical approach is crucial for the positive identification of the plant fibres studied in this thesis, which provides qualitative data.

This thesis also develops a methodological proposal for the recovery and identification of fibres in non-perishable materials such as dental calculus. This approach includes a detailed description of the chemical decalcification processes used to extract and analyse the fibres.

1.5. Dissertation structure.

This dissertation corresponds to a compendium of publications and is divided into four eight chapters. **Chapter I** - which is the current one - contains an introductory section in which the motivation of the research and its justification are explained. A short overview of the materials and methodology, together with the main objectives of the research are also explained in this chapter.

Chapter II corresponds to the theoretical framework on which this research is based and can be divided into two sections. The first aims to define plant fibres, their classification, anatomical characterization in microscopic analysis and their current or traditional use, together with a brief summary about the technological features of the productions that can be made with them (cords and baskets). More specifically, it explains the diversity of raw materials and their taxonomic classification in plants, established by evolution and genetics. It then goes on to describe the steps in the *chaîne opératoire* involved in the production of fibre-based handicrafts: from the availability of raw materials in the natural environment to their selection, acquisition, and processing to make them suitable and malleable for handicraft purposes in terms of the tools required. These types of materials are usually divided into cordage and basketry productions. The section focused on the productions based on plant fibres contains definitions and morphotechnical descriptions used in technological studies of cordage and basketry objects. The range of objects made from vegetable fibres is extremely wide, depending on their morphology, technique and dimensions. This part of the chapter is based on traditional knowledge learnt from different artisans working with plant fibres who were visited during the period of this research. In turn, the second part of the chapter focuses on the direct and indirect register of plant fibres in archaeology in terms of their conservation in different archaeological contexts. It presents an overview of the archaeological evidence of plant fibres from the first remains in the Palaeolithic to the Late Neolithic-Chalcolithic (approximately), covering the chronological framework of the current project. The chapter finishes with an overview of the current state of archaeobotanical research on plant fibres used as raw materials, as regards archaeological tradition and the current state of research in Europe and Iberia.

Chapter III details the chronological and biogeographical framework which this research focuses on. In terms of chronology, the Mesolithic, Early Neolithic and Middle Neolithic are developed regarding the social implications they represented. Furthermore, the biogeographical framework is also developed for the northeast and southeast of the Iberian Peninsula, regarding the geography, climate and current vegetation. The organisation of this chapter follows a chronological order which coincides with a latitudinal one from the south-east to the north-east. Consequently, Chapter III (The Chronological and Biogeographical Framework), Chapter IV (Materials), Chapter VI (Results), Chapter VII (Discussion) and Chapter VIII (Conclusions and further considerations), follow the same sequence.

Chapter IV is devoted to the description of the materials analysed in the current research. The chapter contains an explanation of the archaeological sites from which they come (in a chronological order, as explained): Cueva de los Murciélagos (Albuñol, Granada), Coves del Fem (Ulldemolins, Tarragona), La Draga (Banyoles, Girona), Cova del Pasteral (La Cellera de Ter, Girona).

Chapter V presents an explanation of the methodology used in the current research. The absence of a public reference collection for plant fibres that specifically matches the species, and the archaeological finds included in this research made it necessary to create a specific reference collection. In this sense, the selection, procurement and sampling of both modern and archaeological materials and the creation of this reference collection are explained. The methodology used in the analysis of the archaeological materials will also be explained with regard to the direct or indirect evidence of plant fibres. Experimental Archaeology is also presented as part of the methodology used in this work.

Chapter VI deals with the results of this thesis. This chapter is divided into two main parts: Part I corresponds to the development of the reference collection created during the realization of this thesis, in which the different species included are explained in terms of their anatomical characteristics used for their identification. This reference collection is ordered alphabetically. The second part of Chapter VI (Part II) includes the four peer-reviewed scientific papers published during the production of this thesis. Three of them have been published in high-impact journals of Quartile-1 (Q1): Science Advances, Vegetation History and Archaeobotany journals and the Journal of Archaeological Science Reports. The last paper was published in a Quartile-3 (Q3) journal: MUNIBE Antropologia-Arkeologia (written in Spanish). In addition to these four papers, a further paper is currently submitted to and under review by the journal Open Archaeology (Q1).

Chapter VII discusses the results of Chapter VI in relation to the objectives of the thesis. The methodological discussion considers the importance of a specific reference collection in relation to plant histological knowledge. Other issues relating to the analysis of fibre archaeological remains, such as sampling and consolidation practices and their integrity under different preservation conditions, are also considered. Furthermore, the results of the methodological approach of searching for plant fibres in other materials, such as dental calculus deposits, are included in this chapter as well as an overall evaluation of the research results. The discussion of the results of this study focusses on the identification of raw materials considering the chronological sequence (from the Mesolithic to the Neolithic), the examination about the first steps of the *chaîne opératoire* regarding the obtaining and processing of the materials and the significance of the results in the context of the fibre production in the European context.

Chapter VIII concludes the body of the thesis. It presents the conclusions and final considerations of the research as well as proposing further studies that should be performed in order to continue with the main theme of this research.

Finally, the list of **References** cited in the thesis is given in alphabetic, followed by a **List of the figures and tables**. Further **Annexes** correspond the original papers forming part of their thesis including the supplementary materials, in case they have it, not included in Chapter VI.

CHAPTER II - THEORETICAL FRAMEWORK

2. Theoretical framework.

2.1. Plant fibres: description and diversity.

Plant fibres are basically whole or fragmented stems and leaves of various plants. However, they can also be strips of the inner bark of different tree species or even the whole branches, which are used to make a wide range of objects and tools for daily human activities. Histologically, plant fibres are typically seen as bundles of cells involved in structural support and the transport of water and nutrients within plant structures. Their composition, mainly lignin and cellulose in varying concentrations, gives them properties such as durability, flexibility, and strength (Vydal and Hormozábal 2016). They have been used since prehistoric times to make objects with different functions and they have played a crucial role in human daily life from ancient times to the present (Kuoni 1981). They occupy an important place in the material culture of populations worldwide, serving as a basic raw material for the production of a wide range of items, including cordage, basketry, footwear, textiles and more (Adovasio et al. 2008; Hurcombe 2014). The plant parts used include the stems of certain species (e.g. reed, cane, willow, bulrush or sedge), bark and bast fibres (e.g. lime, willow, hemp or flax) and the leaves of some monocotyledons, used whole or split (e.g. dwarf palm or esparto grass). The choice of the plant part depends on availability, the type of object it will be utilised for, and the technique used (Hurcombe 2014). A key consideration in the choice of raw materials is the technique, which dictates the required qualities of the plant material (Andrews et al. 1986).

From a biological point of view, the origin of plant fibres is natural, and they are extracted from a wide variety of plants, more specifically from vascular plants or tracheophytes which have evolutionary-developed specialized tissues for transporting substances within the plant, known as vascular tissue: xylem and phloem. Water and minerals are transported from the roots to the leaves by the xylem, while sugars produced by photosynthesis are distributed to other parts of the plant by the phloem. Xylem is composed of non-living cells (tracheids and vessel elements) and reinforced with lignin, while phloem consists of living, non-lignified sieve elements. They are both associated with sclerenchyma tissue which reinforces the structures. The vegetative bodies of vascular plants are adapted to terrestrial life in several ways. For example, the roots absorb water and minerals from the soil, and the stem transports water and minerals from the roots to the leaves and distributes carbohydrates produced by photosynthesis from the leaves to the rest of the plant. Likewise, leaves are positioned to maximize sunlight capture for photosynthesis. They present a waxy cuticle that reduces water loss; oxygen, carbon dioxide and water enter and leave the leaf through stomata, which are located mainly along the lower epidermis. The opening and closing of the stomata are regulated by the contraction and expansion of the surrounding guard cells, and gas exchange occurs through numerous epidermal pores called stomata. Those adaptations have enabled vascular plants to thrive in diverse and extreme environments, making them the dominant terrestrial plant group (Evert 2006).

Vascular plants are usually divided into non-seed plants (ferns) and seed plants (conifers and flowering plants) (Figure 1). However, this research focuses on angiosperms. Angiosperms reproduce by means of flowers, which is why they are commonly known as flowering plants. They are typically represented by two basic groups: monocotyledons and dicotyledons. These groups are distinguished by the number of embryonic seed leaves (cotyledons), the number of flower parts, the arrangement of vascular tissue in the stem and leaves, and the way in which the leaves are attached to the stem (Figure 1). Seed plants have stems that branch laterally and contain vascular tissue arranged in bundles around the pith. In seed plants, the stem tissues that arise directly from the tip of the shoot are called primary tissues and contribute to the longitudinal growth of the stem, or primary growth. Secondary growth, which increases the width of the stem, is produced by a meristematic tissue located between the primary xylem and phloem, known as the vascular cambium. This meristem consists of a narrow zone of cells that produce new secondary xylem (wood) and secondary phloem (secondary vascular tissue).

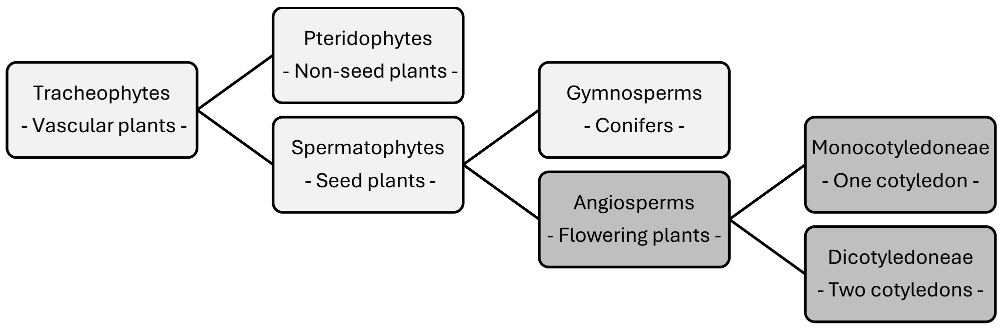

Figure 1. Evolutionary classification of tracheophytes or vascular plants. This research focuses on angiosperms.

The plant body of angiosperms consists of a central axis divided into two parts: the shoot and the root. Shoots consist of two types of organs, the stem and the leaves, while roots consist of one type of organ, the root itself. Classification systems are often based on the longevity of the above-ground parts of the plant. Herbaceous plants (generally monocotyledonous) have soft, flexible aerial parts and usually die back each year. Woody plants are trees and shrubs (generally dicotyledonous) whose shoots are durable and survive for several years. Woody plants are further divided into deciduous and evergreen categories. Deciduous plants shed their leaves at the end of each growing season, whereas evergreen plants retain their leaves for several years (Evert 2006).

There are about 60,000 species of monocots, including some of the most economically important plant families such as Poaceae (grasses) and Orchidaceae (orchids). Other important monocot families include Liliaceae (lilies), Arecaceae (palms) and Iridaceae (irises). Monocotyledons have several key characteristics: seeds with a single cotyledon, leaves with parallel veins, scattered vascular bundles in the stem and leaves, absence of a typical cambium, and an adventitious root system. Their floral parts are usually in multiples of three and their pollen grains usually have a single opening. Because their roots lack a vascular cambium, monocotyledons do not have secondary growth. The leaves, together with the stems, form the shoot of the vascular plant body and are primarily responsible for photosynthesis.

Dicotyledons, commonly known as dicots, are characterised by possessing a pair of embryonic leaves, or cotyledons, in their seeds. There are about 175,000 known species of dicots, including many common garden plants, shrubs, trees and broad-leaved flowering plants such as roses and geraniums. Dicots can be divided into two main types based on their appearance: herbaceous dicots and woody dicots. In herbaceous dicots, the vascular tissue is organised into discrete vascular bundles, each containing both xylem and phloem, arranged in a ring. The cells between these bundles are thin-walled and often store starch. The peripheral region of the stem is called the cortex, while the central region is called the pith. The outermost layer of cells forms the epidermis, and there is no cortex on a herbaceous stem. In contrast, woody dicots develop an outer layer of dead, thick-walled cortical cells which, together with the underlying phloem, form the bark. Most of the diameter of the woody stem consists of a cylinder of xylem derived from the vascular cambium. This xylem often forms annual rings consisting of a broad zone of spring wood and a narrower zone of summer wood. These rings may be absent in tropical trees, which are perennial. The xylem rays, which radiate like the spokes of a wheel, connect with the peripheral phloem.

Not all the diverse families, genera and species of both monocots and dicots are suitable for craft purposes. In the case of monocots, usually leaves and stems are used. They are usually long and flexible elements when they are hydrated and their combinations create very hard objects. On the other hand, the extraction of dicot fibre needs a longer and more complex process, but very fine and resistant fibres are obtained. Table 1 gives a summary of species used for handicrafts in Europe, based on ethnographic and traditional knowledge, and their similarity to other species used in handicrafts.

Table 1. Summary of the species used for handicrafts in Europe. Extracted from Pardo de Santayana et al. 2014, Plants for a Future (PFAF), ethnographic and traditional knowledge.

Class	Order	Family	Genus	Species
Monocotyledoneae	Poales	Arecaceae	*Chamaerops*	*Chamaerops humilis*
Monocotyledoneae	Poales	Arecaceae	*Phoenix*	*Phoenix canariensis*
Monocotyledoneae	Poales	Cyperaceae	*Cyperus*	*Cyperus fuscus* *Cyperus longus*
Monocotyledoneae	Poales	Cyperaceae	*Scirpus*	*Scirpus holoschoenus*
Monocotyledoneae	Poales	Cyperaceae	*Cladium*	*Cladium mariscus*
Monocotyledoneae	Poales	Cyperaceae	*Carex*	*Carex riparia* *Carex pendula* *Carex sylvatica*
Monocotyledoneae	Poales	Juncaceae	*Juncus*	*Juncus acutiflorus* *Juncus effusus* *Juncus inflexus* *Juncus maritimus* *Juncus nigra*
Monocotyledoneae	Poales	Poaceae	*Avena*	*Avena sativa*
Monocotyledoneae	Poales	Poaceae	*Hordeum*	*Hordeum distichum* *Hordeum vulgare*
Monocotyledoneae	Poales	Poaceae	*Lygeum*	*Lygeum spartum*
Monocotyledoneae	Poales	Poaceae	*Phragmites*	*Phragmites australis*
Monocotyledoneae	Poales	Poaceae	*Secale*	*Secale cereale*
Monocotyledoneae	Poales	Poaceae	*Stipa*	*Stipa gigantea* *Stipa tenacissima*
Monocotyledoneae	Poales	Poaceae	*Triticum*	*Triticum avestivum* *Triticum dicoccum* *Triticum durum* *Triticum monococcum* *Triticum spelta* *Triticum timopheevi*
Monocotyledoneae	Poales	Poaceae	*Typha*	*Typha angustifolia* *Typha domingensis* *Typha latifolia*
Dicotyledoneae	Cornales	Cornaceae	*Cornus*	*Cornus sanguinea*
Dicotyledoneae	Fabales	Fabaceae	*Cystisus*	*Cystisus scoparius*
Dicotyledoneae	Fabales	Fabaceae	*Lupinus*	*Lupinus albus*
Dicotyledoneae	Fabales	Fabaceae	*Spartium*	*Spartium junceum*
Dicotyledoneae	Fagales	Betulaceae	*Betula*	*Betula pendula*
Dicotyledoneae	Fagales	Betulaceae	*Corylus*	*Corylus avellana*
Dicotyledoneae	Fagales	Fagaceae	*Castanea*	*Castanea sativa*
Dicotyledoneae	Fagales	Fagaceae	*Quercus*	*Quercus faginea* *Quercus robus*
Dicotyledoneae	Lamiales	Lamiaceae	*Stachys*	*Stachys sylvatica*
Dicotyledoneae	Lamiales	Oleaceae	*Fraxinus*	*Fraxinus* sp.
Dicotyledoneae	Malpighiales	Linaceae	*Linum*	*Linum usitatissimum*
Dicotyledoneae	Malpighiales	Salicaceae	*Populus*	*Populus* sp.
Dicotyledoneae	Malpighiales	Salicaceae	*Salix*	*Salix* sp.
Dicotyledoneae	Malvales	Malvaceae	*Malva*	*Malva alcea* *Malva excise* *Malva mohileviensis* *Malva moschata* *Malva sylvestris*
Dicotyledoneae	Malvales	Malvaceae	*Tilia*	*Tilia cordata* *Tilia platyphyllos* *Tilia tormentosa*
Dicotyledoneae	Malvales	Cannabaceae	*Cannabis*	*Cannabis sativa*
Dicotyledoneae	Malvales	Rosaceae	*Prunus*	*Prunus avium*
Dicotyledoneae	Malvales	Rosaceae	*Rubus*	*Rubus fructicosus*
Dicotyledoneae	Malvales	Ulmaceae	*Ulmus*	*Ulmus glabra* *Ulmus pilulifera*
Dicotyledoneae	Malvales	Urticaceae	*Urtica*	*Urtica dioica* *Urtica urens* *Urtica pilulifera*
Dicotyledoneae	Ranunculales	Ranunculaceae	*Clematis*	*Clematis vitalba*
Dicotyledoneae	Sapindales	Anarcardioidaeae	*Rhus*	*Rhus* sp.

2.2. From the field to their use: plant fibre acquisition, management and work processes.

The diversity of species that can be used to produce fibre-based objects varies by geographical region and it directly depends on their availability in the surroundings. The Plants for a Future (PFAF) database records nearly 300 different plant species used for these purposes worldwide, although it is not an exhaustive list. Furthermore, and as mentioned above, plant fibre can be extracted from different families, but also from different parts of the plant. They can be obtained from leaves, stems, seeds, fruits and even roots, and can be classified according to this origin. In fact, Norton (1990) proposed a classification of raw materials based on the main organs and parts of the plants used and whether they are monocotyledonous or dicotyledonous.

From the point of view of plant fibre artisans, fibres can be also differentiated into two main groups according to their physical, technical and chemical characteristics: hard fibres and soft fibres. Hard fibres are mainly the leaves of monocotyledonous plants such as esparto grass (*Stipa tenacissima*), yucca (*Yucca* sp.) or sisal (*Agave* sp.), as well as the stems from sedges (Cyperaceae family). These have been used mainly in the production of cordage, basketry and footwear. On the other hand, soft fibres are basically found in the stalks of dicotyledonous plants, some examples are flax (*Linum usitatissimum*), jute (*Corchorus capsularis*), hemp (*Cannabis sativa*) or nettle (*Urtica* sp.), and are known as bast fibres. These fibres require more costly and elaborate processing than monocotyledonous fibres and they have been used mainly for the production of fabrics, useful for clothing. This classification will depend on the craftsman's point of view, as young branches of various trees such as willow (*Salix* sp.), which is known as wicker, hazel (*Corylus avellana*), the bast fibres of lime (*Tilia* sp.) or the stems of reeds such as *Arundo donax* or *Phragmites australis* are also considered plant fibres.

Knowledge of plants suitable for basketry as well as the information about their selection, gathering and processing has developed through years of interaction with nature and experimentation over many generations within subsistence economies. The selection of plant material is therefore not simply based on proximity but is a deliberate choice within the basket-making process. However, ethnographic and archaeological evidence suggests that a variety of native species were used in the regions where they are found. In Europe, several local plants have been documented ethnobotanically and histologically. Studies in the Iberian Peninsula have compiled traditional uses of both wild and cultivated plants. Monocotyledons such as esparto grass (*Stipa tenacissima*), albardine (*Lygeum spartum*) and hemp (*Cannabis sativa*) are particularly mentioned, but flax, rush, nettle and the bark of blackberry (*Rubus ulmifolius*) or hazel are also used (Pardo de Santayana et al. 2014). Historically esparto grass is more common in the south and wicker in the north. In the

Canary Islands, leaves of *Phoenix canariensis* as well as cattails (*Typha* sp.) leaves and sedges (Cyperaceae) stems are documented (Galván 1980).

Some plants used for crafting grow wild and spontaneously in forests and anthropized areas, while others are cultivated specifically for this purpose. The collection of raw materials depends on the species, the season and the environment. Authors and artisans suggest that the time of harvesting and the maturity of the plant influence several aspects, including fibre quality, durability and material properties. In addition, the drying process required influences the flexibility and density of the fibres (Norton 1990; Wescott 1999).

Once collected, the materials need to be dried and slightly rehydrated prior to manufacturing to maintain quality and ease of handling. This dehydration process allows flexibility in the timing of harvesting and material preparation, as it does not need to coincide with the manufacturing time. When dehydrated, the raw material can be stored indefinitely (Wendrich and Ryan 2012). Depending on the fibre, this dehydration process can be carried out in the sun or in the shade, which has an aesthetic effect on the final colour of the fibres due to the degradation of chloroplasts from the plant cells.

The preparation of the material is essential as it determines the quality of the final product and the consistency of the fibres in terms of thickness, flexibility and strength (Hurcombe 2014). Each technique requires different methods of material extraction. The process of fibre extraction varies according to species and climate region. According to Maiti (1995), there are two main methods of fibre extraction based on the toughness of the fibre. The method of extraction can be damaging to the plant material (Norton 1990). Soaking in fresh or salt water or mud can lead to mineral salt deposition, while decortication in alkaline chemical solutions can degrade the material by increasing wax, oil or pectin content. According to Norton (1990), plant fibres differ in their tolerance to treatment without excessive weakening. Sometimes only the outer bark is removed after one of the two extraction processes, resulting in more flexible and cleaner inner fibres. In other cases, no processes are required, and fibres are obtained by simply scraping off the outer bark. After extraction, the fibres are often sun-dried for several days, which can lighten their colour.

Generally, hard fibres are obtained by mechanical separation or decortication, while soft fibres are obtained by retting with water. In the case of hard fibres (monocotyledonous), extraction is carried out mechanically, either by hand or by machine. The decortication process consists of crushing the fibres with hard objects (wood or round stones) that break the surface or epidermis of the plants. Today, however, chemical agents are also used in the preparation of hard fibres in order to speed up the process and obtain better prepared fibres. The extraction of soft fibres (dicotyledonous), called retting, consists of immersing the fibres in water, which causes a natural degradation of the organic matter by fermentation, allowing the sclerenchyma tissue to be separated from the plant. This process usually takes between one and four weeks, depending on the characteristics of the fibre, but also on the expertise of the artisan. Once the fibres have been removed from the water, they are cleaned (which may involve physical processing, as in the case of flax, which is crushed and brushed) and then completely dried and stored for long periods (Maiti 1995; Andersson 2012; Hurcombe 2014).

The use of bark strips is a complex process (Myking et al. 2005; Médard 2008). It generally involves cutting branches in spring or early summer, when the tree has reached maturity, the leaves have reached full size and the bark can be easily removed due to the rising sap. This material is usually obtained from young lime trees or new straight shoots from older pollarded or coppiced trees, as this affects the quality of the fibre. The bark is stripped or removed from the wood and then soaked in freshwater or seawater for several weeks to undergo retting: a process in which soaking softens the bark through bacterial decay and the breakdown of pectin and lignin. This facilitates the natural separation of the fibres into layers. However, some experimental archaeological research suggests that the inner bark can be used for craft purposes without retting. In the case of branches of dicotyledons species, they are cut to the right thickness at the right time of the year.

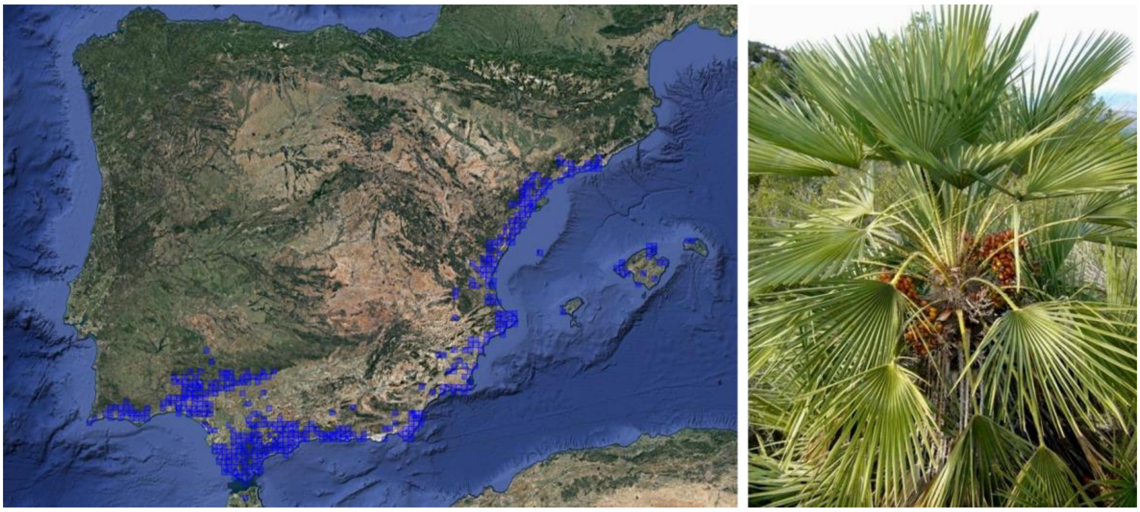

Figure 2. Distribution *Chamaerops humilis* in the Iberian Peninsula (Map distribution: SIVIM, plant image: Associació Flora Catalana).

The tools required for fibre crafting vary according to the type and characteristics of the objects being made (Guinovart 2004). For example, historically, the basic method for making rope was the manual twisting of fibres without tools, as still observed in ethnographic studies (Muscio and Anaya 2018). However, several tools for fibre production have been documented (De Diego 2023). Soffer's (2004) studies on Upper Palaeolithic tools suggest that specialised implements were used for rope and textile production, leaving diagnostic wear marks. This study is in line with other studies showing that rope and textile manufacture required specialized tools, as seen in ethnographic and archaeological records, but also the front teeth were used for fibre crafting.

2.3. Plants used as fibre-based raw material and their traditional and ethnographic use in the Iberian Peninsula, Balearic and Islands.

The geographical scope of these corresponds to the Iberian Peninsula: in this section the most current plants used in fibre-based production are described.

2.3.1. Monocotyledoneae families.

2.3.1.1. Palm-like plants: Arecaceae (*Chamaerops humilis*).

On the Mediterranean coast of Iberia and the Balearic Islands, where temperatures are high, one species of wild palm grows: *Chamaerops humilis* (dwarf palm/European fan palm) whose leaves have traditionally been used in handicrafts (Figure 2).

The use of the dwarf palm is still widespread in some areas of central Mediterranean Iberia and the Balearic Islands. It thrives in poor, dry soils, such as garrigue areas between shrubs, and is the only wild palm species in Europe. It grows naturally from the coast up to 800 metres above sea level and is highly resistant to dry and salty environments. Although commonly known as the dwarf palm due to its size, it can sometimes reach several metres in height. Its trunk is partially buried, giving it a shrub-like appearance rather than a tall tree. Its leaves are fan-shaped, consisting of twelve to fifteen narrow, long leaflets that are folded lengthwise. Traditionally there are two documented methods of obtaining the leaves. The first involves harvesting the fan leaves when they are fully open, drying them and using them to make objects related to various functions, such as agriculture. Alternatively, immature or closed fan leaves are collected by pulling them from the plant. Due to their small size and more delicate aspect, they are used for ornamental purposes. In both cases, collection takes place in summer, from May to September and when the material is dried, it can be stored for a long time; it should be lightly moistened before use. Traditionally, the dwarf palm leaves are plaited into multi-strand braids called 'llata' (CAT), depending on the desired width and strength. These long braids are then sewn together to create the final objects. In addition, several metres of cord are traditionally used to make chair seats with different decorative patterns or even brooms (Kuoni 1981).

Similarly, date palm is used in the middle Mediterranean of the Iberian Peninsula, basically in relation to the production of religious objects. Iberia is the only territory where palm areas are similar to the natural ones present in the African oasis. *Phoenix dactylifera* grows in the most arid latitudes of eastern Iberia and has probably been cultivated since Phoenician times

2.3.1.2. Grass-type plants (Poaceae).

2.3.1.2.1. Esparto grass-type: *Lygeum spartum*, *Stipa gigantea* and *Stipa tenacissima*.

Esparto grass-type refers to three different species of grasses (Poaceae) which grow naturally in different parts of the Iberian Peninsula and which are prepared, treated and used in a very similar way for crafting purposes. These are *Lygeum spartum* (albardine), *Stipa gigantea* (giant feather grass) and *Stipa tenacissima* (esparto grass). However, the information in this section is based on the third specie, which is the most common one.

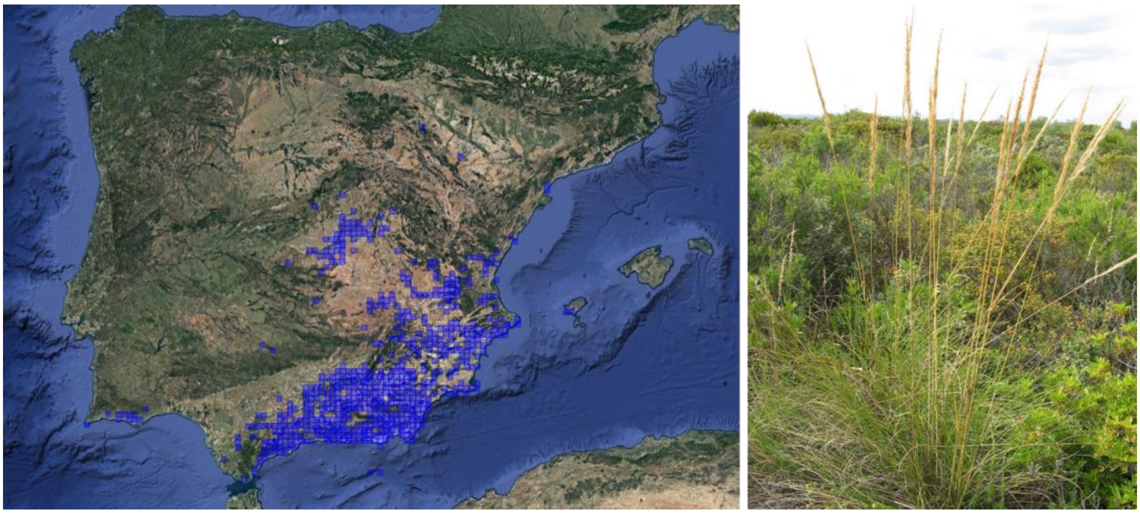

Figure 3. Distribution of *Stipa tenacissima* in the Iberian Peninsula (Map distribution: SIVIM, plant image: AJP by Flora.on).

Esparto grass is an endemic plant in the western Mediterranean and thrives in semi-arid regions with poor limestone soils at altitudes up to 1,000 metres, although its optimum altitude range is between 500 and 700 metres (Figure 3). The diversity of the genus has been debated, but it is generally accepted that there are two species and two subspecies (*Stipa antiatlantica, Stipa tenacissima, Stipa tenacissima tenacissima* and *Stipa tenacissima gabesensis*) in northern Africa. In contrast, only the subspecies *Stipa tenacissima tenacissima* is found in the Iberian Peninsula (Barreña et al. 2006). Esparto grass is a perennial plant characterised by numerous filiform leaves that grow in clusters in the spring. These leaves are circular and rolled to minimise water loss. The plant can grow to a height of about one metre and its flowers form spikes in which several seeds are stored. Esparto grass grows in dense formations called 'espartizales' or 'atochales', each plant being called an 'atocha'. During the first two or three years of life, the plants are sensitive to environmental changes and show slow growth (Kuoni 1981). Esparto grass reproduces both by seed and by planting its roots or rhizomes.

The plant is used in handicrafts, where each leaf is called 'esparto'. In Spain, esparto grass covers more than 400,000 hectares, both cultivated and wild. Publications indicate that this area increased to 648,000 hectares in the second half of the 20th century, reflecting its importance as one of the most important industries in the previous century. The main production areas were in Murcia and Albacete, regions known as the *Campus Spartarius* after the descriptions of Pliny the Elder (Vilá Valentí 1962). These areas are traditionally recognised for producing the best quality esparto grass. In some regions similar plants to esparto grass are considered homologous to *Stipa tenacissima* and they are used in the same way (*Stipa gigantea* and *Lygeum spartum*).

Esparto grass is a wild plant that has been managed and cultivated for centuries for its industrial value (Bañón Cifuentes 2010). Although the esparto industry continues to some extent, it has declined significantly as society has become more technological and moved away from traditional agricultural and livestock practices. The industry also faced competition from other plant fibres such as jute, sisal and coconut, which were introduced in the 1960s, and from synthetic materials such as plastic and rubber. Today, esparto is mainly used as a hobby by retired people who are passionate about the traditional craft and its historical significance. Esparto artefacts, once essential to rural life, are now mainly decorative items in homes rather than practical tools. Only a few elderly villagers continue to practice the remnants of this ancient esparto culture. These techniques, passed down orally since ancient times, are now in danger of disappearing.

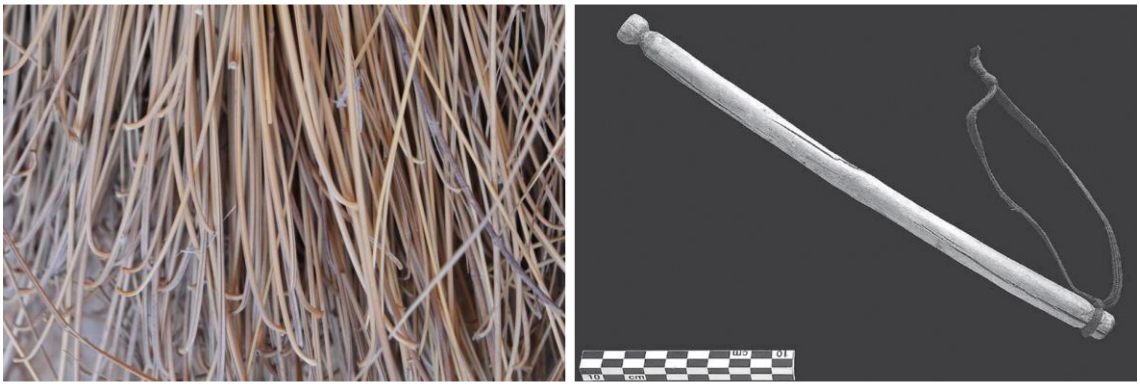

Figure 4. Left: Basal part of the esparto leaves forming a hook when dry. Right: Wooden instrument for manual collection of esparto grass-type plants (M'Hamdi and Anderson 2013).

The long tradition of using esparto has led to the development of specific methods for its gathering, processing and work process. The harvest season usually lasts from August to January, depending on the region. However, the most prized esparto is harvested during the warmest months (June to September) and is known as 'summer esparto' due to its superior properties and colour. The leaves, which are the used part, are attached to the rhizomes by a small part that forms a hook when dry (Figure 4). To collect the leaves, they must be pulled from the plant rather than cut. This can be done manually or with an instrument made of hard wood, such as holm oak (*Quercus ilex*), or metal (Figure 4). This tool is broader at one end and has a handle at the other to attach it to the wrist so that it is not lost during use. The instrument is known by different names depending on the area, including '*cogedera*', '*talisa*' and '*arrancadera*' (SP) (Kuoni 1981). The collection process involves wrapping a bundle of esparto leaves around the stick and pulling it out of the plant.

Once harvested, esparto should be dried for twenty to thirty days, depending on the region and the preferences of the artisan. Complete drying is essential. During this drying process, the leaves lose moisture and weight, and colour changes are noticeable, depending on whether the drying takes place in the shade or in the sunlight, due to chlorophyll degradation (Figure 5). At this point the material is ready for use in various applications and can be stored in bundles for long periods. When ready for use or manufacturing objects, esparto can be subjected to various processes to obtain different categories, such as retted esparto, which is submerged in standing water for 20-40 days, depending on the water temperature. In some regions, this period is traditionally linked to the lunar cycle. This process involves organic decomposition. Another type of material is crushed esparto, which has been physically crushed using hard wood such as holm oak (*Quercus ilex*) (Figure 5). Traditionally done by hand, automatic crushing machines were introduced in the 18th century (Kuoni 1981).

Figure 5. Left: Esparto grass being dried. Right: Traditional wooden hammer for crushing esparto leaves.

Esparto grass has a rich tradition that encompasses a wide range of techniques and objects that can be made from it. As noted in this chapter, esparto handicrafts are now seen primarily as decorative items for the home, with only a few artisans preserving the remnants of the ancient esparto culture. Historically, esparto has possessed a wide range of traditional uses, depending on the technique, the preparation of the fibre and the skill of the artisan. No other species can match the diversity of techniques and objects made from esparto (Kuoni 1981; Fajardo et al. 2015). Examples include the production of ropes, chair seats, multipurpose baskets (for gathering snails, fish, water, etc.), footwear, toys, cheese moulds, cleaning as a scrubbing agent, fire stirrers, fishing tools, animal feed, olive pulp presses for oil extraction, surface protection and construction materials, among others (Fajardo et al. 2015).

2.3.1.2.2. Straw-type plants: *Avena sativa*, *Hordeum vulgare*, *Triticum* sp., *Secale cereale*.

The use of straw is directly related to the long and malleable stems of different Poaceae families, such as wheat (*Triticum* sp.), rye (*Secale cereale*), barley (Hordeum vulgare) and oat (*Avena sativa*). Their cultivation has been widespread in the Iberian Peninsula since Neolithic chronologies or the appearance of agricultural practises. However, in the last centuries, with the new mechanization of agriculture, their use has decreased as cereal stems are usually broken into small pieces that makes them no longer of use for crafting (Kuoni 1981). In fact, all the cultivated cereals are appropriate for a use in straw basketry. They are species that provide numerous products for human communities: the grains for feeding in different forms both for human and animals, the stems in construction by mixing them with clay and water, and the use of the shiniest individuals or more attractive or beautiful specimens for crafting. The use of each of species depends on their availability as well as on the craft preferences, as some species, for example rye, usually possess a brighter appearance and are more often used in ornamental or decoration objects. Nonetheless, its use has been in decline since the introduction of more resistant cereals, and its use in textile production has practically disappeared. Nowadays, it is still utilised in some specific rural areas where mechanical agriculture practices are not widely used (Kuoni 1981).

The use of straw in craft production has usually been described following the case of rye, which is a plant that survives in hard soils and environmental conditions such as cold, wet, and very dry weather and it grows all over Iberia. Its use as a basketry raw material has extended from the west (Portugal), to the rest of the peninsula: Galicia, Aragón, Catalunya, Extremadura, Andalucía and Llevant. These cereals have been used to produce coiled baskets of different sizes and for other multiple purposes (Figure 6). Very big ones were used to store cereal grains and they were so big that they could not be moved for generations, and they were regarded as part of the house. Each region has its particular nomenclature of the objects. Smaller and handled baskets were used in Catalonia for carrying chickens, and others to contain bread during the fermentation process and before it is baked, as traditionally recorded in several places in Iberia. The use of straw basketry is usually related to domestic uses, while the use of other harder and more rigid elements such as branches of *Salix* sp., *Corylus avellana* and *Betula pendula* are related to agricultural uses. Straw has also been used to produce objects to carry liquid as they were very tight or closely coiled products waterproofed on the inside. The use of different species of Poaceae in the same object to achieve decorative patterns has also been recorded in several places. Several types of ornamental objects are also made with straw stems, such as hats for both adults and children to protect their head - traditionally known as 'gorres de cop' (CAT) -, photo frames, toys and construction elements. Their use in construction is directly related to the roofs of the houses which were substituted by non-perishable materials.

Figure 6. Right: *Secale cereale* used for basketry (HFS by Forestry Images). Left: The process of making coiled rye basketry (Google Images).

The stalks are the part of the plant used in straw handicrafts and it is essential to harvest them by hand with a sickle, traditionally during the months of June and July. After harvesting, the raw material is dried and can be stored, although storage methods vary from region to region due to different traditions. It is important to remove the grains by shaking them by hand to avoid crushing the straws. Knots along the stalks, as well as the leaves and their bases, should be cut off. Longer stalks are most valuable in basketry. When the material is ready for use, it should be slightly damp. Straw is used to make the coils of coiled baskets, with binders made from twisted cords of esparto grass in southern regions and strips of blackberry (*Rubus fruticosus*), wicker and birch bark (*Betula* sp.) in northern areas. This technique, using straw stalks, is widespread throughout the Iberian Peninsula.

Straw is also documented in the production of ornamental figures, combining different species to create decorative patterns with variations in colour, width and texture. Stems can be flattened and woven into various shapes. They are also used in straw-based roof construction in some parts of western Iberia (Kuoni 1981). It should be mentioned that between the different species used in straw basketry, rye was basically used for coarser basketry purposes such as transport or storage while wheat and barley straw, combined with oat straw and spelt straw (*Triticum spelta*), were used for finer basketry because of their golden colour and attractive appearance (Verde et al. 1998).

2.3.1.3. Hydrophyte-type plants.

2.3.1.3.1. Poaceae family: Canes (*Arundo donax*) and reeds (*Phragmites australis*).

Canes (*Arundo donax*) and common reeds (*Phragmites australis*) naturally grow on the shores of water bodies in the whole territory of Iberia. They are commonly found in wetlands, including marshes, estuaries, riverbanks, and along the shores of lakes and ponds. They thrive in areas with high water tables and can grow in both freshwater and brackish environments. These species are highly tolerant of a wide range of soil types, from sandy to clayey soils, and can withstand periodic flooding, and form dense stands, creating extensive reed beds that provide important habitats for wildlife. Both canes and reeds are prominent in the wetland ecosystems of the Iberian Peninsula and often coexist in similar environments. However, *Arundo donax* is more tolerant of drier conditions than *Phragmites australis*, which thrives in wetter, waterlogged soils. Both species play an important role in their ecosystems, providing habitat and stabilising soils, but they can also become invasive, outcompeting native vegetation and altering local habitats.

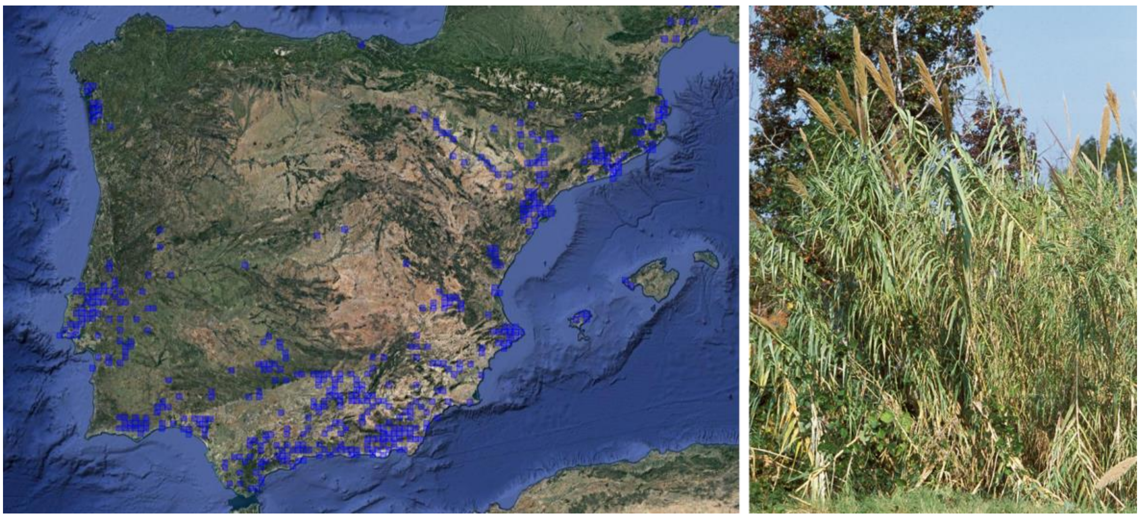

Figure 7. Distribution of *Arundo donax* in the Iberian Peninsula (Map distribution: SIVIM, plant image: JHM by Bug Wood).

Arundo donax (Figure 7) has an eastern origin and spread throughout antiquity, despite the confusing citation of other reed species with similar uses for rustic and agricultural constructions, handicrafts and medicinal purposes. The various biblical references to reeds give an idea of the antiquity of this culture, which spread to all the countries in the Mediterranean basin. Probably originating from temperate or tropical Asia, it is now widely cultivated and naturalised in the Mediterranean region. It is found throughout much of the Iberian Peninsula and the Balearic Islands, although it is less common in the north-western part of the peninsula. It is an herbaceous plant with great plasticity in size, bud position and duration of aerial stems, which can be annual or perennial. It has a strong root system, similar to a rhizome, but distributed at different levels, from the surface to depths of up to 7 metres, allowing it to resprout and survive after heavy flooding. The stems can reach 6 metres in height, are very tough and have hollow internodes. The leaves are flat, glaucous, very broad and long, with smooth edges and a large sheath that covers part of the stem. The seeds are sterile, so reproduction is purely vegetative. It invades riparian forests when these are felled or burned. The roots do not tolerate prolonged waterlogging, it grows from 0 to 900 metres, and it flowers from autumn to early spring.

In turn, *Phragmites australis* (Figure 8) is of European origin and is widely distributed around the world, being present in temperate regions of all five continents. It is an evergreen reed with a long, woody, and very active creeping rhizome that has the ability to grow on the surface in search of water. It can be confused with common reed as they look very similar. The common reed can grow up to 3 metres high. It is a robust, perennial plant with thick, hard, stiff stems. The flowers are silky feathers, initially reddish and later straw coloured. It forms dense clumps in shallow waters, marshes and riverbanks.

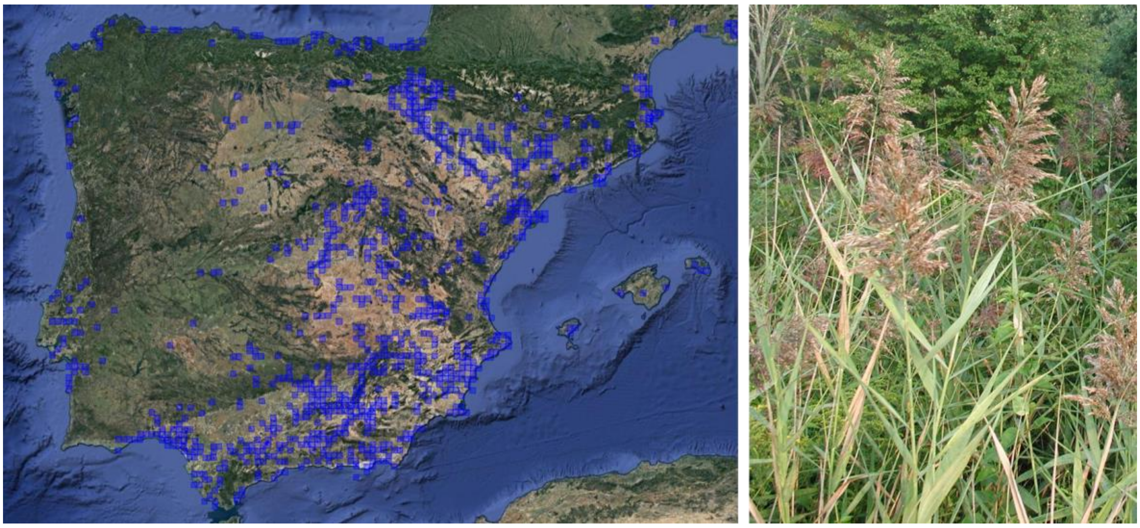

Figure 8. Distribution of *Phragmites australis* in the Iberian Peninsula (Map distribution: SIVIM, plant image: LJM by Bug Wood).

Both species are cut from the second half of December until February or March, during a full moon, before the sap rises. The reeds are left to dry, peeled and then cut into strips using a splitter. The lightness of the reed makes it possible to make large, light baskets (Kuoni 1981; Verde et al. 1998). In the work of Pardo de Santayana et al. (2014), it is mentioned that in different parts of the Iberian Peninsula, as well as in the Balearic and Canary Islands, reed is often used in basketry, either alone or combined with rush, willow, olive branches (*Olea europaea*), esparto grass or palm trees. Both canes and reeds have been used in the construction of roofs, buildings and even some agricultural structures, like fences, walls and barriers. It has also been used to make mats, trays and baskets.

2.3.1.3.2. Sedges (Cyperaceae), rushes (Juncaceae) and cattails (Typhaceae).

Sedges (Cyperaceae), rushes (Juncaceae) and cattails (Typhaceae) are all hydrophytes with very similar growing conditions, harvesting and processing for craft purposes (Figure 9). Therefore, although they belong to three different families, they are discussed together in this section.

Figure 9. Left: *Scirpus holoschoenus* (Cyperaceae) (CER by Flora.on). Middle: *Juncus inflexus* (Juncaceae) (CA by Flora.on). Right: *Typha latifolia* (Typhaceae) (JDA by Flora.on).

The Cyperaceae family (sedges) is one of the largest families of flowering plants, with around 5,000 species found on all continents except Antarctica, with greater diversity in tropical regions. The ecological diversity of sedges is enormous, with species occurring in almost all habitats except extreme deserts and marine and deep-water ecosystems. The Juncaceae family (rushes) contains about 415 species, and they are generally perennial herbs with a creeping underground stem and erect, unbranched aerial stems bearing slender leaves that are either grass-like or cylindrical or reduced to membranous sheaths. They are also found in temperate regions, especially in damp or shady places, and are used throughout the world for weaving chair seats, mats, baskets and hats. The third family, the Typhaceae (cattails), contains the genus *Typha*, which includes about 30 species of tall, reedy marsh plants found mainly in temperate and cold regions of both hemispheres. These plants live in fresh to slightly brackish water and are considered aquatic or semi-aquatic. Cattails are important for wildlife and many species are also cultivated as ornamental pond plants and for dried flower arrangements.

Species from each family have been used for basketry from ancient times to the present day. Sedges and rushes have basically cylindrical stems that grow in clumps with cattails and other species in wet marshes. The stems of sedges and rushes, together with the leaves of cattails, are collected in summer and left to dry in the sun for about fifteen days. If not harvested before winter, this vegetation dies and regrows in April or May. Once dried, the stems are split and soaked in clear water until they are moistened to be used in crafting activities (Kuoni 1981; Pardo de Santayana et al. 2014).

2.3.2. Dicotyledoneae families.

2.3.2.1. Bast fibres: Linaceae (*Linum usitatissimum*) and Urticaceae (*Urtica dioica*).

Bast fibres are soft and woody fibres obtained from the stems of dicotyledonous plants between the epidermis (bark surface) and inner woody core. They are strong and widely used in the manufacture of textile-related objects. This group of fibres is characterised by its fineness and flexibility and includes various species from different families such as flax (*Linum usitatissimum*), hemp (*Cannabis sativa*), jute (*Corchorus capsularis*), kenaf (*Hibiscus cannabinus*), nettle (*Urtica dioica*), ramie (*Boehmeria nivea*), and others. However, only flax and nettle will be discussed in this section, as they are the ones that could have been used in the chronological and geographical framework of the current research. When harvesting bast fibres, the plant stalks are cut or pulled up close to the base. The fibres are usually separated from the stalk by the process called retting explained above (immersion in water), but can also be obtained by decortication, which involves manual or mechanical peeling. The released fibre bundles are often used without further separation.

Flax (*Linum usitatissimum*) (Figure 10) is an annual herbaceous plant in the Linaceae family and it is harvested in late summer or early autumn when the soil is dry enough for easy collection. It is native to the Middle East, although it has been cultivated all over Europe since the Neolithic period, and represented the most important material for textile production in Israel until the beginning of the Bronze Age (Abbo et al. 2015). Flax fibre processing usually begins in late autumn or early winter. Its fibres are very strong and it is considered one of the strongest natural fibres. According to Gibby (1999), flax fibre can be obtained by scraping the green stalks to remove the fibrous skin with a cutting tool, or by biochemical processes (retting) which allow easier manual extraction. The stalks are used to make cloth, while the seeds are used to make flour and oil.


Figure 10. Distribution of Linum usitatissimum in the Iberian Peninsula (Map distribution: SIVIM, plant image: Tierra Pura).

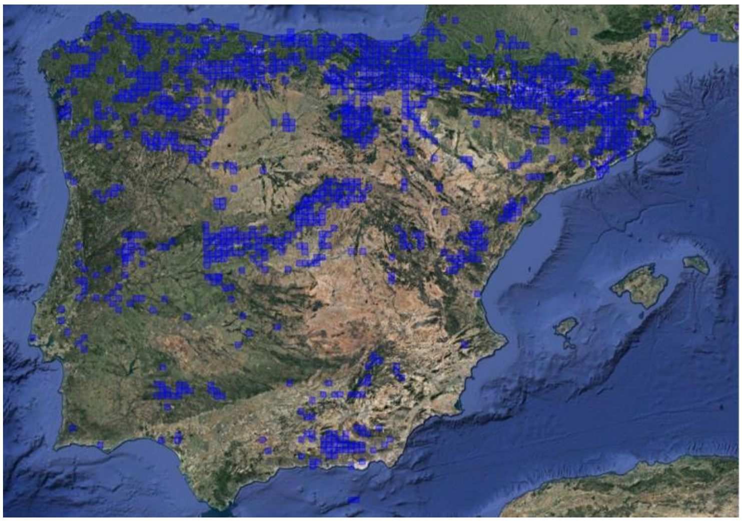


Figure 11. Distribution of Urtica dioica in the Iberian Peninsula (Map distribution: SIVIM, plant image: La Huertina de Toni).

Nettle (*Urtica dioica*) (Figure 11) is an herbaceous plant known for its stinging hairs. It has serrated leaves and stems covered with fine hairs that release histamine and other chemicals on contact, causing a stinging sensation. The plant can grow up to 1-2 metres tall and has opposite, coarsely toothed leaves. Stinging nettle thrives in nutrient-rich soil and is common in temperate regions of Europe, Asia, North America and parts of Africa.

It often grows in disturbed areas such as riverbanks, roadsides and forest margins. It quickly colonises areas with rich soil and plenty of sunlight and it plays an important role in ecosystems by providing habitat and food for a wide range of insects. Nettle has a long history of use in traditional medicine, cooking and textiles. In textile production, nettle has historically been used to make cloth and ropes. The obtaining of the fibres is very similar to the process explained in the case of flax; in fact retting eliminates the stinging sensation when touched.

2.3.2.2. Bark fibres: Malvaceae (*Tilia* sp.).

The lime tree (*Tilia* sp.) (Figure 12) is an arborescent woody plant growing spontaneously in the temperate zones of Europe, Asia and North America. It can grow up to 40 metres high and the quality of the lime bast fibre is influenced by both the age of the plant and the growing conditions. It has been used as a source of bast fibre in northern Europe at least since the Mesolithic period.

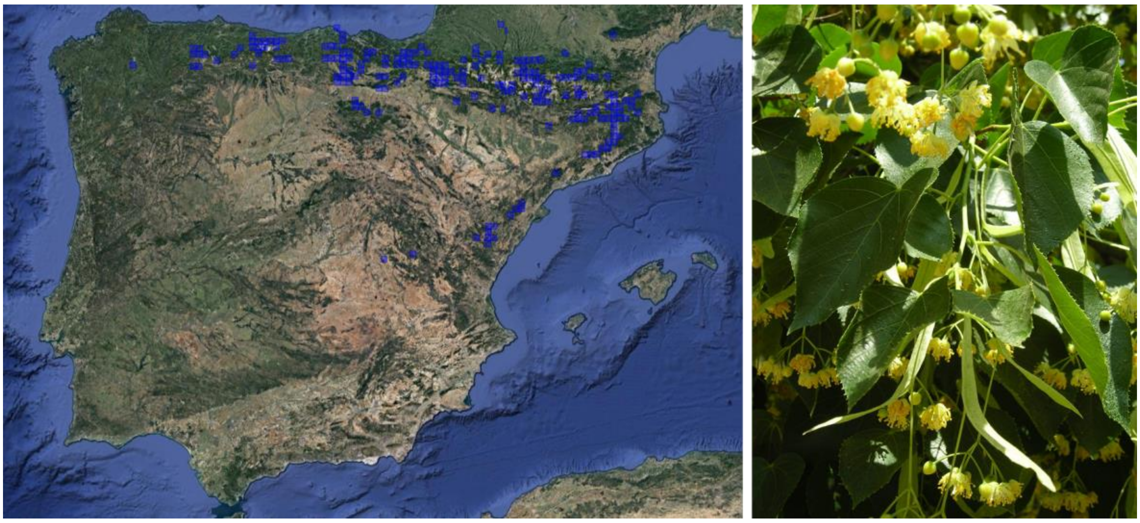

Figure 12. Distribution of *Tilia platyphyllos* in the Iberian Peninsula (Map distribution: SIVIM, plant image: Google Images).

Historically, lime trees have been managed by pruning every 5-10 years to produce good quality bark fibre for extraction (Myking et al. 2005), although sapwood removal is a complex process (Médard 2008; Myking et al. 2005). Branches are typically cut in spring or early summer when the tree is mature and the leaves are fully developed, as that is when the bark is easily removed because of the rising sap. The material is usually taken from young lime trees or new straight shoots on thicker branches of older pollarded or coppiced trees, as this affects the quality of the fibre. The bark is then stripped from the wood and soaked in fresh or sea water for several weeks for retting, a process in which soaking causes the material to soften through bacterial decay and the breakdown of pectin and lignin. This facilitates the natural separation of the fibres into layers. However, some experimental archaeological studies suggest that the inner bark can be used for craft purposes without retting (Herrero-Otal et al. 2023). The duration of retting, an essential operation to obtain a fine fibre that can be used in textiles, depends on many factors including the choice of method, water quality and bark quality, but it is likely to be completed by late autumn. Some authors suggest that trees or branches are generally cut in early summer, a few weeks before the summer solstice, when the leaves have reached their full size (Myking et al. 2005). Once retted, the strips can be dried and stored for long periods of time until the time of craft production of a wide range of products such as cords, ropes, baskets or other woven goods (Myking et al. 2005).

2.3.2.3. Rigid branches-type: Ranunculaceae (*Clematis vitalba*) and Salicaceae (*Salix* sp.).

A long list of species can be mentioned regarding the use of branches, as they are traditionally used in the Iberian Peninsula (Morales et al. 2011). Some of these species are willow (*Salix* sp.), clematis (*Clematis vitalba*), hazel (*Corylus avellana*), alder (*Alnus glutinosa*), ash (*Fraxinus excelsior*), poplar (*Populus* sp.), birch (*Betula* sp.), broom (*Ginesta sphaerocarpa*), olive (*Olea europaea*) and oleander (*Nerium oleander*). The use of branches and woody stems of these species is due to their rapid growth without knots, which can compromise their quality, as they are easy to split if necessary. In this section, two different species are considered: *Clematis vitalba* and *Salix* sp. which were two of the most used ones during the Neolithic in the study area.

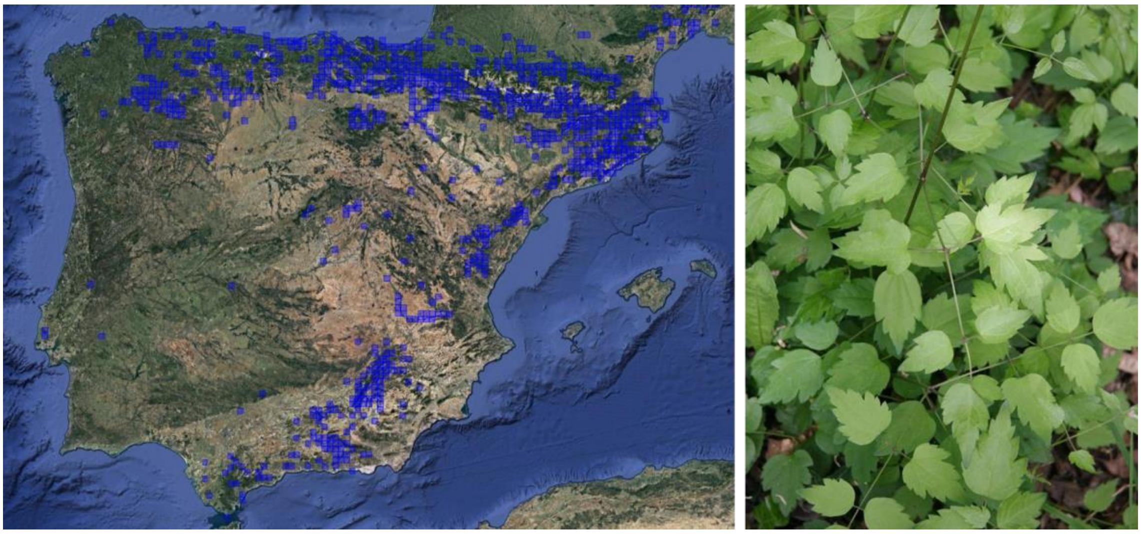

Figure 13. Distribution of *Clematis vitalba* in the Iberian Peninsula (Map distribution: SIVIM, plant image: Bug Wood).

Clematis (*Clematis vitalba*) (Figure 13), commonly known as old man's beard, is a perennial climbing plant in the Ranunculaceae family. It can reach 10 to 30 metres in length, with woody stems and fissured bark in mature specimens. Native to Europe and western Asia, it is widespread in the Mediterranean region and thrives in woods, roadsides, hedgerows and scrub. It prefers well-drained soils and can grow in full sun as well as partial shade but thrives best in nutrient-rich soils. Ecologically, it supports biodiversity by providing habitat and food for a variety of species. Traditionally, *Clematis vitalba* has been used in basket weaving because of its flexible and strong stems. The long, slender vines are ideal for weaving strong, lightweight baskets. Historically, these stems were harvested and soaked to increase pliability before being intricately woven into various shapes and sizes of basket. This practice used a readily-available natural resource to create functional items, highlighting the plant's versatility and usefulness in traditional crafts.

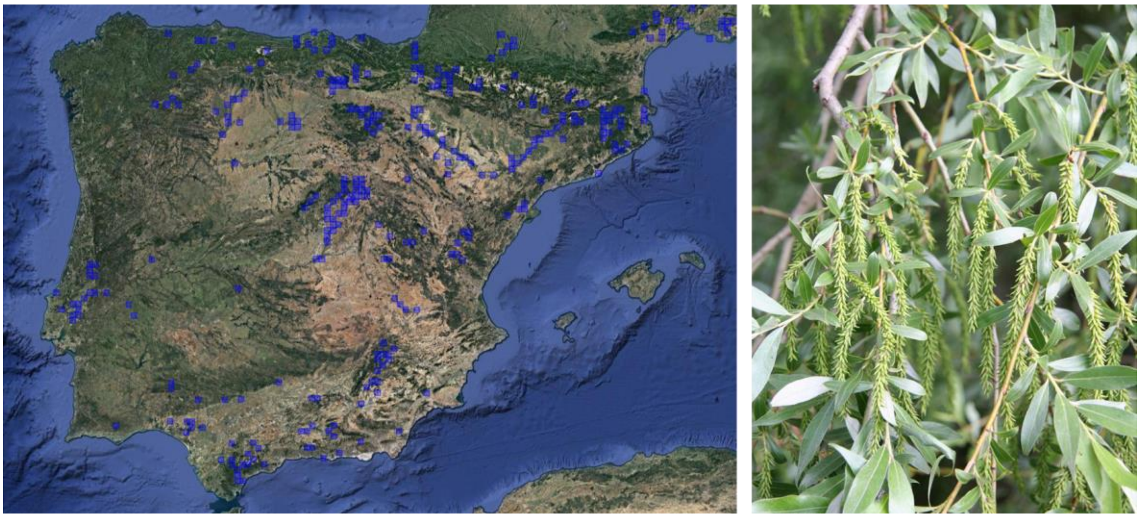

Figure 14. Distribution of *Salix alba* in the Iberian Peninsula (Map distribution: SIVIM, plant image: Bug Wood).

Willow (*Salix* sp.) (Figure 14) belongs to the Salicaceae family and is one of the most widespread species used for fibre-based products (Verde et al. 1998), as the younger branches are very flexible and highly valued for basketry. Two different varieties are considered, depending on whether the bark is peeled or not, giving a light or dark colour to the raw material. Willow trees require abundant water and are found in humid areas throughout most of the peninsula and are currently cultivated in various parts of Iberia, although mainly in the north-west. Trees are carefully managed to obtain the flexible willow rods or branches (Soto 2015). In fact, it is essential to prune annually between January and April to keep the willow in shrub form. Wicker can be worked either green or dried. Like other plant fibres, it should be soaked in water for hours when it is green and for almost two weeks when it is completely dried. If the artisan prefers to peel the branches, this is usually done in June, when the sap is rising, and the bark can be easily removed. The decision to peel the branches is directly related to aesthetic reasons, as they have different colours (Soto 2015).

2.4. Fibre-based productions.

The study of prehistoric textiles and its terminology is highly diverse, influenced by researchers' individual objectives, languages and interpretations. Many researchers (Wendrich 1999; Adovasio 2010; Banck-Burgess 2023) have emphasised the importance of establishing international communication. Therefore, it is important to create standardised definitions of textile materials and techniques, as the complexity of this research makes it difficult to develop technical classifications that meet the needs of all researchers. Existing terminology tends to prioritise textiles made from flax and wool, often neglecting other techniques and materials, both plant and animal. While some researchers define 'textiles' as objects made of flexible threads, others include two- or three-dimensional objects made of perishable materials, such as cords and baskets. In order to solve this diversity of textile terminology, and thus their classification, a greater focus on structural, technical or functional aspects, or a combination of these, is needed to better understand the material and its composition (Mason 1901, 1904).

In this sense, some researchers use the term 'textile' in a broad sense, including different categories (basketry, textiles, fabrics, weaving and clothing), while others do not. The following lines will explain each type of textile category mentioned above in order to show some of the differences in the focus of different researchers. Understanding these terms is essential to improve communication and standardisation between prehistoric textile researchers.

Basketry. This term is widely used but not well defined. Some authors describe it by distinguishing the use of rigid materials and the absence of tools for weaving (Mason 1901, 1904). This is very similar to others who differentiate basketry as a rigid three-dimensional form from the typical two-dimensional flexible textiles (Harris 2014).

Textiles. Historically closely associated with woven, knitted and warp-knitted products, mainly for the clothing industry, but also for other uses such as sailcloth and household items (Bravermanová and Březinová 1999; Březinová 2003). According to Emery, the term should refer only to woven products made on a loom, while Adovasio and colleagues include twisted or spun threads interlaced by tools in two systems (warp and weft) (Adovasio et al. 1996, 1999, 2005; Valoch 2007).

Fabrics. Some authors use it as a generic term for all fibrous structures (Emery 1980), while others use the term 'fabric' for nonwoven techniques with other manufacturing methods (Jørgensen 1992).

Weaving. Some authors use this term for flexible structures, distinguishing between weaving and coiling techniques in basketry (Mason 1904; Adovasio et al. 2001), while others include objects made of twisted threads in 'weaving systems' (Wigforrs 2014) or apply it to twined textiles in basketry (Harris 2014).

Clothing. It denotes flexible structures, excluding basketry with rigid systems (Emery 1980), but for other authors it has a broader meaning, including flexible sheets that can cover, clothe and contain, and groups fibre-based products such as textiles and basketry with animal skin products (Harris 2014).

Following this issue in textile terminology, in this dissertation the term 'textile' is used broadly and it includes different materials made of perishable materials such as cordage, basketry, textiles, fabric, weaving, clothing and footwear. However, the term is specified when discussing each of them. In fact, most of the terms used in this thesis are those related to 'cordage', 'basketry' and 'footwear', which are the type of materials studied, and they and their analysis will be developed in the following paragraphs.

2.4.1. Cordage.

The term cordage refers to ropes or cords, which are long flexible structures created by twisting or braiding multiple strands or fibres. They are items designed to increase mechanical strength and manipulability, allowing tension to be applied to supporting materials as well as to handle objects, among other uses. Prehistoric cords could be made from organic materials such as animal hair and leather, or from plant materials, which is the focus of this thesis. Adovasio (2010) suggests that the use of rope encompasses a wide range of technological and cultural insights, and played an essential role in various daily and specialised tasks within prehistoric communities. Thus, it has been suggested that rope studies also provide insights into social settings, as different communities may develop unique rope-making techniques that reflect their cultural and social identities (Pryor and Carr 1995). So, the study of rope production and use provides important knowledge about the technological endeavours and social dynamics of past societies, and this type of study is crucial for a comprehensive understanding of both the tangible economies and the intangible social and cultural dynamics that shape human interactions in different historical and prehistoric settings.

The terminology used to describe cords has varied over time as different concepts have been proposed to standardise their use and avoid terminological confusion (Emery 1952). To solve this problem, terms from technical textile terminology have been adapted by authors such as Emery (1952), Hurley (1979), Wendrich (1991) and Veldmeijer (2009), with slight differences between them. The concepts used in the current dissertation follow the works of Emery (1952), Hurley (1979) and Carr and Maslowski (1995) to describe the elements needed to manufacture a cord.

2.4.1.1. Defining cords and techniques.

Although the underlying methodology is consistent, a standardised nomenclature has been established to clarify the different rope manufacturing techniques across different studies. Basically, rope manufacture involves the joining of short, discontinuous fibres into a long, continuous thread by three primary methods: twisting, braiding and knotting (Figure 15). Consequently, a rope is created by combining elements that are fixed to a common starting point in twisting, aligned along a starting line in braiding, or connected as required in knotting. These three methods will be described below, but first it is important to clarify the basic elements that form a rope (Figure 16).

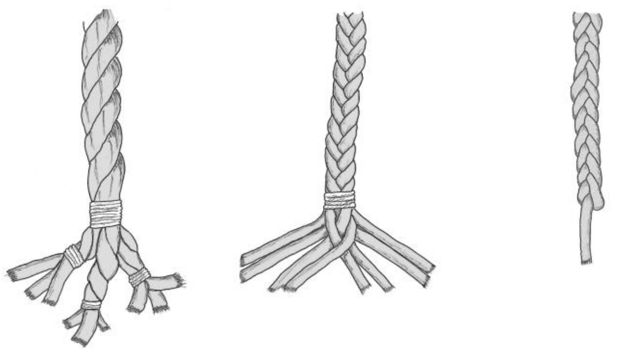

Figure 15. Rope manufacturing methods: twisting (left), braiding (middle), and knotting (right) (Bkeithropemaker.com).

Fibre. The basic unit of a cord that has not been twisted. It consists of the raw material prepared to make a cord or a rope even if they can also be used twisted.

Yarn. Created when fibres are combined and twisted together to form a spun yarn. The twisting action causes the fibres to stick together and gradually lengthen.

Strand. Serves as the building block of a rope and consists of a bundle of yarns that include counter twists to prevent unravelling. A rope is typically made up of two or more strands, although not all strands are made up of multiple yarns.

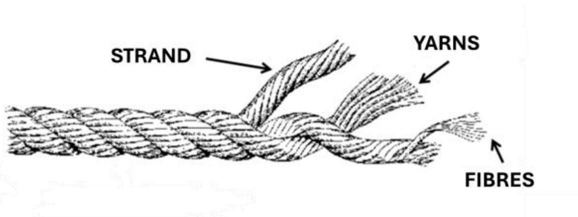

Figure 16. Schematic basic elements of a rope (pbo.co.uk).

The methods and materials used to make cordage and cloth are extremely varied. Hurley (1979) provides a comprehensive overview of cordage techniques, while detailed accounts of fabric production are provided by Birrell (1959), Broudy (1979), Hollen et al. (1979), and Emery (1980), among others. This section will outline the key manufacturing processes involved in cordage and fabric technologies.

2.4.1.1.1. Twisted cords.

In the manufacture of twisted cords, fibres are twisted uniformly to form a simple rope, which manifests itself in two specific directions. When held vertically, the direction of twist of the fibres can be seen and categorised as either S or Z twist, indicating the direction of rotation of the fibre (Hurley 1979; Alfaro 1984, Romero Brugués 2021). More specifically, an S-twist results from a right-hand twist, causing the rope to lean to the right, whereas a Z-twist results from a left-hand twist, causing the rope to lean to the left.

Ropes can also be made more complex in order to increase their strength and rigidity for their intended function. The complexity of a rope is determined by the number of yarns or strands used in its construction, e.g. 2-ply for two strands, 3-ply for three strands and so on. A simple rope can be made from short strands twisted together, typically by joining two ends (2-ply), whereas a complex rope involves twisting more than two strands or ends in different directions. To prevent the strands from tangling or separating during the formation of a simple rope, they are twisted using the principle of opposing forces.

The full range of possible rope combinations is unknown, suggesting an almost infinite number of possibilities. However, some authors suggest that certain mechanical limitations may exist in their production. The method used to make a rope is also determined by the characteristics of the material used, in particular the fibre length. This aspect dictates that ropes can be made from irregular or short fibres using techniques such as twisting, braiding or knotting (Carr and Marlowski 1995), of which twisting is the one most commonly used (Hurley 1979). The choice of materials for cord manufacture can influence the direction in which the fibres are spun and the twist of the yarns in subsequent layers. Certain materials have a tendency to twist in a particular direction. For example, bast fibres such as flax, hemp and nettle generally twist in one direction, whereas leaf fibres such as yucca and agave, and seed fibres such as cotton, wool and silk do not. Nevertheless, fibres are often spun in the opposite direction for a variety of reasons, including cultural practices associated with magical or religious beliefs, or historical traditions and preferences. This practice of counter spinning does not usually affect the quality of the spinning and can even improve it when carried out by experienced spinners (Carr and Marlowski 1975). Identifying local methodological variations in rope-making can provide insights into the social boundaries between different cultures. In terms of techniques, rope production is broadly divided into manual and spindle-based methods. Ethnographically, the most commonly reported method involves manually rolling fibres down the right thigh with the hand to create an initial S-twist, followed by threading two or more yarns up the thigh to create a Z-twist. This method is described by several indigenous groups, highlighting its prevalence in traditional fibre manipulation (Carr and Marlowski 1995). Edholm and Wilder (1999) state that both twisted and braided ropes require overlapping of fibres or strands. This can be achieved by various methods such as rolling over the thigh or twisting by hand or mouth. Techniques using the leg and mouth produce very fine and strong cords suitable for making bows, while twisting by hand is slower.

Various authors have worked on the morphotechnical description of archaeological cords, such as the recent work of Romero-Brugués (2021), who reports different characteristics to be described in each typology of cords. In the case of twisted cords, the following aspects and characteristics can be identified:

Number of strands or yarns. A simple rope consists of two strands (2-ply) for twisted ropes, while more complex ropes (consisting of more than two strands) are made up of more than two strands.

Rope length. This refers to the maximum preserved length of the sample. However, due to the preservation of the ends, average minimum and maximum measurements are also taken.

Diameter. The diameter of the rope is measured at the widest point. However, if the rope varies considerably in diameter, it may be more useful to consider the maximum and minimum diameters. There is a direct correlation between rope diameter, twist angle and number of twists per linear centimetre (Hurley 1979; Norton 1990).

Twist direction. According to the direction of twist, there are two basic types: (i) S-twist to the right, where there is an inclination from the top left to the bottom right, and (ii) Z-twist to the left, where there is an inclination from the top right to the bottom left (Figure 17).

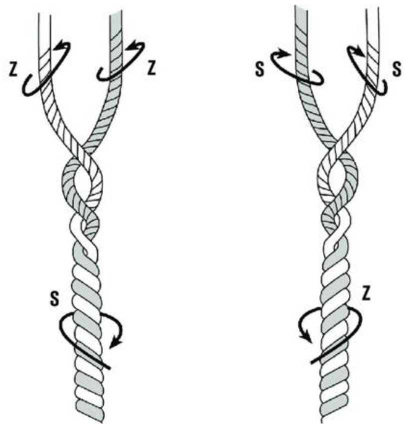

Figure 17. S-twisted (left) and Z-twisted rope making (Connoly et al. 2017).

Initial and final direction of twist. According to Hurley (1979), the initial twist direction of a rope corresponds to the direction of the fibres making up the strands or ends of the rope.

Twist angle. It corresponds to the angle that the twist inclination makes with the vertical axis of the rope. There are three general categories corresponding to (i) a soft angle not exceeding 10°, (ii) a medium angle between 10° and 25° and (iii) a tight angle between 25° and 45° (Hurley 1979).

Number of twists per unit length. The number of twists per unit length can be measured by the number of twists per centimetre (Hurley 1979).

Torsional stiffness. It is determined by the angle of twist and the number of twists per unit length and classifies the strength of the rope into four categories: soft, medium, strong and very strong (Emery 1952; Norton 1990).

Visibility of division lines. Visibility of the divisions of a segment marked by the number of strands used to form a rope or the number of ropes used to form a complex rope, which are easily identifiable because they are usually opposite to the twist angle of the strand.

2.4.1.1.2. Braided cords.

A braided rope is constructed by intertwining three or more strands of material, which greatly increases its strength and durability. This involves arranging the strands or bundles of strands in a specific way, typically crossing them over each other in various patterns to form a cohesive unit (Figure 15). The most recognised method within this technique is known as braiding or oblique interlacing. In this approach, each strand or element is woven in an alternating under and over pattern with adjacent strands that it crosses. Each element in the braid is meticulously interwoven with its neighbours, creating a tight and secure structure that is essential to maintain the integrity and functionality of the rope or fabric. This method of braiding ensures that each strand is integrally connected to the others, contributing to the overall strength and flexibility of the rope.

In terms of analysis, the same morphological measurements considered for a twisted rope can be applied to a braided rope. A braided rope is characterised by the number of strands, the twist angle and the number of twists per linear unit (twist tightness) as well as by metric measurements (diameter or thickness and length).

As in the case of twisted cords, Romero-Brugués (2021) recorded the features that should be identified in braid analysis to describe these remains:

Number of strands or yarns.

Rope length.

Width. For ropes that have lost their original shape, width is used instead of diameter. Due to variations within the same piece, average minimum and maximum measurements are taken.

Thickness. For ropes that have lost their original shape, thickness is used instead of diameter. Due to variations within the same piece, average minimum and maximum measurements are taken.

2.4.1.1.3. Knotted cords.

Fibres or bundles of fibres are knotted from end to end to form a continuous thread (Figure 15). This method is particularly effective with long fibres, such as those from monocotyledonous species, which can be up to 2 metres long (Norton 1990). According to Charlton (1996), a knot consists of three parts: the end where the rope is tied, the bend between the ends, and the inactive part of the rope within the knot. Charlton (1996) identifies two main types of knot: the stopper knot, which creates a button-like end on the rope to prevent unravelling or fraying, provides a grip or stops the rope when passing through an object, and the loop knot, which forms a loop or bow along the length of the rope.

As in the case of twisted and braided cords, Romero-Brugués (2021) recorded the features that should be identified in braid analysis to describe these remains, and which correspond to the number of strands or yarns and the rope length.

2.4.2. Basketry.

Basketry is closely associated with the use of cordage, netting, and other fibre-based items. The term 'basketry' encompasses a wide variety of objects ranging from containers and bags to mats, fishnets, and hats.

It is useful to distinguish at least two categories of basketry objects for analysis: flat or two-dimensional objects, commonly referred to as mats, and three-dimensional objects such as baskets or containers themselves. Bags occupy a middle ground between these categories, as their dimensions vary depending on whether they are empty or full. While this classification is helpful, it can sometimes be imprecise. For this reason, the term 'basketry' or 'basketry products' are used in this thesis to refer broadly to all products (except for the sandals) made from plant fibres. When a specific identification of mats or bags is possible, this is also noted. Thus, the term is related to the techniques used not to the final product due to the complexity that occasionally appears in describing its original shape. All basketry techniques can be made by hand without the use of a frame or loom, although other tools may be used in the production of baskets. While some researchers use the term 'woven' for fibre-based productions, this is generally reserved for cloth fabrics, which typically require some form of structural loom. Basketry is seen as a precursor to textiles used in clothing, and this relationship is the subject of ongoing debate.

In addition, the terminology used to describe basketry has also been historically under-described and the terms have not been standardised, which is more problematic when translating between languages. Wendrich (1999) pointed out that these differences are not only linguistic aspects, but they also reflect different classifications: Croes (1977) defended that there exist two main ways of basketry production (coiled and plaited) with several subcategories, while Adovasio (2010) proposed that each basketry technique is unique and distinguishes three main ways of basketry: (twisting, coiling and plaiting). The classification system adopted by these researchers focuses on the interaction between the basic components of all textiles: the weft and the warp. In addition, there are some other variations that may be related to traditional uses, and it must be remembered that within each technique there are multiple variants that respond to artisan criteria, functional purposes, raw materials and stylistic features (Fluharty 2003). All these characteristics allow for cultural comparisons and chronological assessments, parallel to the methods used in ceramic studies. The following description of basketry techniques follows

Adovasio's (2010) framework, although the concepts from the works of Croes (1977), Wendrich (1989) and Adovasio (2010) are also present.

2.4.2.1. Defining basketry and techniques.

The analysis of basket production involves a detailed examination of the objects, including measuring various dimensions, identifying the construction techniques and their variations, and determining the raw materials used. Each basket typically has several distinct parts: the centre or starting point, the base, the walls, and the rim, and sometimes additional elements like handles. The wall, or main body, is the most substantial part of the basket but is absent in flat objects like mats. Other attributes that should be recorded include the shape, rigidity, flexibility, and any decorations, among other characteristics.

There is a vast diversity in basketry production techniques, traditionally classified into three primary categories: twining, coiling, and plaiting. These methods vary globally, influenced by cultural practices, and some are unique to specific regions, as will be detailed later. Basketry manuals typically outline these three basic techniques, but numerous sub-classes, variations, and combinations exist, making each basket unique. Standardization of certain attributes may be culturally prescribed, while other variations could be linked to the preferences or skills of the craftsperson.

2.4.2.1.1. Twined basketry.

Twining baskets or twined productions are products made by moving horizontal elements, called wefts, around fixed vertical elements, called warps (Figure 18). The wefts are therefore the active elements, while the warps are the passive ones. This technique can be used to produce 2- and 3-dimensional objects such as containers, mats, bags, fishing nets, and clothing, among others. The technique consists of a series of warps that are interlaced with warps in each cycle. When describing twined production several attributes should be considered:

Distance between rows of wefts. It refers to the distance between each row - or line - of wefts, which can be (i) Close twining with no space, (ii) Open twining where rows are deliberately spaced and, (iii) Open and close twining in which the rows are alternate with or without space between the different rows. This is associated with decorative effects.

Number, arrangement and sequence of warps. (i) Simple twining where a single warp is engaged at each weft crossing and this pattern is always followed, which makes the weft rows parallel. Each warp and weft, although possessing different subunits, are worked as a single unit, (ii) Diagonal twining where warps are alternated at each weft crossing between them. While the wefts are parallel between their rows (as in simple twining), the alternation of warps creates a diagonal effect that is visible when open twining is produced, giving a decorative pattern, (iii) Simple and diagonal twining where the last two typologies of twining are combined to give the production decorative motifs, (iv) Cross warp twining which refers to the double crossing of the warps each time the weft engages them, giving a X-crossed pattern. The combination of several cross warps can create hexagonal decoration on the production, (v) Wrapped twining implies that an extra rigid element perpendicular to the warps is engaged with the warps. It is kind of variation of simple twining.

Number, arrangement and sequence of wefts. At least two single elements are needed on the weft, although they can also be tripled or quadrupled as multiple weft elements, giving the final product different patterns of weft rows.

Stitch inclination of the weft. It refers to the inclination of the wefts when they interlace with the warp, depending on which weft element interlocks first. The warp stitches can be inclined (i) To the right, in which case the inclination is to the right (\), forming an 'S', and (ii) To the left, in which case the inclination is to the left (/), forming a 'Z'. They can also be alternated to create decorative visual patterns.

Splices. It refers to the insertion of new warp and weft elements during the construction of the objects in order to increase their dimensions. They are necessary to make the product resistant. There are different ways of adding new elements to the warp and weft, which can consist of inserting longer and higher quality elements to replace the older ones that are too short or have deteriorated due to the natural characteristics of the fibres.

Initial or starting point. Twined baskets usually have a centre or starting point of the twine, although it is possible for other objects to start from other points and have a 'real centre' because they start from one of the edges.

Finishing the object. In twining, the final edge of the product is called the 'selvage', which is the edge of the basket. There exist two different ways to make this edge, (i) Simple selvages in which the warp is cut or knotted beyond the last row of weft to prevent it from coming loose, (ii) Composite selvages in which extra elements engage the warp with the weft and prevent the unravelling of the product. There is a wide range of variability in both types of selvage.

There is a wide range of possibilities in the combination of the attributes described, and these should be recorded in the analysis of the materials. In addition, a number of measurements should be taken in relation to both warp and weft, together with the documentation of other features. Some examples are: the distance between the rows of wefts, the number and arrangement of the warps, the inclination of the wefts, the number of elements in both the warp and the weft, the characteristics of the elements (flexible to rigid), the diameter of the warp and the weft, and others. Furthermore, the use of these attributes in combination with others can help the construction of decorative patterns with dyed fibres or other elements displaying different characteristics in both the warp and the weft, giving each product unique properties.

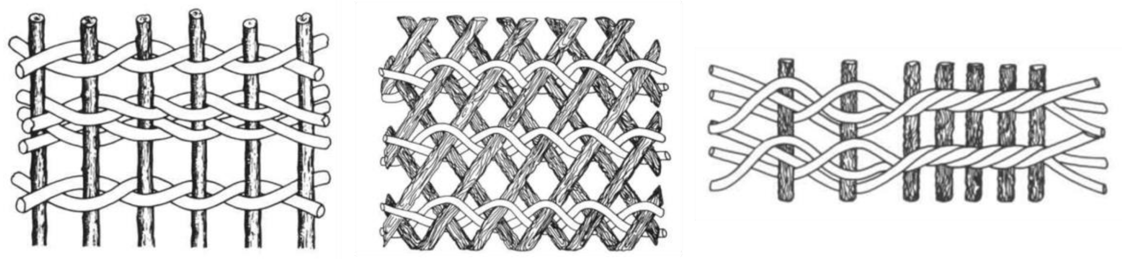

Figure 18. Twined basketry technique variation (Adovasio 2010).

2.4.2.1.2. Coiled basketry.

Coiling baskets or coiled basketry technique is based on a horizontal passive element called the bundle/foundation/coil, which is sewn by an active vertical element called stitches/binders. The structural unit of coiled basketry is the coil, which forms a spiral secured by successive stitches (Figure 19). It consists of a single coil that begins in the centre of the production (which is the centre of the base of the basket) and is extended to the edge or the final part of the production regardless of whether it is a three- or two-dimensional object. Adovasio (2010) reported that this technique is used almost exclusively for containers, hats and, very rarely, bags, mats and other shapes.

When describing coiled baskets, three basic variations should be considered in terms of the size of the base, the type, number and arrangement of the coiled elements, and the type of stitching (Figure 19). A general description of each is given below, following the guidelines of Wendrich (1989), Adovasio (2010) and Romero-Brugués (2021), although in each case variety can be recorded.

Spacing of the foundation. Refers to the distance between the coils, they can be (i) Close coiling where successive coils are sewn together leaving no space between them, (ii) Open coiling where successive coils are not sewn closely, leaving some space in between. This spacing can result from the specific type of stitching used and can affect the overall aesthetics and flexibility of the basket, (iii) Open and close coiling with a combination of both closed and open coils. This alternating pattern has a decorative objective, adding visual interest and textural variety to the resultant object.

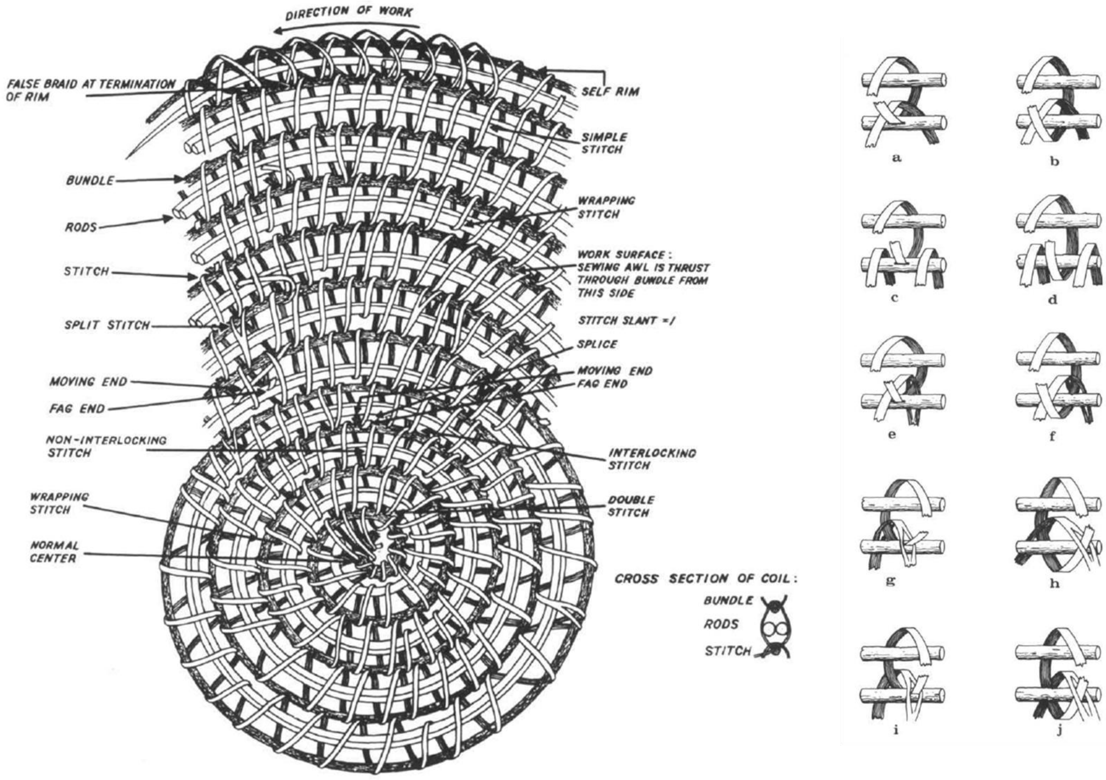

Figure 19. Schematic drawing of the coiled basketry technique: Features to be considered in its study (left), coiling variations (right) (Adovasio 2010).

Kind and number of the coil elements. Refers to the sort of material inside the coils and how numerous they are. They can be a (i) Rod, as a rigid or semi-rigid element used either alone or with other rods, (ii) Bundle of different flexible plant materials such as fibres (leaves, stems, even a cord), (iii) Welt, or a rigid flat element used always in combination with other rods and not usually pierced by the stitches.

Arrangement of coil elements. How the elements are placed inside the coil (i) Single element which may be whole or halved, (ii) Horizontal arrangement of two or more elements placed side by side giving the production an important thickness, (iii) Stacked arrangement of two or more elements placed one in top of the other, (iv) Bunched arrangement of three or more elements placed to form a triangle.

Stitching typology. There exist three basic stitches to bind both open and closed coils. They are (i) simple stitches used exclusively for close coiling of which three basic types have been recorded: (i.i) In the interlocking stitching the new stitch passes diagonally through the top of the stitch that sewed the coil below piercing or encircle the coil, (i.ii) In the non-interlocking the new stitch pierces the previous coil without passing across the stitches piercing or encircle the coil, (i.iii) In the split stitches the stitches in the previous coil are bifurcated by the new stitch. This split may be intentional or accidental in the worked, non-worked or both surfaces. Intentional ones may be related to decorative motifs while accidental ones may be related to carelessness during basket production, (ii) Intricate stitches are used exclusively for close coiling in which a new stitch is wrapped around in a false knot, creating a separation between the coils. It presents a potential range of diversity in variations, (iii) Wrapping stitches are used exclusively for both close and open coiling and in which a stitch encircles the new coil one or several times without engaging any part of the coil below. This may be combined with other simple stitches in order to sew the different coils. This is used for decorative objectives.

Surface. Each object has two different surfaces whose characteristics are different if it corresponds to a worked surface or to a non-worked surface: (i) The worked surface, or the right side, is the one into which the sewing awl is inserted to make a path for the stitch. It is usually, not exclusively, the side facing the crafter during the production process, (ii) The non-worked surface, or wrong side, is the one that the awl used in the production process comes out of. It is usually, not exclusively, the side away from the crafter during manufacture.

Work direction. It is the direction in which the crafter sews the basket along the coil (Figure 20). It can be to the right or to the left and it is evidenced by the slant of the stitches. In the case of a production to the (i) Right, the slant is to the right (\) shaping an 'S', and if it is to the (ii) Left, the slant is to the left (/) shaping a 'Z'.

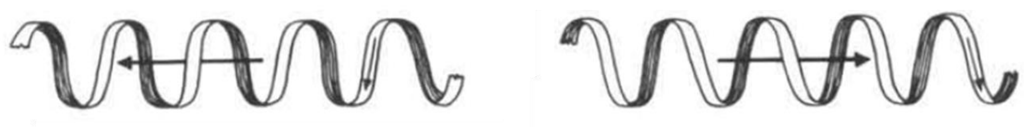

Figure 20. Schematic drawing of working direction: to the left (left), to the right (right) (Adovasio 2010).

Expansion stitches. These are double stitches or wraparound stitches needed to increase the diameter of the item being worked.

Initial or starting point. This refers to the method by which the production begins, which can vary (i) Normal centres in which a foundation is tightly wrapped with a stitch to form a circle, which forms the base of the basket. There may be variations of this method, (ii) Oval centres very similar to normal centres, but designed to form an oval, used to create oval or rectangular objects and (iii) Plaited centres in which the production begins with fibres braided at right angles, then the elements are folded to begin the coiling technique.

Finishing the object. The edges of the coiled baskets represent the final circuit that can be (i) Self rims where the stitches are the same as those used throughout the production, (ii) False braid rims which are used as decorative rims and (iii) Combined rims which incorporate different styles or techniques.

The basic characteristics to described coiled baskets have been described, although a wide diversity of attributes and variations of each of the describe characteristics could be considered. Moreover, several measurements, such as maximum and minimum width of coils and bundles, stitching gaps, among others, should be taken. However, it should be taken into account that many of those attributes would not be visible on all the productions, so it will not be possible to record them.

2.4.2.1.3. Plaited basketry.

Plaiting is a type of basketry technique in which there is no distinction between warp and weft, or active and passive, elements, but all are referred to as active elements. It consists of strips that can be single elements or sets of elements that pass over and under each other without any other kind of engagement, as this technique lacks real sewing. The composition of all the elements is usually the same and they are usually flexible, but in case they are rigid elements the basketry technique is also known as wickerware. This word has been adapted to other basketry techniques as its use is not precise. The structural plasticity of this technique is wide, and it can be used to make containers, bags, mats, among other objects. Two basic typologies of plaiting (simple and twill) can be distinguished with regard to the number of strips in each set crossed by the strips in the other set. This is numerically described as 1/1, 2/2, and so on. The simple plaiting type is based in several elements crossing each other at intervals of one (1/1), so they appear alternately one after the other. On the other hand, twill plaiting presents the elements in a single set passing over two or more in the other set at staggered intervals, such as 2/2, 3/3 or 4/4, so that each crossing must involve two or more elements (Figure 21) (Adovasio 2010).

The list of attributes of this technique is shorter than in the previous described basketry techniques and they will be described in the following lines:

Element engagement. It refers to the main type of plaiting structure in the object, although variations can be present.

Shifts. Intentional or accidental alterations of the main pattern which can be the product of the manufacturing process or can also be related to decorative patterns. Accidental ones are usually unidirectional, while intentional shifts are commonly bidirectional. They are more common in twill plaiting than in the simple type.

Number, orientation and composition of plaiting elements. Elements used in plaiting are usually flat flexible elements (vegetal or animal based) which are called strips. Nonetheless, rigid plaiting can also be produced with rods.

Method of preparation. The elements are usually physically prepared to obtain the strips which the objects will be made of. This modification of the raw material should be described, as branches can be peeled to obtain the bast strips or even the branch for rigid elements.

Initial or starting point. Many plaited baskets lack centres as they do not usually present a central or initial point. This technique allows them to be started in different ways which are often intangible. However, rigid plaiting can present a centre, for example a spiral, although there is no standardised terminology to describe them.

Splices. Flexible strips are inserted when necessary and used in a normal way. In the case of rigid plaiting, splices closely resemble the twining splices.

Finishing the object. The term 'selvage' is also used in plaited basketry and the possibilities are extremely diverse. The principal types are (i) Clipped selvages in which the terminal plaiting elements are truncated in the final part which can also be reinforced with a row of twining to avoid fraying, (ii) Self selvages in which elements are folded back and plaited again into the body of the object, (iii) Coiled selvages in which a coiled edge appears in a foundation which is sewed as in coiled basketry.

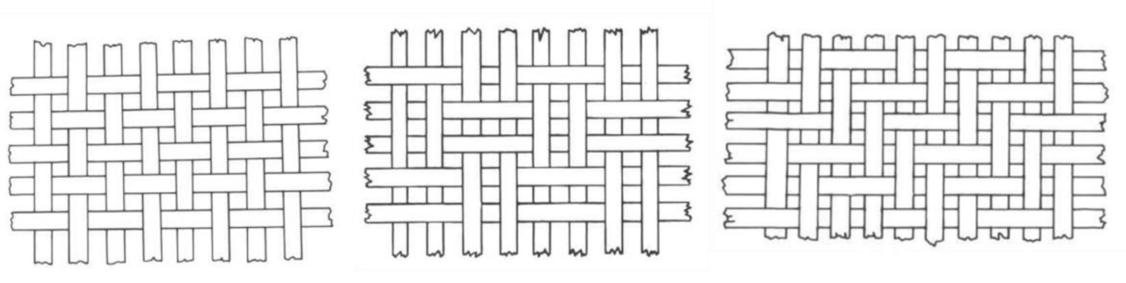

Figure 21. Plaited basketry technique variations (Adovasio 2010).

Decoration can be made both structurally and non-structurally by using dyed fibres of strips. Moreover, several measurements can be taken of the plaiting technique, such as the diameter or width of plaiting elements and the angle of crossing between them.

2.4.2.1.4. Other basketry techniques.

Twined, coiled and plaited basketry techniques are those described in basketry manuals, but plant fibres offer a wide range of possibilities and other techniques can also be made with them. In the archaeological basketry assemblages studied in this thesis, some rare types appear and will be developed further, although there is one whose use is widespread throughout Iberia.

This technique is called pseudobraided (Alfaro 1984) or traditionally known as '*cofín*' in Spain, where it was widely used (Fajardo et al. 2015). The name comes from the Spanish word for the baskets used to press the olive paste in the mill to obtain olive oil (Fajardo et al. 2015). The technique consists of braiding three (or five) bundles of fibres, one of which is changed in each round to form the warp of the basket. The technique can be 'closed' or 'open', depending on the distance between the braided rows. This method is only widely documented in Iberia, in different chronologies, and does not appear in basketry atlases. As in plaiting, there is no difference between warp and weft (or active and passive) elements as all of them are active. As it has not been described in handbooks, there are no specific characteristics to describe it, although some may be based on those described in the previous typologies, such as element engagement, number of pseudobraiding elements, work direction, expansion elements, initial or starting point, splices and the way the object is finished.

2.5. Functionality of fibre-based objects.

Cords, baskets and textile products have been used to meet the basic needs of human groups, as shown by archaeological, historical and ethnographic sources. They were used for transport, storage, cooking, clothing, food gathering (both hunting and gathering), as well as for making shoes and warm, comfortable mats and bedding. Ethnographic and archaeological evidence are interwoven in a complex discussion to understand the use of the wide variety of objects that can be made using plant fibres as a raw material.

The use of ropes has been directly linked to the function of support and transport since the invention of any kind of tool. The similarities between the use of ropes in human societies and those found in nature are striking, as some of these new inventions may have emerged from the careful observation of nature and the attempt to replicate those elements that could be useful to human groups. The size and shape of cords, as well as other morphotechnical characteristics such as length and diameter, are related to their properties - such as strength - and thus to their functionality. The presence of cords in archaeological assemblages highlights their past use, as they were part of the toolkits of past human populations, along with other non-perishable objects. These contexts are crucial to understand their purposes in past societies. In addition, ethnography and recent history provide numerous examples of rope functions, as will be shown in the following paragraphs to illustrate some examples of the wide variety of uses that cords can put to. Ropes have a wide range of uses, including domestic applications such as clothing, decoration and securing roofs of houses with plant stems and leaves. They facilitate transport, especially with draught animals, and are useful in agricultural work for carrying heavy materials. In the food sector, ropes are used for traps, nets, bags and for hanging things for protection. They are also used for climbing. Ropes play an important role in suspending objects for protection or cooking, using tools such as hunting bows and drills, and fixing parts of tools. In the funerary context, ropes are used to bind bodies in a flexed position, and are often found preserved in caves, indicating their role in transporting bodies to hard-to-reach places.

In turn, the production of baskets has also satisfied basic needs since ancient times, as can be seen from historical and ethnographic sources. These objects were designed and produced according to their functionality, using the materials available in the immediate vicinity. The archaeological record is essential to document their functionality through the different depositional contexts. Architectural, domestic and funerary uses have been proposed (Miškolciová 2015). The need for shelter and protection from the elements led to the development of structural plant frames, as seen in ethnographic examples such as huts, roofs and stilt houses in countries such as Equatorial Guinea, Gabon, Nepal, Cambodia and Panamá (Soriano 2000). Buildings constructed entirely from plant materials have been documented in Chile and Argentina (Vydal and Hormazábal 2016). Plant fibres were also used to make structures to protect and dry food, as shown by the reed walls in Teruel and the garden huts with reed walls, roofs or enclosures from the Ebro to southern Portugal (Kuoni 1981). Basketry took architectural forms, with mats used as coverings in Jericho and the Zagros region, and impressions of woven basketry in Neolithic layers at Tepe Ali Kosh and Tepe Sabz (Hole 1959). The Uros of Lake Titicaca used reed stems for the construction of walls, roofs and partitions (Vydal and Hormazábal 2016). Domestically, basketry appears in items such as baskets, fans, rattles, furniture, ornaments, and even games, such as the spiral-sewn baskets used by Oglala Lakota women for dice games (Jolie 2006). For transportation, basket design is influenced by the way items are carried, often by women using baskets with handles. For animal transport, baskets were used to carry goods, grass, dung, and materials for farming or construction (Kuoni 1981). For food, basketry served functions such as storing, cooking and transporting liquids in waterproof containers, and making traps for hunting and fishing (Ibáñez and Rovira 2011). Basketry is also documented in pottery production, as moulds or for drying (Miškolciová 2015). The archaeological record also shows basketry in mortuary contexts, with containers holding the deceased in the foetal position, found at sites such as Tell Halula (Guerrero et al. 2009), Çatalhöyük (Wendrich and Ryan 2012), and the Cave of the Warrior (Gleba and Harris 2019). In America, pre-Hispanic examples include basketry containers in the Azapa Valley (Muñoz Ovalle 2017) and the Doncellas site in Jujuy (Pérez de Micou 2001).

2.6. Plant fibres and Archaeology

2.6.1. The 'missing majority': archaeological record and preservation conditions.

Archaeology usually deals with fragmentary data and preservation, which is an issue to be taken into account in different preservation conditions. The history of an object and its nature have meant that most information about the past has been suggested by the analysis of non-perishable or durable materials such as stone, bone, pottery and metal, depending on the chronology. Nevertheless, the importance of perishable material culture is widely accepted from the earliest human groups. Indeed, the absence of evidence is not considered to be the same as evidence of absence. Hurcombe (2014) referred to the lack of a record of perishable material culture as 'the missing majority', and this has been used to name the present chapter in this dissertation. Faced with the poverty of the archaeological record compared with other non-perishable remains, ethnography and ethnoarchaeology of contemporary hunter-gatherer and agricultural human groups becomes essential to understand the importance of this perishable material culture in the production of utensils to obtain calorific energy (Heizer 1963; Piqué 1999; Peña-Chocarro et al. 2000; Piqué 2006; Picornell 2009; Hurcombe 2014, among others). This non-durable culture is still present in modern human life, considering constructions, clothes, furniture, utensils, among a long list of purposes. In fact, it is estimated that eighty or ninety per cent of the utensils used in daily life are based on perishable materials, while only fifteen per cent of that amount is recovered archaeologically (Clarke 1968; Soffer et al. 2001).

Human groups used the plant resources available in their immediate environment for a variety of purposes, such as gathering wood for building and carpentry, wild fruits for food, and plant fibres for baskets, string, clothing and shoes (Berihuete et al. 2020). Since prehistory they have also been adept at altering and modifying their environment to sustain their livelihoods, for example by cultivating land or managing forests for resource extraction (Out et al 2013, 2017, Zohary 2020, Bleicher and Staub 2022, López-Bultó et al. 2023). These plant materials were transported into their habitats, where they entered the archaeological record as firewood, construction materials, wooden objects, processed seeds, consumed fruits, and the associated waste remains of these activities. Typically, such remains are found in areas associated with archaeological structures or scattered throughout the sediment (Martín-Seijo et al. 2010). In this way, plants were incorporated into the archaeological context in the course of different work processes related to the transformation of plant resources into useful artefacts.

Organic archaeological remains, but more specifically prehistoric fibre-based remains, unlike lithic or pottery remains, can only be recovered under special conservation conditions. Once buried, organic archaeological plant remains adapt to their new environment. During this adaptation, the material undergoes an initial period of rapid decomposition, which slows down until it stabilises, often culminating in complete decomposition. However, stable environments where conditions slow down bacterial activity and thus the decay and disintegration of organic compounds or the direct contact with corrosion products which act as bactericides can stop plant degradation.

Direct conservation of organic materials in archaeology refers to the preservation of organic remains in their original, unaltered form due to specific environmental conditions that prevent or slow down the natural processes of decay. This type of preservation allows the recovery of materials such as wood, leather, textiles, bones, seeds, and other biological substances in a state that closely resembles their original appearance and composition (Martín-Seijo et al. 2010; Adovasio et al. 2016). The specific conservation conditions in which organic materials can be preserved archaeologically are explained below:

Dry environments. Organic materials are preserved by the loss of moisture in natural conditions. This type of preservation typically occurs in very arid environments, where the lack of moisture prevents the growth of microorganisms that would normally cause the materials to decompose. A classic example of this type of preservation can be seen in the cases of natural mummies found in desert regions, where the extremely dry climate naturally preserves organic tissues. This is common in the Americas (Jolie 2022), the Middle East, Egypt (El Hadidi and Hamdy 2011) and the southern part of the Iberian Peninsula (Martínez-Sevilla et al. 2023).

Charred or carbonised environments. Preservation by carbonisation takes place when organic materials are exposed to high temperature conditions in a limited oxygen environment. This process prevents the complete combustion of the materials, transforming them into charcoal that can resist decomposition for thousands of years.

Carbonisation preserves the physical form of the materials but changes their chemical composition. This is the most common preservation method for this type of remains and is found at different latitudes, as at La Draga site (Romero-Brugués et al. 2021b), and Coves del Fem (Romero-Brugués et al. 2021a), but also in Egypt (El Hadidi and Hamdy 2011) or in America (Jolie 2022).

Wet or waterlogged environments. In places where the materials are under the water table or submerged (rivers, riverbanks, seas and coastal areas), organic materials can be preserved by the anaerobic conditions in which they are buried. The lack of oxygen prevents the growth of bacteria and fungi that would normally cause decay. This method of preservation is particularly common in central and northern Europe, including exceptional cases such as the circum-Alpine region or some specific sites in southern Europe like La Marmotta on Lake Bracciano (Italy) (Mineo et al. 2023) or La Draga on Lake Banyoles (Romero-Brugués et al. 2021b) in north-eastern Iberia, or the site of Ohalo II in Israel (Nadel et al. 1994).

Frozen environments. Preservation by freezing refers to the process by which organic materials are kept intact by maintaining low temperatures that inhibit bacterial and enzymatic activity. This type of preservation is particularly common in permafrost zones or other high mountainous regions with low temperatures. One of the most famous examples of preservation by freezing is the case of the Tisenjoch Iceman -also known as Ötzi- in the Alps (Junkmanns et al. 2019).

Contact with metals. In exceptional cases where copper is present, organic material may be preserved due to the biocidal effects of copper. Conservation by mineralisation occurs when organic materials are replaced or infiltrated by minerals, preserving them in a fossilized form. In this process, environmental minerals infiltrate the cellular structure of organic tissues, gradually replacing organic components with minerals. An example could be the mat found in the Thracian Kitova tumulus in southeastern Bulgaria (Andonova et al. 2023).

The degree of change in these remains depends on the actions of the archaeologist and the specialists who carry out the extraction and subsequent treatment processes (Martín-Seijo et al. 2010). The recovery of perishable materials is also an important factor in the lack of their study and also in their limited visibility in archaeological contexts. Their excavation requires specific techniques that are not very common in traditional archaeology, as they are invisible remains (Adovasio 2010). Planning for recovery is therefore both feasible and crucial. Inorganic materials tend to be well preserved in different burial environments, whereas organic materials tend to deteriorate rapidly but preservation in different substrates can usually be predicted on the basis of specific burial conditions, although there are exceptions (Martín-Seijo et al. 2010). In this sense, archaeobotany, as a branch of archaeology focused on the recovery and classification of organic remains in order to understand their evolutionary and biogeographical history, has been well developed in recent decades when more research has focused on the organic material culture (di Lernia et al. 2012, Wendrich and Ryan 2012; López Bultó 2015; Morales et al. 2015; Alday 2021; Martin-Seijo 2021; Romero-Brugués et al. 2021a, 2021b; Andonova et al. 2023; among others).

2.6.1.1. Prehistoric direct recording of plant-fibre based materials.

As noted above, although studies of hunter-gatherers have contributed to our understanding of early human groups, fibre production has not been studied in detail for many reasons (Hardy 2007; Hurcombe 2008). In recent years, however, evidence for fibre production in Europe and Asia is expanding our knowledge of the importance of fibre use in early human groups from the Palaeolithic onwards. The oldest direct evidence to date relates to Neanderthal groups: a small bundle of left twisted conifer fibres attached to a Levallois flake found at Abri du Maras (France) and dated between 50,000 and 40,000 BC (Figure 22) (Hardy et al. 2020). This relates to cord production, although the oldest documented basketry remains were found in North America at the Meadowcroft Rockshelter (Washington) and dated to 15,200 BC, corresponding to a fragment of a woven basket (Adovasio and Illingworth 2004).

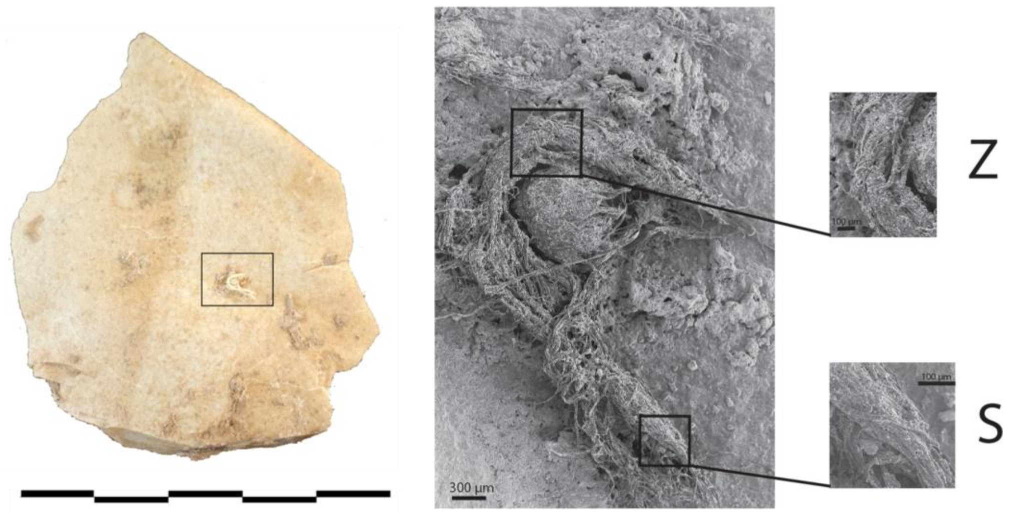

Figure 22. Oldest evidence of plant fibre use by Neanderthal groups. Conifer fibres attached to a Levallois flake found at Abri du Maras (50,000-40,000 BC; France) (Hardy et al. 2020).

To summarise the direct evidence for plant fibre production around the world, a few examples are discussed in the following paragraphs and in Table 2. Table 3 summarizes

European examples, and Table 4 Iberian cases. For ease of reading, the evidence is organised chronologically and geographically, from the earliest times to the Neolithic/Chalcolithic, as this is approximately the chronological framework of the current study.

2.6.1.1.1. Worldwide prehistoric direct evidence.

As far as the earliest cord evidence is concerned, in addition to that from Abri du Maras mentioned above, other examples include the nettle yarn from 32,000-29,000 BC found at the Dolni Vestonice site (Czech Republic), and other examples from Dzudzuana Cave (Georgia). Here, right-twisted flax fibres and knots dated to 26,000-22,000 BC were found (Kvavadze et al. 2009; Wigforss 2014). It is also important to mention the fragments of undetermined monocot yarn found at the Ohalo II site (Nadel et al. 1994) and dated to 17,300 BC in Israel, as well as the set of more than thirty fibre-based registers found at Takarkori (Libya) and dated to 8300-6100 BC. These examples show the development of fibre technologies among early hunter-gatherer groups.

On the American continent, an extensive inventory of materials of different chronologies and categories - cords and baskets - has been studied by several authors (Andrews et al. 1986; Fowler et al. 2000; Adovasio and Illingworth 2004; Geib and Jolie 2008; among others). Their work is largely based on the archaeological sites in the Great Basin where cords and coiled, twined and plaited basketry have been recovered and dated between 9000 and 7200 BC. However, there is a long list of sites where fibre-based archaeological remains have been recovered on the same continent (Falcon Hill Cave, Fishbone Cave, Humboldt Cave and Lovelock Cave, Fort Rock, Dirty Shame Rockshelter, Grimes Burial Cave, among others).

In Central America, the Cueva del Pendejo (Mexico) has provided one of the most extensive and studied assemblage of ancient string remains and a fragment of twined basketry dated to 9900-9300 BC (Hyland et al. 2003). Other sites with direct evidence of fibre production in Mexico include the Cuatro Ciénegas Basin (7450-3959 BC) and the caves of the Sierra Madre de Tamaulipas (6950-4950 BC) (Hyland et al. 2003). Moving to South America, specifically the north-central Andes of Peru, the Cueva del Guitarrero (8600-5600 BC) should be mentioned. Here, *Agave* sp., *Furcraea* sp., *Puya* sp. and *Tillandsia* sp. were used for a variety of fibre products (cords, nets and bags) (Adovasio and Maslowski 1980; Jolie et al. 2011). The Monte Verde site in Chile (ca. 11,000-10,500 BC) also provided good examples, although the references do not mention the raw materials used (Adovasio and Lynch 1973). These finds illustrate the early use of plant materials for practical purposes in ancient Andean cultures.

In East Asia, direct evidence for early plant-based basketry production is scarce or consists of unpublished examples. One comes from the Late Jōmon period in Japan, such as the basketry remains from the Higashimyo site dated to 5930-5710 cal BC (Nishida et al. 2006; Kuzmin et al. 2012), and another example is the textile found at the wet site of Tianluoshan (China), where a plaited mat made of reed (*Phragmites australis*) was identified and dated to 4825-4695 cal BC (Zhang et al. 2016).

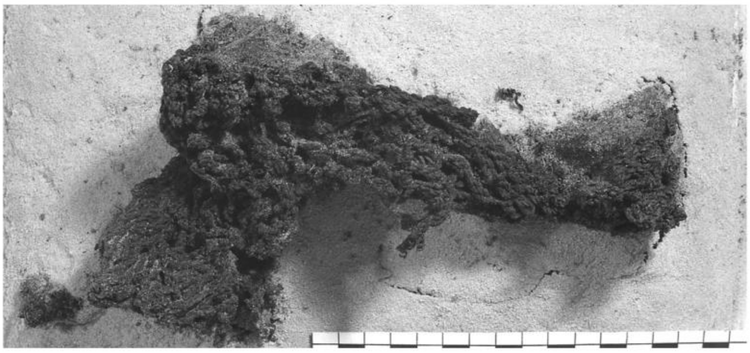

Figure 23. Fragment of a preserved knotless bast yarn net from the Friesack-4 site (7700 BC; Germany) (Gramsch and Kernchen 2023).

There is a long list of examples from the Middle East. To mention some of them, the oldest ones correspond to the basket fragments from Shanidar Cave (Iraq) (ca. 9850 BC) (Solecki 1963; Castro 1990; Adovasio 2018) and those from Jericho dated to ca. 9700-8500 cal BC in the PPNA levels (Pre-Pottery Neolithic A) (Castro 1990; Galili and Schick 1990). Other examples in Israel include fragments of coiled basketry at Nahal Hemar from the Early Neolithic (ca. 9100-8300 cal BC), at Nahal Haver in the Chalcolithic, at Nahal Mishmar dated to ca. 4000-3300 cal BC (Galili and Schick 1990), and at the Cave of the Warrior, where a coiled basket was found in a burial context and dated to the Late Chalcolithic (3900-3600 cal BC) (Gleba and Harris 2019). The archaeological site of Çatalhöyük (Turkey; 4750-4550 BC) also provides examples of coiled basketry made of wild panicoid grasses, sedges and cereal straw, while mats were mainly made of sedges and occasionally common reeds (*Phragmites australis*) (Wendrich and Ryan 2012; Adovasio 2018). In addition, several artefacts at the same site were made of oak (Rast-Eicher et al. 2021) suggesting local collection of wild plants to obtain bast fibres. Similar objects have been found at archaeological sites in the middle Euphrates valley, such as Tell Halula (Syria) in the PPNB levels (Pre-Pottery Neolithic B) (7600-7300 BC), where basket fragments were found in a funerary context (Guerrero et al. 2009), or at Tell Bouqras, also in Syria, dated to 6350-5850 BC (Miškolciová 2015). More recently, water-saturated basketry remains have been preserved in the coastal region of Israel. At the site of Kfar Samir, basketry remains, and a mat fragment dated to ca. 4620-4220 BC were recovered from an unlined silo, probably the oldest example found in a water-saturated state in the Near East. The organic material has not been identified (possibly reed or straw), but the technique is intricately stitched coiled basketry (Galili and Schick 1990; Galili et al. 2018). In Egypt, the coiled basketry technique is the oldest among the basketry finds (Wendrich 2016), dating from the Neolithic period (ca. 5900-4000 BC). Examples include lined silos found at El Fayum or El Badari, both dating to around 4000 BC, although some other techniques have been documented. Raw materials used in the area include wheat straw, grasses or cattails (Wendrich et al. 2017; Wendrich and Holdaway 2018).

2.6.1.1.2. European prehistoric direct evidence.

In Europe, other early direct evidence for the use of plant fibres, probably bast, to make rope comes from Lascaux Cave in France, dated to 15,000 BC (Barber 1994), although these remains could not be recovered. During the Mesolithic and Neolithic periods (9000-3000 BC) rope made from lime bast fibres has been documented at several European sites (Myking et al. 2005). Wetland sites in the northern part have yielded examples of cords and nets, such as those made of lime tree (*Tilia* sp.), willow (*Salix* sp.) and stinging nettle (*Urtica dioica*) found at the site of Antrea (Finland) and dated to 8400-8300 cal BC (Bender Jørgensen 1992; Miettinen et al. 2008; Wigforss 2014), or those made of lime tree bast found at the Friesack-4 site (Germany) and dated to 7700 BC (Figure 23) (Gramsch 1992; Gramsch and Kernchen 2023). Other examples are the strings and twisted nettle cords from Denmark, such as those from the sites of Dejrø and Skjoldnæs dated to 6500 cal BC or Tybrind Vig dated to 5400-4000 cal BC (Figure 24) (Bender Jørgensen 1992; Wigforss 2014).

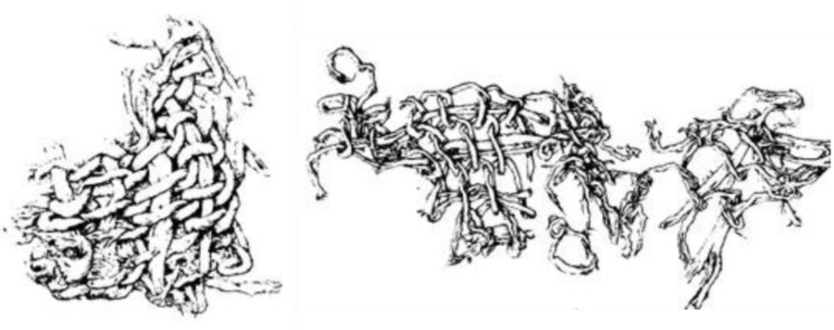

Figure 24. Textiles from Tybrind Vig (5400-400 cal BC; Denmark): Z-spun plant fibres knotted in needle-netting technique (Andersen 1985).

In a similar chronology six fragments of twined conic baskets - creels typology - were found in the humid archaeological site of Noyen-sur-Seine (France), made of *Ligustrum vulgare* and *Pinus sylvestris* fibres and dated ca. 6050 BC (Figure 25) (Mordant 2024). For

Neolithic chronologies, there are remarkable plant craft remains from lacustrine settlements in Central Europe, such as those located in the Circum-Alpine zone. They have provided cordage materials from various sites, such as Arbon-Bleiche (Switzerland; 3384-3370 BC), where the materials were made from lime tree bark and flax (Médard 2003), and the Wetzikon-Robenhausen site, also in Switzerland and dated to 3700-3300 BC, where lime tree bark was also used (Altorfer and Médard 2000). The extensive use of lime bark as well as monocot fibres in the Lake Constance (Bodensee) (Neolithic-Calcholithic) archaeological sites should be mentioned, in addition to the huge collection of fibre-based elements (cords, baskets, mats, textiles and footwear) found in the German archaeological sites of Hornstaad, Sipplingen, Allensbach, Wangen, Bad Buchau, among others (Figure 26) (Feldtkeller 1998; Maier 1999; Altorfer and Médard 2000; Billamboz et al. 2010; Banck-Burgess 2023; Böhm et al. 2023) as well as Swiss sites such as the aforementioned Arbon-Bleiche 3 (Médard 2003).

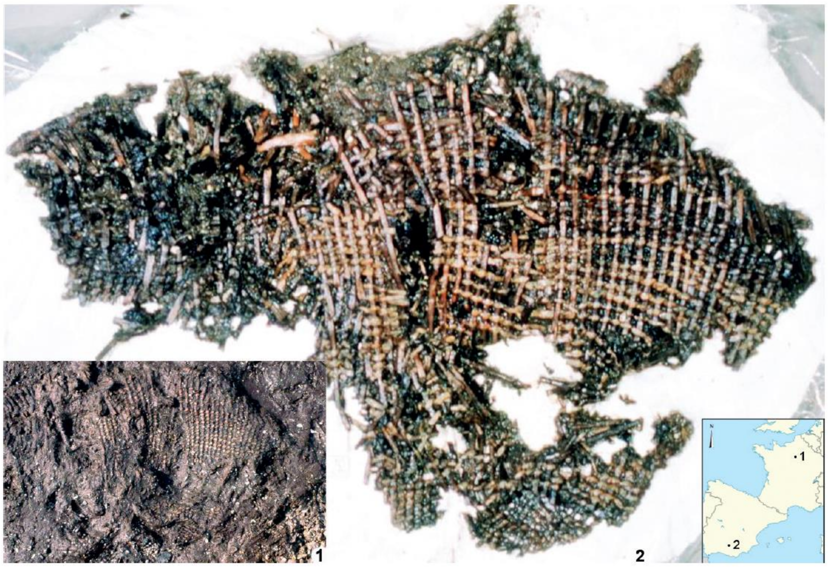

Figure 25. Twined conic baskets - creels typology – from the Noyen-sur-Seine site (ca. 6050 BC; France) made of *Ligustrum vulgare* and *Pinus sylvestris* fibres (Mordant 2024).

Different uses of bast fibre production in the Old World in later periods reveal a wide range of raw materials, including flax, hemp and oak bast, which were used across Europe (Gleba and Harris 2019). Tree bast fibres, such as poplar (*Populus* sp.) and grasses, were used in various textile artefacts found at Mesolithic Scandinavian and Baltic sites (Harris and Jones 2017). In Central Europe, numerous textile artefacts have been discovered, especially clothing made of flax. Flax, one of the earliest domesticated plants in Neolithic Europe, was used extensively as a source of fibre by early farmers (Harris 2014). These discoveries highlight the diversity and adaptation of bast fibre use across regions and time periods.

Table 2. Worldwide prehistoric direct evidence of fibre-based production.

Archaeological site	Localisation	Chronology	Preservation condition	Type of object and production technique	Raw material used	Reference
Abri du Maras	France	50,000-40,000 BC	Non-specified	Twisted fibres	Conifer	Hardy et al. 2020
Dolni Vestonice	Czech Republic	32,000-29,000 BC	Non-specified	Yarn	Nettle	Kvavadze et al. 2009 Wigforss 2014
Dzudzuana Cave	Georgia	26,000-22,000 BC	Non-specified	Twisted fibres Knots	Flax	Kvavadze et al. 2009 Wigforss 2014
Ohalo II	Israel	17,300 BC	Non-specified	Yarn	Monocotyledon	Nadel et al. 1994
Meadowcroft Rockshelter	North America	15,200 BC	Non-specified	Woven basket	Non-specified	Adovasio and Illingworth 2004
Monte Verde	Chile	ca. 11,000-10,500 BC	Non-specified	Cords	Non-specified	Adovasio and Lynch 1973
Cueva del Pendejo	Mexico	9900-9300 BC	Non-specified	Twined basketry	Non-specified	Hyland et al. 200
Shanidar Cave	Iraq	ca. 9850 BC	Non-specified	Basketry	Non-specified	Solecki 1963 Castro 1990 Adovasio 2018
Jericho	Palestina	ca. 9700-8500 cal BC	Non-specified	Basketry	Non-specified	Castro 1990 Galili and Schick 1990
Nahal Hemar	Iraq	ca. 9100-8300 cal BC	Non-specified	Coiled basketry	Non-specified	Galili and Schick 1990
Great Basin sites	Oregon Nevada	9000 and 7200 BC	Non-specified	Diversity of objects	Non-specified	Andrews et al. 1986 Fowler et al. 2000 Adovasio and Illingworth 2004 Geib and Jolie 2008
Takarkori	Libya	8300-6100 BC	Non-specified	Left twisted fibres	Monocotyledon	Nadel et al. 1994
Cuatro Ciénegas basin	Mexico	7450-3959 BC	Non-specified	Cords	Non-specified	Hyland et al. 2003
Sierra Madre de Tamaulipas	Mexico	6950-4950 BC	Non-specified	Cords	Non-specified	Hyland et al. 2003
Tell Halula	Syria	7600-7300 BC	Dehydrated	Basketry	Non-specified	Guerrero et al. 2009
Cueva del Guitarrero	Peru	8600-5600 BC	Dehydrated	Cords Nets Bags	*Agave* sp. *Furcraea* sp. *Puya* sp. *Tillandsia* sp.	Adovasio and Maslowski 1980 Jolie et al. 2011
Tell Bouqras	Syria	6350-5850 BC	Non-specified	Basketry	Basketry	Miškolciová 2015
Higashimyo	Japan	5930-5710 cal BC	Non-specified	Basketry	Non-specified	Nishida et al. 2006 Kuzmin et al. 2012
El Fayum	Egypt	4000 BC	Dehydrated	Diversity of objects	Straw Grasses Cattails	Wendrich et al. 2017 Wendrich and Holdaway 2018
El Badari	Egypt	4000 BC	Dehydrated	Diversity of objects	Straw Grasses Cattails	Wendrich et al. 2017 Wendrich and Holdaway 2018
Tianluoshan	China	4825-4695 cal BC	Non-specified	Plaited mat	*Phragmites australis*	Zhang et al. 2016
Çatalhöyük	Turkey	4750-4550 BC	Dehydrated	Coiled basketry	Panicoid grasses Sedges Cereal straw *Phragmites australis* Oak	Wendrich and Ryan 2012 Adovasio 2018 Rast-Eicher et al. 2021
Kfar Samir	Israel	ca. 4620-4220 BC	Waterlogged	Coiled basketry Mats	Reed or straw	Galili and Schick 1990 Galili et al. 2018
Nahal Mishmar	Israel	ca. 4000-3300 cal. BC	Dehydrated	Coiled basketry	Non-specified	Galili and Schick 1990
Cave of the Warrior	Syria	3900-3600 cal BC	Dehydrated	Coiled basketry	Non-specified	Gleba and Harris 2019

Table 3. European prehistoric direct evidence of fibre-based production.

Archaeological site	Localisation	Chronology	Preservation condition	Type of object and production technique	Raw material used	Reference
Lascaux cave	France	15,000 BC	Carbonised	Twisted cord	Probably bast	Barber 1994
Antrea	Finland	8400-8300 cal BC	Waterlogged Carbonised	Cords Nets	*Tilia* sp. *Salix* sp. *Urtica dioica*	Bender Jørgensen 1992 Miettinen et al. 2008 Wigforss 2014
Friesack-4	Germany	7700 BC	Waterlogged Carbonised	Diversity of objects	Lime tree bast	Gramsch 1992 Gramsch and Kernchen 2023
Dejrø	Denmark	6500 cal BC	Waterlogged Carbonised	Twisted cords	Nettle	Bender Jørgensen 1992 Wigforss 2014
Skjoldnæs	Denmark	6500 cal BC	Waterlogged Carbonised	Twisted cords	Nettle	Bender Jørgensen 1992 Wigforss 2014
Noyen-sur-Seine	France	ca. 6050 BC	Waterlogged	Twined baskets	*Ligustrum vulgare* *Pinus sylvestris*	Mordant 2024
Tybrind Vig	Denmark	5400-4000 cal BC	Waterlogged Carbonised	Twisted cords Textiles	Nettle Lime tree bast	Bender Jørgensen 1992 Wigforss 2014
Arbon-Bleiche	Switzerland	3384-3370 BC	Waterlogged Carbonised	Diversity of objects	Lime tree bast Flax	Médard 2003
Wetzikon-Robenhausen	Switzerland	3700-3300 BC	Waterlogged Carbonised	Diversity of objects	Lime tree bast	Altorfer and Médard 2000
Bondensee sites*	Germany Switzerland	Neolithic Calcolithic	Waterlogged Carbonised	Cords Basketry Mats Textiles Footwear	Lime tree bast Monocotyledonous	Feldtkeller 1998 Maier 1999 Altorfer and Médard 2000 Billamboz et al. 2010 Banck-Burgess 2023 Böhm et al. 2023
La Marmotta	Italy	Six millennium BC	Waterlogged Carbonised	Cords Basketry Textiles	Non-specified	Mineo et al. 2023
Clairvaux Station III	France	ca. 4000-2000 BC	Non-specified	Cords Diversity of objects	Flax Oak	Pétrequin 1986 Rots 2008
Etton	England	4000-2800 BC	Non-specified	Cord	Bast fibres	Cooper 2009
Des Baigneurs	France	2750-2730 BC	Non-specified	Cord	Non-specified	Rots 2008
Tisenjoch Iceman	Italy	3350 BC	Frozen	Cords Footwear Basketry	Lime bast	Spindler 1995 Junkmanns et al. 2019

*Hornstaad, Sipplingen, Allensbach, Wangen, Bad Buchau, among others.

In Italy, the site of La Marmotta on Lake Bracciano has yielded various plant remains, both wood and fibre-based, including ropes, baskets and textiles (Figure 27) (Mineo et al. 2023). In France, the use of flax for cordage is well documented at Clairvaux Station III (ca. 4000-2000 BC), together with oak fibres for other fibre-based products (Pétrequin 1986; Rots 2008). On the shores of Lake Paladru also in France, another Neolithic rope was found at Des Baigneurs and dated to 2750-2730 BC (Rots 2008). In the Italian Alps, the Tisenjoch Iceman - also known as Ötzi - dated to 3350 BC was found with a wide variety of textile-related objects, such as cords and cord-based footwear, both made of lime bast (Spindler 1995; Junkmanns et al. 2019). In England, a rope made from bast fibres has been documented at a Neolithic site called Etton (Peterborough; 4000-2800 BC) (Cooper 2009).

Figure 26. Examples of the variety of objects and techniques found in the archaeological sites from the Lake Constance (Modified from Banck-Burgess 2023).

Figure 27. Fibre-based remains from the neolithic archaeological site of La Marmotta on the Lake Bracciano (Italy) (Mineo et al. 2023).

2.6.1.1.3. Iberian prehistoric direct evidence.

In the Iberian Peninsula, the oldest known rope remains are the three charred fragments of three-strand braided fibre cords recovered from the Coves of Santa Maira (Castell de Castells, Alacant) dating from 12,900-10,200 cal BC and made of esparto grass (*Stipa tenacissima*) (Figure 28) (Aura-Tortosa et al. 2019).

Also noteworthy is the diverse collection of objects (baskets, cords and footwear) made of *Stipa tenacissima* from Cueva de los Murciélagos (Albuñol, Granada), dated to 7986-3740 cal BC (Martínez-Sevilla et al. 2023). The assemblage of cords and baskets from the Neolithic pile-dwelling site of La Draga (Banyoles, Girona), dated to 5324-4977 cal BC, is also noteworthy for its chronology and state of preservation. Various Poaceae, but also Cyperaceae and Typhaceae, lime-tree bast, and also nettle fibres were utilised to make them (Bosch et al. 2000, 2006; Piqué et al. 2018; Herrero-Otal et al. 2021, 2023; Romero-Brugués et al. 2021b). Another important collection from the northeastern Iberian Peninsula includes the charred and dehydrated fragments of coiled basketry and a small cord fragment from the Coves del Fem site (Ulldemolins, Tarragona; 4941-4545 cal BC) made from Cyperaceae and non-identified monocot plants (Bogdanovic et al. 2017; Palomo et al. 2018; Romero-Brugués et al. 2021a). The materials from the archaeological sites of Cueva de los Murciélagos, La Draga and Coves del Fem are part of the study cases in the current dissertation, so a detailed description is provided below.

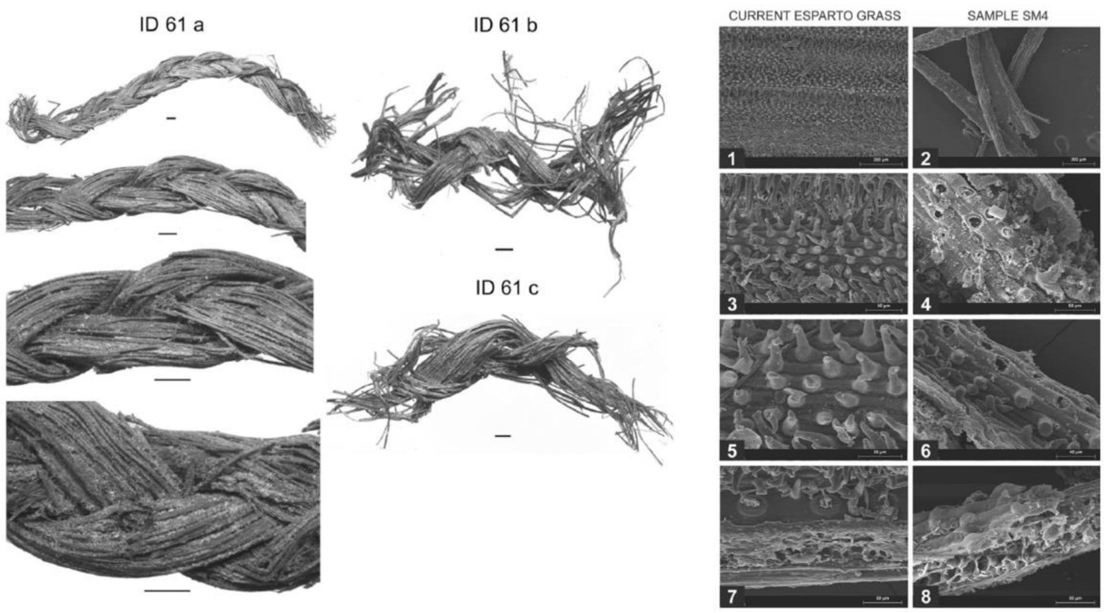

Figure 28. Fragments of charred braids made of *Stipa tenacissima* from the Coves de Santa Maira site (12,900-10,200 cal BC; Alacant) (Aura-Tortosa et al. 2019).

Table 4. Iberian prehistoric direct evidence of fibre-based production.

Archaeological site	Localisation	Chronology	Preservation condition	Type of object and production technique	Raw material used	Reference
Coves of Santa Maira	Alacant	12,900-10,200 cal BC	Charred	Braided cords	*Stipa tenacissima*	Aura-Tortosa et al. 2019
Cueva de los Murciélagos	Granada	7986-3740 cal BC	Dehydrated	Twisted cords Braided cords Twined basketry Coiled basketry 'Cofín' basketry Braided basketry Footwear	*Stipa tenacissima*	Martínez-Sevilla et al. 2023 This thesis
La Draga	Girona	5324-4977 cal BC	Waterlogged Carbonised	Twisted cords Braided cords Coiled basketry	Poaceae Cyperaceae Typhaceae Lime tree bast	Bosch et al. 2000, 2006 Piqué et al. 2018 Herrero-Otal et al. 2021, 2023 Romero-Brugués et al. 2021b This thesis
Coves del Fem	Tarragona	4941-4545 cal BC	Dehydrated Carbonised	Cords Coiled basketry	Cyperaceae Poaceae	Romero-Brugués et al. 2021a This thesis
Cova de les Cendres	Alacant	4550-4470 cal BC	Carbonised	Plaited basketry	Esparto grass	Bernabeu-Aubán and Fumanal-García 2009
Campos	Almería	Final Neolithic Chalcolithic	Carbonised	Cord	Esparto grass	Papí 1992-1994
Cueva de Nerja	Málaga	Early Chalcolithic	Non-specified	Cord	Esparto grass	Jordà et al. 1983
Cueva Sagrada	Murcia	Chalcolithic	Dehydrated	Cords Bundles of fibres Mats	Esparto grass	Jordà et al. 1983
Sierra de la Curra	Málaga	Chalcolithic	Mineralised	Cord	Non-specified	Jordà et al. 1983
Los Millares	Almería	3100-2100 BC	Non-specified	Coiled basketry	Non-specified	Gleba and Harris 2019
Cueva del Toro	Málaga	3000 BC	Non-specified	Braided cords	Esparto grass	Martín Socas et al. 2004
Cabezo Redondo	Alacant	2429-2065 cal BC	Non-specified	Basketry	Non-specified	Alfaro 1984
Cueva de Peñacalera	Córdoba	3400/2500-2300 cal BC	Dehydrated	Textiles	Flax	Gleba et al. 2021
Villa Filomena	Castelló	3000-1800 BC	Non-specified	Braided cord	*Stipa tenacissima*	Alfaro (1984)
Cerro de la Virgen	Granada	2600-1500 BC	Non-specified	Braided cord	*Stipa tenacissima*	Schüle 1980
Ifré	Almería	2360-1910 BC	Non-specified	Braided cords Coiled basketry Plaited basketry	*Stipa tenacissima*	Alfaro 1984
El Oficio	Almería	2000-1500 BC	Non-specified	Coiled basketry	*Stipa tenacissima*	Alfaro 1984
Almizaraque	Almería	Argaric culture	Non-specified	Coiled basketry	*Stipa tenacissima*	Alfaro 1984
Las Angosturas	Granada	2350-1919 BC	Non-specified	Plaited basketry Cords	*Stipa tenacissima*	Cacho et al. 1996
Motilla del Azuer	Ciudad Real	2200-1300 BC	Carbonised	Braided cords	*Stipa tenacissima*	Alfaro 1984
El Pendo cave	Cantabria	2400-1500 cal BC	Non-specified	Cords	Non-specified	Alfaro 1984

The remains of a basket made from plaited esparto grass found at the Cova de les Cendres site (Teulada, Alacant), dating from 4550-4470 cal BC and used to reinforce the walls of a silo, is another notable find from the area (Bernabeu-Aubán and Fumanal-García 2009). In more recent prehistoric times, carbonised esparto ropes have been found at Campos (Cuevas del Almanzora, Almería) from the Final Neolithic to the Early Chalcolithic (Papí 1992-1994), and at Cueva de Nerja (Nerja, Málaga), where a fragment of esparto rope has been documented in the Early Chalcolithic level (Jordà et al. 1983). Other Chalcolithic remains include those from Cueva Sagrada (Lorca, Murcia), where mats, ropes, and unbraided bundles of esparto grass were found, and a calcified plant fibre fragment from Sima de la Curra (Carratraca, Málaga) (Jordà et al. 1983). Coiled baskets are also known from the site of Los Millares (3100-2100 BC; Santa Fe de Mondújar, Almería) (Gleba and Harris 2019), as well as braided esparto fibres from Cueva del Toro (3000 BC; Antequera, Málaga) (Martín Socas et al. 2004), or the fragment of a possible basket from Cabezo Redondo (2429-2065 cal BC; Villena, Alacant) (Alfaro 1984). The flax textiles coloured with cinnabar found in the Cueva de Peñacalera site (Córdoba) dating from 3400/2500-2300 cal BC should also be mentioned (Figure 29) (Gleba et al. 2021).

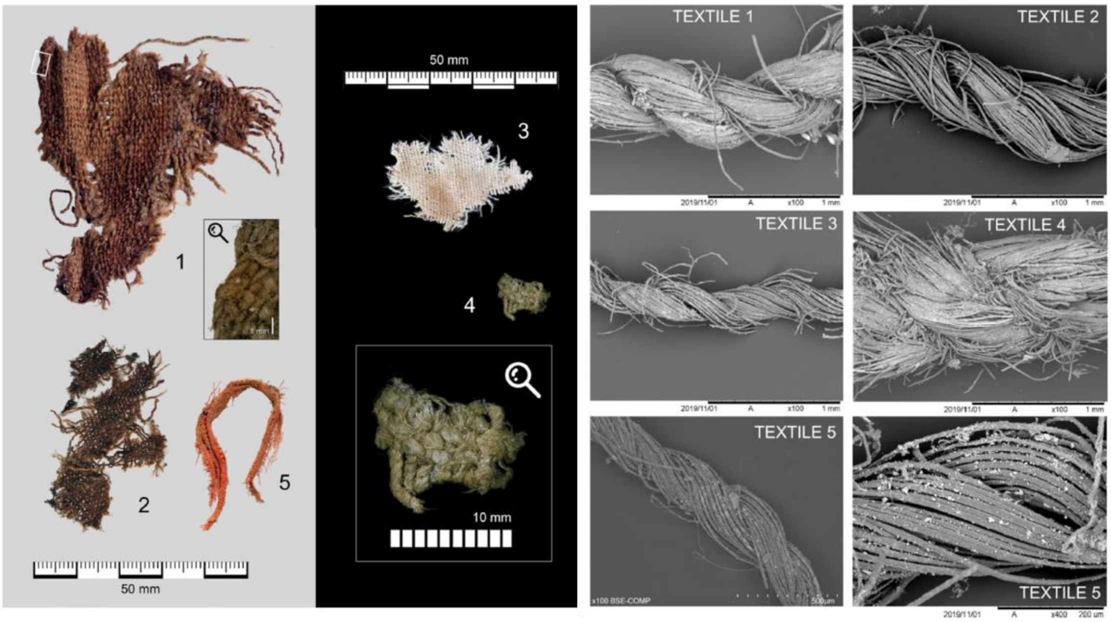

Figure 29. Flax-based textiles coloured with cinnabar found in the Cueva de Peñacalera site (3400/2500-2300 cal BC; Córdoba) (Gleba et al. 2021).

According to Alfaro (1984), esparto rope remains become more common in the Bronze Age, with numerous examples and although this thesis does not focus on that chronological period, some examples are mentioned to illustrate the widespread use of *Stipa tenacissima* in Mesolithic/Neolithic times in the Iberian Peninsula. The site of Villa Filomena (3000-1800 BC; Villarreal, Castelló) provided a braided rope, as well as at the

Cerro de la Virgen (2600-1500 BC; Orce, Granada) (Schüle 1980). Remains of braids and plaited and coiled baskets were also found at the Ifré site (2360-1910 BC; Ifré, Almería) (Alfaro 1984). At the site of El Oficio (Cuevas del Almanzora, Almería), dated to the Late Bronze Age (2000-1500 BC) fragments of coiled basketry were found in a burial context, as in the Argaric site of Almizaraque (Cuevas del Almanzora, Almería) (Alfaro 1984). Furthermore, fragments of plaited basketry and cord fragments are documented at the site of Las Angosturas (2350-1919 BC; Gor, Granada) (Cacho et al. 1996), like the charred braided esparto rope fragments from the Motilla del Azuer site (2200-1300 BC; Daimiel, Ciudad Real) (Alfaro 1984). Though the raw material has not been identified, a recent discovery of plant materials, including a rope, in El Pendo cave (Escobedo de Camargo, Cantabria), dated to the Bronze Age (2400-1500 cal BC), stands out.

2.6.1.2. Indirect evidence and prehistoric register of plant-fibre based materials.

Indirect conservation of organic materials in archaeology refers to the preservation of evidence or traces of organic materials rather than the materials themselves. This form of conservation is crucial when the original organic substances have decayed or degraded beyond recognition but have left behind detectable residues or altered the surrounding environment in a way that provides information about their presence and nature. Indirect conservation methods enable archaeologists to infer the existence and characteristics of organic materials through various types of analyses and artefacts.

2.6.1.2.1. Portable and cave art.

Portable art is another archaeological record that provides information on the use of plant fibres, using indirect records such as engravings on stones and rock art. Several examples of the use of baskets and cords have been recorded in different latitudes and show the beginnings of the development of cord and basket technologies.

Regarding cord representations, ancient examples have been found in the Mediterranean region in two archaeological sites: the Grotta di Cavallone (36,000-28,000 BC) and the Grotta di Romanelli (9930 BC), both in Italy (Castro 1990).

Magdalenian examples have also been found in France in the cave of Saint Michel d'Arudy (15,000-10,000 BC), where ropes associated with a horse are represented (Castro 1990), but these are controversial due to the domestication of animals. Gravettian figurines made of clay, ivory and stone have also been recorded in several sites, where the representation of detailed clothing and ornaments has been defined. Some examples are found in Central and Western Europe (27,000-20,000 BC) (Soffer et al. 2000) where clothing elements were suggested to be of plant origin, highlighting that twisted fibres were used around 30,000 BC. Other examples are the hats recorded on the ivory heads from Pavlov I (25,000 BC; Czech Republic), the figurine from Brassempouy (24,000-22,000 BC; France) (Figure 30) or the examples from the Russian sites of Avdeevo (19,000-18,000 BC) and Gargarino (18,000 BC). Similar examples made in stone have also been identified in France, such as the Femme à la tête quadrillée (30,000-18,000 BC; Laussel) and the Femme à la tête négroïde (28,000-18,000 BC; Balzi Rossi), but also the figurine from Willendorf (22,000-20,000 BC; Austria) (Figure 30) or the one found at Kostenki (21,000-19,000 BC) in Russia (Soffer et al. 2000). Barber (1994) identified ribbons in the clothing of various figures, such as those found on the figurine from Lespugue (18,000 BC; France), which were identified as a kind of skirt with twisted ropes, or the one from Gagarino (18,000 BC; Russia), which is supposed to wear a small, short rope skirt (Soffer et al. 2000).

Figure 30. Clothing plant fibre-based elements representations in ivory materials: figurine from Brassempouy (24,000-22,000 BC; France) (left), figurine from Willendorf (22,000-20,000 BC; Austria) (right) (Google images).

In the Upper Palaeolithic site of Cova del Parpalló (9000-8000 BC; València, Spain), engraved plaques provide representations of plant fibres, such as ropes, baskets and textiles (Castro 1990), although some of these engravings were initially identified as snails (Stone 2009). Without specifying the archaeological sites, it has also been assumed that rock art in the Cantabrian region of Iberia may also represent fishing artefacts such as nets (Straus 1992; Bahn 2001; Stone 2009). Other female clay figurines depicting women wearing skirts have also been found at Sipintsi (ca. 1500 BC; Ukraine), at Vinca (2500 BC; Serbia), and at Crnokalacka Bara (ca. 1000 BC; Yugoslavia) (Barber 1994).

The oldest known evidence of basketry in Iberian rock art is seen in the Levantine style. The honey collection scene in the Cova de L'Aranya (8000-5000 BC, València) is a good example (Figure 31) (Jordà Cerdà 1974; Alfaro 1989; Ochoa et al. 2021). Similar chronological representations can be found in Cingle de la Mola Remígia, Cova Remígia and Racó Molero (Castelló), where seven compositions with baskets and objects are represented (Sarrià 1988-1989), as well as the basket in Abric de l'Arquer (Valencia) (Jordà Cerdà and Alcàcer Grau 1951).

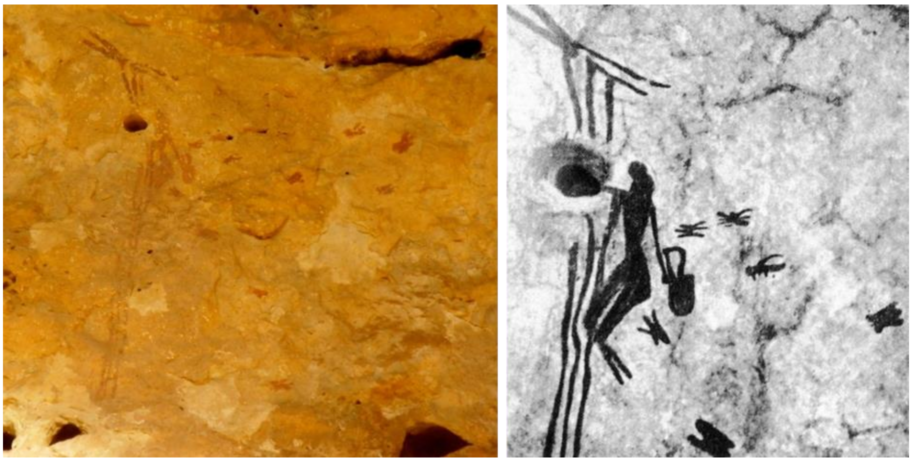

Figure 31. Honey collection scene using baskets in the Cova de L'Aranya (8000-5000 BC, València) (Jordà Cerdà 1974; Alfaro 1989; Ochoa et al. 2021).

2.6.1.2.2. Plant fibre processing tools and traces of use.

In archaeological contexts, the preservation of textile production tools exceeds that of the textiles themselves, due to their material durability. During the prehistoric period, artefacts typically associated with textile production were predominantly made of bone and wood, with the occasional use of lithic materials like lithic blades or malacofaunal shells and pottery. Functional analysis of hard materials provides us with valuable indirect information about working with plant fibres (Legrand 2007; Legrand and Sidéra 2007; Mozota and Gibaja 2015, De Diego 2023).

It has been suggested that numerous Upper European Palaeolithic bone or antler artefacts, traditionally associated with hunting, may also have been used with plant-fibre products (Siffer 2004; Stone 2009). Notable examples include bone awls from Vogelherd (30,000 BC; Germany) as well as Gravettian bone and ivory fragments from Dolní Věstonice (26,000-23,000 BC; Czech Republic) and Avdeevo (20,000 BC; Russia) (Soffer 2004). In addition, several authors propose that bâtons de commandement, mainly made of antler, were used as ropemaking tools (Rigaud 2001; Soffer 2004; Boucherat 2009), despite their common association with spear throwing. Wear traces on some objects from Gönnersdorf (11,000 BC; Germany) showed patterns similar to those present on ethnographic artefacts related to fibre-twisting from Iceland and Portugal (Soffer 2004). Similar finds have been reported from the Magdalenian cave of Saint Michel d'Arudy (15,000-10,000 BC; France), where a reindeer antler was interpreted as a netting hook (Bahn 2001). In fact, these hooks probably possessed multiple functions, assisting in different aspects of rope production (Rigaud 2001).

Significant insights have been registered in the Near East (ca. 10,550-8250 BC) where a diverse range of bone instruments including spatulas, combs, needles and awls have been documented and related to textile functions (Mellaart 1975). Similar items were found in Mureybet (Syria) confirming the widespread use of bone tools during this period (Mellaart 1975). Furthermore, in the Zagros region, sites such as Zawi Chemi and Shanidar Cave (both in Iraq) have yielded spatulas and impressions of baskets dated to 8920-8650 cal BC (Mellaart 1975). Many instruments associated with textile production have been identified in the site of Tell Halula (7600-7300 cal BC; Syria). These include smoothers, punches, spatulas and needles explicitly associated with weaving activities (Molist et al. 2004; Alfaro 2012). At Çatalhöyük (6000 BC; Turkey) bone spatulas and spoon tools found in women's graves have been used to suggest a gender division of labour in domestic activities including textile production (Mellaart 1967). Regarding fibre spinning, evidence from the same area includes Neolithic and Chalcolithic spindle whorls made of terracotta and limestone, suggesting their use as early as 5500 BC. Spindle whorls have also been documented in Syrian Neolithic contexts from 8000 cal BC as in Tell Sabi Abyad (Rooijakkers 2012). In America, similar analyses determined that certain spatulas from 9000 BC at the Arenosa Shelter site (Texas) were probably used to process bark and leaves (Jurgens 2005).

In Europe, the pile-dwelling sites in the Circum-Alpine region have provided a wealth of information on changes and developments in plant-fibre use from the Neolithic to the Bronze Age. This applies not only to the technological shift from fibres, but also to the types of associated tools. At the Horgen site (c. 3080-3030 BC) wooden combs and staffs have been documented as tools used to separate flax fibres during the fibre extraction process (Barber 1991; Akeret and Jacomet 1997), and these may have disappeared with the introduction of wool into textile production. Similar tools, including punches, spatulas, spindles and spindle whorls, have also been found in the lake dwellings of southern Germany in Lake Constance (Maier and Schlichtherle 2011).

Extensive research on bone and stone industries from the Neolithic period onwards has demonstrated that the processing of plant fibres was a routine activity for early agricultural communities. Notable studies include those on bone materials from the prehistoric pottery site of Khirokitia (ca. 6000 BC; Cyprus) (Legrand 2007).

Additionally, a register of artefacts linked to prehistoric textile technology has been identified in the Iberian Peninsula. In northern Spain, the discovery of shell tools from Santimamiñe (10,860-10,720 BC; Bizkaia) (Cuenca et al. 2014) demonstrated that bone tools were not the only instruments employed to process plant fibres. On the Iberian Mediterranean coast, the Early Neolithic site of La Draga (Girona) has revealed evidence of plant fibre processing which includes bone and wooden tools, such as needles and awls, as well as combs, scrapers, spindles and shells (*Mytilus galloprovincialis*) (Legrand 2007; Clemente and Cuenca 2011; De Diego et al. 2017, 2018). The most recent studies in this site have revealed differences in the use-wear on wooden and bone artefacts for plant fibre processing. This has permitted the inference of the function of several categories of items, including combs, spindles, punches and thread tensioners (De Diego 2023), revealing the emergence of a new technology related to the processing of plant fibres, rope-making, basketry, and weaving in the Early Neolithic in the north-eastern Iberian Peninsula. Moving to the south, several spatulas have been recovered in the Early Neolithic site of Cueva de la Sarsa (València) (García Borja et al. 2011). In the site of Cueva de los Murciélagos (Granada), the archaeological materials collected in the 19th century revealed bone punches and spatulas traditionally associated with fibre processing (De Góngora 1868; López 1980). However, these have not yet been subjected to in-depth study. These finds, in conjunction with the newly recovered materials from the most recent archaeological fieldwork, are currently undergoing micro-striation and use-wear analysis.

Spindle whorls were linked with spindles and served as weights to aid the spinning process during thread production. They have been documented from the Late Neolithic (Martínez Rodríguez et al. 1989; Martínez and Alcázar 1992). The first specimens were made in pottery and stone. However, ephemeral materials may have been utilized in earlier times, as indicated by both ethnographic and archaeological studies (Médard 2000; Kemp and Vogelsang-Eastwood 2001; Burke 2010; among others). Thread tensioners are used in current ethnographic communities (Arnold and Espejo 2013), although their identification in the archaeological record from the Iberian Peninsula is debated. However, some examples have been found at the sites of Cueva del Toro, Cueva de Hundidero and Cueva de Nerja (Málaga, Spain), and in Cueva de la Murcielaguina (Córdoba, Spain) (Cardito 1996; Carrasco et al. 2009; Ruiz de Haro 2012). Moving to the Late Neolithic/Chalcolithic onwards, evidence of needles and copper awls have been documented in several sites in Iberia, such as Cueva de la Almanzora (Almería, Spain) (Maicas and Montero 1988), Barranco Calderón (Almería, Spain), Barbacena (Portugal), Dolmen de la Vega (Badajoz, Spain) and Granja de Céspedes (Badajoz, Spain) (Sos Baynat 1962; Muñoz López-Astilleiros 1999).

These finds underscore the integral role of textile production tools in prehistoric societies, highlighting not only their functional diversity, but also their cultural and chronological significance in different archaeological contexts.

2.6.1.2.3. Plant fibres imprints on non-perishable materials.

Impressions of fibre-based artefacts on non-perishable materials, such as clay or pottery, also provide indirect information about these technologies. They may have been made intentionally as decoration, but also accidentally as a result of production processes or to facilitate production. This is due to wet clay materials being left in contact with plant fibre-based objects during pottery making or when sealing containers (Hollander and Schwartz 2000; Rovira 2006). These remains allow the production technique to be determined and, in some cases, the raw material used as well as their shape. These impressions have been extensively analysed (Hyland et al. 2003) and have been observed all over the world and in different historical periods.

The oldest fibre impressions date from the Upper Palaeolithic, corresponding to artefacts from the Pavlov Culture (29,000-24,000 BC; Czech Republic), and provide the earliest evidence for rope and basket production (Soffer et al. 2000; Wigforss 2014). They have also been recorded in Eastern Europe as cord and basket impressions on clay (Soffer et al. 2000; Rots 2008). Similar impressions have been recorded in Lascaux Cave (15,000 BC; France), where rope marks on clay have been documented (Leroi-Gourhan and Allain 1979; Leroi-Gourhan 1983). In Asia, cord impressions on pottery have been dated to 14,000 BC in China (Kuzmin et al. 2012) and 13,000 BC in Japan (Hurley 1979). Following a chronological sequence, twisted basketry impressions have been recorded at the Coves de Santa Maira site (12,900-10,200 cal BC; eastern Spain) (Aura-Tortosa et al. 2019). The Japanese Neolithic is known as the Jōmon culture period (13,600-9000 cal BC), which is directly related to cord impressions on pottery that are more representative of the Middle Neolithic in the area (3500-2500 cal BC), the most notable examples of which are found in the eastern part from north to south (Tohoku, Honshu and Hokkaido) (Zhushchikhovskaya 2007).

In the United States, one of the oldest known examples of basketry impressions was found at Graham Cave (8200-6990 BC; Missouri) (Andrews and Adovasio 1996; Klippel 1971; Logan 1952) and represents the earliest corded basketry imprint in clay found in North America (Adovasio and Illingworth 2004), together with the ones found at Ice House Bottom (7450-7250 BC; Tennessee) (Chapman and Adovasio 1977) and at Modoc Rockshelter (6450-6250 BC; Illinois) (Fowler 1959; Styles 1983).

In the Near East, examples of plant textile impressions dated to preceramic layers are known, such as those in bitumen from Shanidar Cave (9850 BC; Iraq) and on pottery from Jericho (9700-8500 cal BC; Israel) (Castro 1990; Galili et al. 2018). Similar finds are reported from Tell Magzalijah (Iraq), Ali Kosh and Tepe Sabz (Iran), and Nahal Hemar (Israel) around 9100-8300 BC, and sites in Jordan such as Gilgal I and Beidha (Schick 1988, 2010). In the Neolithic, clay impressions of large woven mats at Çatalhöyük (7400-6000 BC; Turkey) should be mentioned (Wendrich and Ryan 2012), as well as the clay impressions at the Early Neolithic site of Shir (7050-6400 cal BC; Syria) (Nieuwehuyse et al. 2012). More recent examples include basketry impressions on bitumen, clay and pottery fragments from Tell Sabi Abyad (7000-5300 cal BC; Syria) (Berghuijs 2013), and fabric and woven basketry impressions from the site of Jarmo (7000-6000 cal BC; Iraq) (Adovasio 2018).

In Europe, as in the Middle East, Corded Ware pottery is known for its unique decoration, created by imprinting cords or ropes into soft clay. Such fragments have been recovered from Tell Labwé (6100-5640 BC) (Kirkbride 1969; Haïdar-Boustani et al. 2011; Ibáñez et al. 2012) and Tell Hmaira (6000-5000 BC) (Bartl 1998-1999; Müller-Neuhof 1998), both in Lebanon, as well as the Syrian sites of Tabbat al-Hamman (6000-4000 BC) (Braidwood 1940; Hole 1959) and Tell Nebi Mend (3400-3100 cal BC) (Copeland 1999). More recent finds include impressions of baskets on bitumen from the site of Hacinebi Tepe (3700-3300 BC; Turkey) (Hollander and Schwartz 2000). In Europe, there are no impressions that are chronologically consistent with materials from the Near East (Adovasio 2018). However, numerous impressions of mats on pottery sherds have been recovered from Late Neolithic sites in Hungary and the Balkans (Forbes 1964). Some examples are those found at the Sebeş-Valea Janului site (c. 4450-4300 BC; Romania) (Mazăre 2011) and the woven mat imprint on pottery from the Divostin site (4000-3500 BC; Serbia) (Adovasio and Maslowski 1988). This style is associated with the Kurgan cultures and was widespread during the Chalcolithic, extending from the Caucasus to the Volga, the Urals, Scandinavia and the Danube basin. In addition, remains of Neolithic corded ware pottery from the Battleaxe Culture dating from 2900-2350 BC have been documented in southern Sweden (Cooper 2009).

In this sense, it is argued that the development of pottery was closely linked to basketry, serving as a model for this craft. This relationship is evident in the fact that many forms originally made in softer materials such as fibre were later replicated in more durable materials (Alfaro 1989). The production of cord impressions is also confirmed in the eastern part of Iberia, where Late Neolithic to Early Chalcolithic pottery is richly decorated with ropes, braids and cords. These bell beaker vessels are relatively rare in the peninsula

(Garrido 2014), although notable examples have been found at Villa Filomena (3000-1800 BC; Alacant). Corded bell beaker pottery is characterised by the use of ropes and cords as horizontal decorative elements while the clay is still malleable. Iberian Neolithic sites such as Cova de la Pastora (Alacant) (Alfaro 1989) and the Campos site (Almería) have yielded pottery with basket impressions dating from the Late Neolithic to Early Chalcolithic (Papí 1992-1994). Similar impressions have been documented in clay from the Cova de les Cendres site (4550-4470 cal BC; Alicante) (Bernabeu Auban et al. 2019) and from Cova 120 (4340-4200 cal BC; Girona) (Agustí et al. 1986), and in pottery vessels from the Gavà Mines site (3822-3692 cal BC; Barcelona) (Calvo 2019).

The frequency of this type of evidence increases significantly during the Bronze Age. In northeastern Iberia, mat impressions on Bronze Age pottery have been found at the sites of Cova d'en Merla, Cova de La Guia, Cova El Garrofet, Cova de Vallmajor, (Rovira 2006) and Cova Fonda, all of them in Tarragona (Figure 32) (Romero-Brugués et al. 2022), Cova del Foric (Lleida), Cova de Can Paloma (Barcelona) and Camí dels Banys de la Mercè (Girona), among others (Rovira 2006). Also, in the central/southeastern part of the peninsula, as in the Mas de Menente and Cabezo Redondo sites (2429-2065 cal BC), and Las Angosturas (2350-1919 BC; Granada) (Cacho et al. 1996). These finds highlight the widespread use and regional adaptations in the production and decoration of pottery with plant materials throughout the Iberian Peninsula.

Figure 32. Examples of coiled basketry impressions on pottery fragments from the Bronze Age site of Cova Fonda (Tarragona) (Romero-Brugués et al. 2022).

2.6.1.2.4. Plant fibres mineralized in dental calculus matrix.

As noted above, organic materials are preserved under rare environmental conditions, such as prolonged waterlogging, aridity, or when materials have undergone carbonisation or mineralisation. The scarcity of direct evidence for fibre-based materials in the archaeological record limits our understanding of past craft practices, including variability in raw materials, technologies, functionalities and distribution. Filling this gap requires a careful search for evidence of plant fibre use in other non-perishable contexts, such as durable or mineralised materials, including dental plaque adhering to teeth. These studies have proven effective in extracting information in the absence of direct remains of fibre-based artefacts, such as baskets or textiles.

Dental calculus, the naturally mineralised form of bacterial plaque adhered to teeth, becomes calcified if not removed while still soft. It consists of an organic fraction (amino acids, peptides, carbohydrates and lipids) and an inorganic fraction consisting mainly of calcium phosphate salts (Lieverse 1999; Middleton 1994; Blatt et al. 2011). It is associated with saliva production, which prevents post-mortem inclusions. During its formation, it entraps a variety of particles, including starch granules, phytoliths, fungal spores, plant fibres, animal hairs and other lithological substances, such as pigments (Blondiaux and Charlier 2008; Power et al. 2018; Radini et al. 2019).

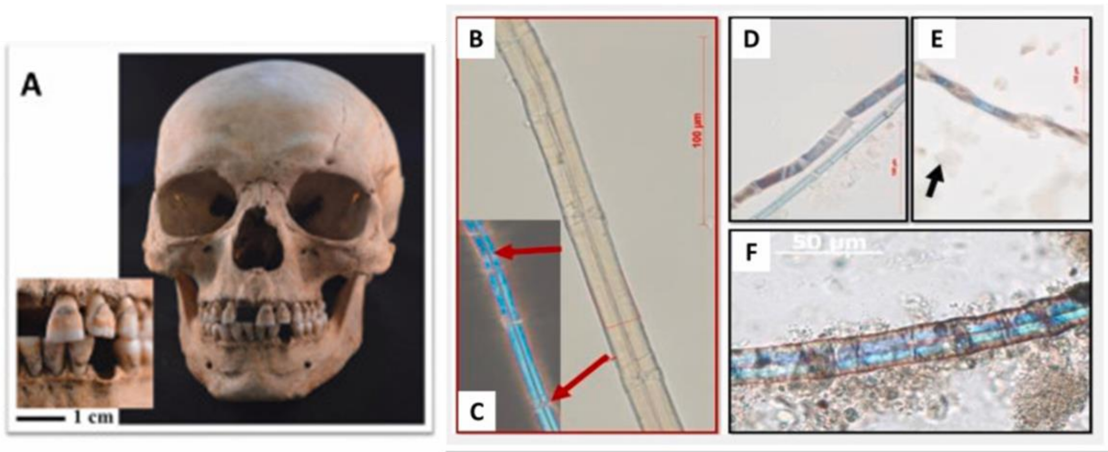

Figure 33. Flax fibres determination in dental calculus samples (Radini and Nikita 2023).

New insights into ancient dietary and subsistence patterns have been provided by the identification of microremains trapped in the calculus matrix, demonstrating the consumption of inhaled or ingested materials during daily activities or the use of teeth as tools for tasks beyond eating (Masaubach 2012; Mickleburgh and Pagán-Jiménez 2012; Buckley et al. 2014; Warinner et al. 2014, Fiorin 2015; Hardy et al. 2016; Radini 2016; Cristiani et al. 2018; Sperduti et al. 2018; Herrero-Otal et al. 2018; among others). Molecular analyses have furthered our understanding of dental calculus by examining proteins, isotopes, DNA and associated metabolites (Preus et al. 2011; Adler et al. 2013; De La Fuente et al. 2013; Warinner et al. 2014; Hendy et al. 2018; Wright et al. 2021). In addition, particles within the dental calculus matrix provide an opportunity to infer past human life through a combination of physical anthropology, biomolecular analysis and archaeobotany.

While traditional analysis of dental calculus microdebris has focused primarily on the presence of starch and phytoliths to explain dietary practices (Henry et al. 2011; Hardy et al. 2012, 2016a; Horrocks et al. 2014; Power et al. 2014, 2018; Tromp and Dudgeon 2015), plant fibres are also found. Remnants of bast fibres such as hemp (*Cannabis* sp.), flax (*Linum usitatissimum*), nettle (*Urtica dioica*) and cotton (*Gossypium* sp.) have been identified by various researchers (Figure 33) (Blatt et al. 2011; Warinner et al. 2014; Cristiani et al. 2016; Radini et al. 2016; MacKenzie 2021). The presence of plant fibres can result from craft activities such as textile and basket production (Blatt et al. 2011; Radini et al. 2017), working with building or repair materials (Norström et al. 2019), or even the use of pigments to decorate fibres (Radini et al. 2019). Although linking the presence of fibre debris on dental calculus to craft activities can only be established in conjunction with other anthropological parameters, such as dental wear, it is possible when there is a high concentration of debris and a sufficient number of individuals available for statistical analysis (Radini et al. 2019). This presence is justified by the use of teeth in extra-masticatory activities, as documented from both ethnographic and archaeological perspectives (Figure 34) (Schulz 1977; Milner and Larsen 1991; Bocquetin et al. 2005; Scott and Jolie 2008; Lozano et al. 2008, 2021).

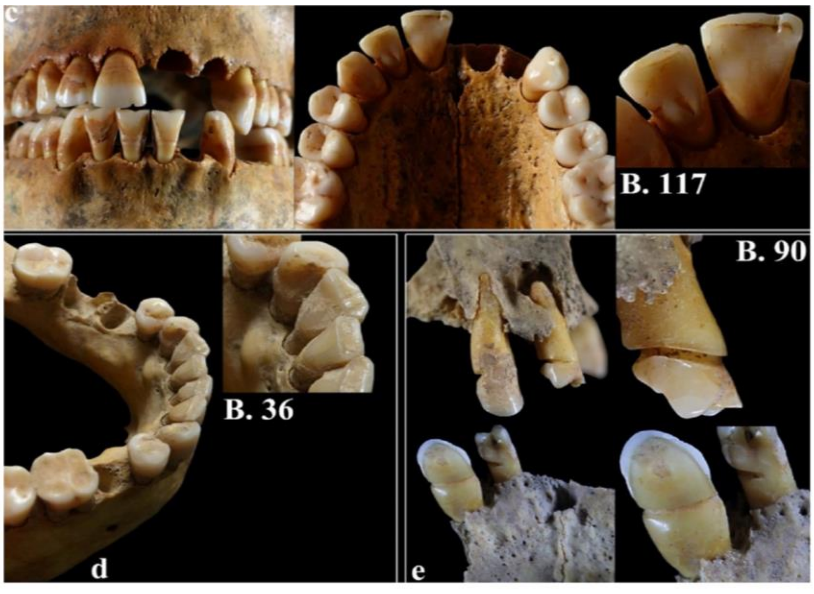

Figure 34. Extra-masticatory dental wears suggested to be produced by fibre processing activities (Lozano et al. 2021).

Dental calculus analyses can be highly informative for the study of plant-human relationships, although limitations in interpretation should be considered (Hardy et al.

2018). Discussions have arisen about how representative these results are, both qualitatively and quantitatively, of the role plants played in human activities and environmental descriptions (Hardy et al. 2018; Power et al. 2021; Radini and Nikita 2023). Methodological considerations also arise in relation to results from debris immersed in dental calculus deposits, as some chemical compounds typically used to disaggregate the matrix can damage organic remains such as plant debris (Tromp et al. 2017; Le Moyne and Crowther 2021). Ongoing research aims to refine the methods used to extract remains (Radini et al. 2017; Hardy et al. 2018; Power et al. 2021).

2.6.2. Archaeobotany research of vegetal fibres as raw materials: archaeological tradition and the current state of research in Europe and the Iberian Peninsula.

Analytical and descriptive studies of archaeological basketry vary considerably between regions, reflecting differences in archaeological practices and the emphasis placed on these materials in traditional research. For example, North America has a strong tradition of basketry research dating back to the late 19th century. Early studies often focused on ethnographic material (Holmes 1884; Nordenskjold 1994; Mindeleff 1896) as well as prehistoric examples (Mason 1885). This is because in North America traditional manufacturing techniques are still practiced by indigenous peoples and, together with anthropological documentation methods, this facilitates easier and more comprehensive knowledge. In contrast, countries lacking this traditional knowledge face challenges in archaeological research on textiles due to a scarcity of visible examples (Banck-Burgess 2023), as happens in Europe and the Iberian Peninsula. Throughout the 20th century, research continued to develop, although questions of systematisation and taxonomy remained controversial as mentioned above.

In Europe, weaving is often considered central to textile production and is believed to have played an important role in the Neolithisation process. Analyses of textile crafts typically emphasize weaving and the raw materials used, as highlighted by Siennicka et al. (2018). However, the significance of other textile forms, such as cordage, baskets, and nets, has not been as widely recognized as weaving, the cultivation of flax and the use of wool. In recent years, many researchers have shifted their focus to these types of textiles (Körber-Grohne and Feldtkeller 1998; Bazzanella et al. 2003; Medárd 2010; Rast-Eicher and Dietrich 2015), and significant research projects have concentrated on these materials, leading to European conferences and international publications. These studies consider the use of vegetal fibres within a broader context of environmental, cultural, economic, and social interactions. Despite this, some authors have noted that most research focused on loom-weaving with flax and sheep's wool, and neglected other materials and techniques (Desrosiers 2010; Rast-Eicher 2005). This focus aligns with the linguistic derivation of the term 'textile' explained above and it often excludes products like basketry and nets. In Central Europe, research on cordage, baskets and nets has increased in recent years as part of various projects aimed at broadening the range of raw materials, especially tree bast. Analyses of materials from sites around Lake Constance have resulted in numerous publications over the years (Banck-Burgess 2018; Böhm et al. 2023). Neolithic pile dwellings at sites such as Hornstaad-Hörnle, Sipplingen and Allensbach have yielded a wealth of textile artefacts (Körber-Grohne and Feldtkeller 1998; Bazzanella et al. 2003; Medárd 2012; Rast-Eicher and Dietrich 2015). The Hornstaad-Hörnle site alone, for example, has yielded more than 1,600 textile objects, demonstrating a wide range of manufacturing techniques and materials used for specific purposes like storage, food preparation, transport and clothing (Banck-Burgess 2018; 2023). Although many textile remains are degraded and discoloured, their properties and manufacturing techniques provide clues to their original functions. These properties include stiffness, suppleness, tear resistance and moisture regulation. Textiles were often multipurpose or reusable, such as ropes and cords, and their aesthetic qualities were also important. The research in this area has paid particular attention to the identification of raw materials: wood bast, especially from lime trees (*Tilia* sp.), received special attention as it was a primary raw material at wetland sites (Banck-Burgess 2018; Böhm et al. 2023).

Iberia does not enjoy a long tradition of analysing textile objects, although several studies were published some years ago. The works of Alfaro (1980, 1984) should be highlighted, as they published a monograph describing most of the textile remains (woven and non-woven) from the Iberian Peninsula from prehistory to the Roman period, including some of the materials analysed in this thesis, such as those from Cueva de los Murciélagos (Albuñol, Granada). Dyed decorations on these materials were also analysed in the 1990s by Cacho et al. (1996). Although it is known that some textile remains have been found in the Iberian Peninsula as they have been mentioned in old documents and publications, it was not until the second and third decades of the 21st century that specific analyses of both the technology and the raw materials used in textile production were published. Some examples are the analysis of both cordage and basketry objects from the Neolithic site of La Draga (Banyoles, Girona) (Piqué et al. 2018; Romero Brugués 2021; Romero Brugués et al. 2021b; Herrero-Otal 2023; Herrero-Otal et al. 2023), Coves del Fem (Ulldemolins, Tarragona) (Romero-Brugués et al. 2021a; Herrero-Otal et al. 2021), Cova des Pas (Romero-Brugués et al. 2018), Coves de Santa Maira and Cueva del Moro (Alcolea and Rodanés 2019), and Peñacalera (Gleba et al. 2021), among others. Some of these materials are analysed in this thesis, and therefore they will be described in greater detail below.

Textile research in the field of prehistoric textiles has advanced significantly in the last twenty years, with new research analyses of these materials (Rast-Eicher and Dietrich 2015; Siennicka et al. 2018; Desrosiers 2010; Alday 2021; Romero-Brugués 2021; among others). The wide range of structures and differences in raw material preparation illustrate the complexity of textiles in terms of manufacturing processes and functions, making systematisation almost impossible as each artisan has their own way of working. This diversity also indicates the multiplicity of manufacturing techniques and uses present even in early prehistory. Prehistoric European textiles are usually found as fragments, rarely revealing their original form, function, or precise manufacturing technique. However, years of research have shown that different types of products and techniques, made from rigid and flexible raw materials, were present in different regions and at different times. The fact that most studies of raw materials used in basketry production in the prehistory of the Iberian Peninsula were published 30 years ago attests the necessity of revising and carrying out new analysis to obtain more precise knowledge of this type of material. In this sense this thesis represents one of the first raw material studies of the oldest examples of prehistoric fibre-based objects.

Identifying archaeological fibres is a challenging task. Common diagnostic features between families and species make it difficult to distinguish between plants. In addition, metric analyses such as fibre diameter, lumen size, and characteristics of the plant epidermis in processed fibres are often modified or altered by technological processes, further complicating accurate identification and making them unreliable for fibre identification.

A detailed microscopic examination of plant tissues, including structural, vascular and epidermal tissues, was carried out on archaeological samples. This involved using a modern reference collection of unprocessed bast fibre plants and comparing these samples with archaeological specimens. By focusing on specific characteristics unique to certain plant families, such as parenchyma cell structure and stomatal configuration, the researchers were able to identify the fibres more accurately.

This method provided a more profound understanding of the materials used in ancient fibre-based production and offered new insights into early Iberian perishable technologies. As well as identifying the specific plants used in ancient textiles, the research has also increased our knowledge of early technological processes in fibre production. The ability to identify specific plant species provides a clearer picture of the technological capabilities and ecological knowledge of early human societies.

CHAPTER III - CHRONOLOGICAL AND BIOGEOGRAPHICAL FRAMEWORK

3. Chronological and biogeographical framework.

3.1. Palaeoenvironment and chronological framework.

3.1.1. Early and Middle Holocene: climate, vegetation history and human impact.

During the Holocene in Europe, a warmer and wetter climate favoured the expansion of deciduous broadleaf forests into regions previously dominated by pine forests and steppes. This expansion peaked around 7550-7050 cal BC in the Iberian Peninsula (Carrión et al. 2010, Pérez-Obiol et al. 2011, González-Sampériz et al. 2017; Roberts et al. 2018; Finné et al. 2019). Two significant climatic shifts marked crucial phases around 6250 cal BC and 2750 cal BC (Wanner et al. 2011). The first was marked by a global cooling event that separated the Early and Middle Holocene around 6250 cal BC. This event, documented in ice cores, cave speleothems and pollen records, is thought to have triggered societal changes such as migration or a shift from the hunter-gatherer model to agricultural practices and animal domestication, known as neolithization in the Mediterranean (Weninger et al. 2006, 2009; Berger and Guilaine 2009; Fernández-López de Pablo and Gómez-Puche 2009; González-Samperiz et al. 2009; Mercuri et al. 2011). The second shift occurred around 2750 cal BC, marking the boundary between the Middle and Late Holocene (Mayeswki et al. 2004; Staubwasser and Weiss 2006; Wanner et al. 2011; Renssen et al. 2012; Walker et al. 2012; Innes et al. 2014). However, other researchers suggests that this shift occurred around 750/550 cal BC (Roberts et al. 2011; Wanner et al. 2011). This period is characterised by aridity in the Mediterranean region, which may have influenced migrations and cultural changes during the Chalcolithic to Early Bronze Age in the Iberian Peninsula (Lilliois et al. 2016).

Despite the overall stability of the Holocene climate, it has experienced oscillations of cooling and drying. In addition, two significant cold and dry episodes occurred during the Middle Holocene, one in the late 6th millennium cal BC and the other in the 4th millennium cal BC, which have influenced current climate patterns. This period, the Mid Holocene, has been the subject of debate regarding environmental change, causation, and anthropogenic influences, making it a compelling period for the study of human-environment interactions and ecological causation (Bond et al. 2001).

These climatic events had a significant impact on the vegetation, with the expansion of deciduous forests into regions that were previously dominated by pine forests and steppes, with *Quercus* sp. and *Corylus* sp. dominating as shown by palynological analyses (Jalut et al. 2009; Carrión et al. 2010; Pérez-Obiol et al. 2011). The expansion of mesophilous forests reached its peak during the establishment of drier conditions in the

Middle Holocene. This period, also known as the Holocene Climate Optimum, was detected in the Mediterranean during the transition to the Late Holocene (3050-2050 cal BC), coinciding with the expansion of sclerophyllous forests (Sadori and Narcisi 2001; Jalut et al. 2009; Carrión et al. 2010; Pérez-Obiol et al. 2011; Roberts et al. 2011). However, this change was not uniform across the region, as resilient broadleaf forests persisted on the northern coasts of the central Mediterranean until the Late Holocene (Sadori et al. 2011).

This environmental transition played a key role in the introduction of a wide range of new raw materials, which were rapidly integrated into the economic system for the production of various goods, as evidenced by archaeobotanical studies. It is therefore crucial to consider human activities in order to fully understand the environmental changes that have occurred since the Middle Holocene, particularly when human groups began domesticating plants and animals. Researchers consider the introduction of these new agricultural activities to mark the beginning of the Anthropocene (Ruddiman 2003; Ruddiman et al. 2015). Following this, significant vegetation changes were observed due to the escalation of deforestation activities (Riera and Esteban-Amat 1994; Sadori and Narcisi 2001; Yll et al. 2003; Drescher-Schneider et al. 2007; Colombaroli et al. 2008; Kouli and Dermitzakis 2008; Vannière et al. 2008; Vescovi et al. 2010; Marinova et al. 2012; Revelles et al. 2014, 2015, 2018), as well as an increase in fire occurrence (Vannière et al. 2008; Carcaillet et al. 2009; Tinner et al. 2009), accelerated soil erosion rates (Dearing 1994; Dotterweich 2008; Dusar et al. 2011; Simonneau et al. 2013; Notebaert and Berger 2014) and processes leading to water eutrophication (Hillbrand et al. 2014).

Through the first half of the Holocene, Europe underwent significant socio-economic transformations characterised by such innovations in food production and consumption as plant and animal domestication, but also resource management, social structure, land use and settlement patterns (Bailey and Spikins 2008; García-Puchol and Salazar García 2017). These changes in subsistence strategies led to the development of new technologies for food procurement and processing, in particular the adoption of agriculture (Bogaard 2004, 2005) and early animal domestication during the Middle Holocene. These novel subsistence practices also led to the development of innovative tools and techniques for the use of plant raw materials (Ibáñez-Estévez et al. 2008; Palomo et al. 2011; Terradas et al. 2017; López-Bultó et al. 2020). The significance of plant resources is highlighted by the creation of specialized tools designed for working with them, from their harvesting to their processing, especially within agrarian societies (Palomo et al. 2013). Such tools greatly enhanced the ability of these societies to modify the environment.

The Mid-Holocene period (6250-2750 cal BC) corresponds to Late Prehistory in the western Mediterranean, from the last hunter-gatherer societies (Late Mesolithic) to the development of Bronze Age societies. This period represents the climatic and environmental framework of the Neolithization process, which is a significant historical period that will be developed further in the thesis. In this context, the materials studied in this PhD dissertation will assess human-environmental interaction during the Middle Holocene in the Western Mediterranean, more specifically the Mediterranean side of Iberia, in order to comprehend the use on very specific raw materials by the last hunter-gatherer communities and the first farming groups.

3.1.2. Chronocultural periods, territory settlement and human groups.

3.1.2.1. Mesolithic: the last hunter-gatherer communities.

The Mesolithic period corresponds to a short period of time that represented the transition between the Palaeolithic and the Neolithic and occurred ca. 8250-5650 cal BC. This is a significant moment in history due to the new ways of life human groups had to adapt to because of the new environment caused by climatic, environmental, demographic, and technological changes (Cucart-Mora et al. 2022). As mentioned above, warmer and wetter climate conditions stabilised across the territory between colder oscillations: the most singular one in 6250 cal BC, at the beginning of the Middle Holocene.

Human communities in the Mesolithic period are commonly known as 'the last hunter-gatherer groups'. Interaction between groups resulted in a social network together with the resources mobilized to sustain them, and their spatial extent characterized these communities (Wobst 1974; Gamble 1998; Whallon 2006). Social exchanges were introduced into the daily lives of all hunter-gatherer groups, shaping the material culture evident in the archaeological record (Coward 2010). In this sense and in the context of Europe, two formal profound analyses of their social networks have been performed (Riede 2014; Gravel-Miguel 2016). There was a notable shift in subsistence strategies in the Mesolithic, marked by increased diversification in hunted species and heightened exploitation of marine resources (Aura-Tortosa et al. 2009; Alday and Soto 2017). From a demographic standpoint, a logistic model of population growth indicates a general rise in population levels (Fernández-López de Pablo et al. 2019). Although subregional patterns exist, as in the Atlantic region of central and southern Portugal (McLaughlin et al. 2021), in the northeast of Iberia, there is a gap in the archaeological record of Holocene hunter-gatherer groups (Morales and Oms 2012; Piqué et al. 2019), especially in their later stages, and the social networks discussion has not acquired the same relevance as in other territories.

In terms of cultural entities, the Mesolithic in the Iberian Peninsula is usually divided into two main phases. The first phase, from approximately 8250 to 6650 cal BC, is known as the Early Mesolithic or Notches and Denticulates Mesolithic. This period is characterised by rapid flake production techniques, resulting in tool assemblages consisting mainly of notches, denticulates, scrapers and macrolithic tools (Alday 2006). The second phase is dated ca. 6650-5650 cal BC, and it is known as the Late Mesolithic or the Geometric Mesolithic. During this period there is a notable transition in debitage methods towards the production of blades, bladelets and geometric microlithic projectiles, particularly trapezes and triangles, using the microburin technique (Utrilla and Montes 2009).

Mesolithic settlements in the Iberian Peninsula are predominantly found along coastal areas as also occurs in other European regions. The most singular Mesolithic evidence in the Iberian Peninsula is located in central and southern Portugal, the northern Cantabrian region, the Pyrenees, the Ebro valley and specific sites on the Mediterranean coast (Juan and Martí 2002). The archaeological record for the first half of the Holocene remains notably scarce, often leading to interpretations of minimal human activity. However, it remains uncertain whether this distribution reflects a real absence of hunter-gatherer activity, or it comes from biases in research methods (Morales et al. 2010; Zilhão 2010).

3.1.2.2. Early Neolithic: the domestication of plants and animals.

Socioeconomic changes occur during the appearance of the Early Neolithic, which labels this period as the Neolithization process. Innovations in food consumption and production (both animals and plants), resource management, and the social and settlement organization pattern took place. The adoption of farming practices implied a new way of interaction with the environment, which induced a transformation of the landscape resulting in its anthropisation. A wide range of causal explanations has been proposed regarding climate change (Childe 1952; Richerson et al. 2001; Weninger et al. 2006; Berger and Guilanie 2009; Gronenborn 2009), demography and social reproduction (Cohen 1981; Testart 1982; Bocquet-Appel 2002), disequilibrium between population and resource capacity (Binford 1968; Renfrew 1973), and the appearance of new ideologies (Thomas 1988; Cauvin 1994, 2000), among others. Thus, the Neolithic consisted of the appearance of new organizational strategies based on the appropriation of the reproductive cycle of some plants and animals. There was a shift from hunting and gathering to farming practises which implied a change in the way in which culture and environment interacted (Wright 1971), although those old practises were not abandoned. When referring to transformations from the hunter-gatherer to the farming mode of production, attention must be paid not only to changes in production but also to the social relationships that determined them. The domestication of both animals and plants allowed accessibility to different resources artificially without considering their natural circles. This implied an increase in knowledge of the environment and the resources it offers, but also in the task this new way of live involved (Castro et al. 2005).

The appearance of this new model of social organization established the foundations on which present societies are based on as regards food production and storage, sedentism, labour specialization, and social complexity, among others (Banks et al. 2013). These changes also implied transformations to the landscape that, together with climatic Holocene oscillations, significantly modified the natural geosystem. In this sense, palaeoecological research during the Early and Middle Holocene is important to understand the consequences to the environment during this moment of change called Neolithization, that has been discussed in terms of human alteration of ecosystems (Ruddiman 2003, 2013; Ruddiman et al. 2015) and of human niche-constructing behaviour, modifying ecosystems through the domestication of resources, both plants and animal (Smith and Zeder 2014).

It has been assumed that the Neolithization process started in south-eastern Europe in the 7th millennium cal BC and reached the rest of the continent at the beginning of the 4th millennium cal BC (O'Connell and Molloy 2001; Kouli and Dermitzakis 2008; Marinova et al. 2012; Woodbridge et al. 2012). The first Neolithic groups arrived in the Iberian Peninsula ca. 5700-5650 cal BC and extended farming activities to the Mediterranean area (Bernabeu and Fumanal 2009; Bernabeu et al. 2015). In the northeast of Iberia the first evidence of farming is dated in 5650 cal BC (Antolin and Saña 2022).

The process of Neolithization brought about transformations that significantly intensified the alterations to the palaeoecological record, as these new economic strategies would imply the adoption of new activities that influenced landscape transformation. In the Iberian Peninsula, the Early Neolithic witnessed a rich diversity of crops, indicating a rapid adoption of important agricultural knowledge by peasant communities. However, the evidence indicates that this diversity decreased during the Middle and Late Neolithic periods (Antolín 2013; Pérez-Jordà and Peña-Chocarro 2013; Antolín et al. 2015). Archaeological evidence for the earliest agricultural activities extends across the entire Iberian Peninsula, from the second half of the 6th millennium BC to the 5th millennium BC. This evidence spans different regions, including the northwest (Ramil-Rego et al. 1994; Ramil-Rego and Aira 1996), the northern areas (Peñalba 1994; López-Sáez and López-Merino 2007; Iriarte 2009; López-Merino 2009;), central areas (López-Sáez 2002; López-Sáez et al. 2005; Aranbarri et al. 2015), the Ebro valley (González-Sampériz 2004; López-Sáez et al. 2005; López-Sáez et al. 2006;), the eastern regions (Dupré et al. 1996; Carrión and van Geel 1999; Yll et al. 2003), the southwestern areas (van der Knaap and van

Leeuwen 1995; López-Sáez et al. 2007) and the southern part of Iberia (Carrión et al. 2007; Fernández et al. 2007; Cortés et al. 2008).

3.1.2.3. Middle Neolithic: the consolidation of agropastoral practices.

During the Middle Neolithic, changes are still evident, and the archaeological record of this phase is characterised by the flourishing of funerary practices, with most studies focusing on burial sites. This is due to the abundance of funerary contexts and the scarcity of domestic sites. More than 650 funerary structures have been recorded in the northeastern part of Iberia (Morell 2019), leading to the designation of this period as corresponding to the Pit Burial culture or 'Sepulcres de fossa' (CAT) (Martín et al. 1996, 2010; Martín 1998; Gibaja 2003, 2004; Gibaja et al. 2010; Roig et al. 2010; Gibaja and Clop 2012; Bravo et al. 2015). In this area, burials typically took place in pits, both in the lowlands and in the valleys, although caves and rock-shelters were also used, although less frequently. Two main types of burials are documented in this chronocultural period: those dug into the ground and those enclosed in structures made of stone slabs, and their distribution has been explained by economic reasons (Fontanals 2015; Fontanals et al. 2017).

With regard to domestic sites, which are sparsely documented, caves and rock-shelters were largely abandoned in the northeast as valleys and plains became the preferred sites for habitation. This shift was associated with the deliberate selection of fertile soils, which is also related to agropastoral activities (Ribé 1996). Agropastoralism was still practised, and although habitation sites are rare, some are known and show evidence of combustion and storage structures, as well as hearths (Oms et al. 2016). The information for this chronology is mainly documented through the discovery of negative structures such as ditches, silos and graves (Terradas et al. 2016). In addition, the number of domesticated plant and animal species increased during this period, as agriculture became the main economic activity (Antolín et al. 2018).

In southern Iberia, this period corresponds to a social crisis that included ecological, demographic and epidemiological events, resulting in a significant absence of radiocarbon dating. There was also a significant cultural change that led to the appearance of megalithic monuments, which served as an expression of social identification with the territory (Aranda et al. 2017). In addition, this period saw the emergence of large settlements, largely characterised by moat enclosures and excavated structures, which became the main archaeological reference for those communities (Márquez-Romero and Jiménez-Jáimez 2010).

3.2. Biogeographical framework.

Two European biogeographical regions are well-documented in the territory of the Iberian Peninsula: the Eurosiberian and the Mediterranean regions. These represent distinct areas with unique climatic, floristic, and landscape characteristics. Within these regions, diverse plant species develop and share similarities in origin, ecological requirements, and distribution areas resulting in different vegetation profiles (Costa et al. 1997). However, the extension of those two biogeographical varies considerably: the west and north of the Iberian Peninsula correspond to the Eurosiberian region, while the rest of the territory belongs to the Mediterranean region. The current research has been carried out in this Mediterranean area (Figure 35).

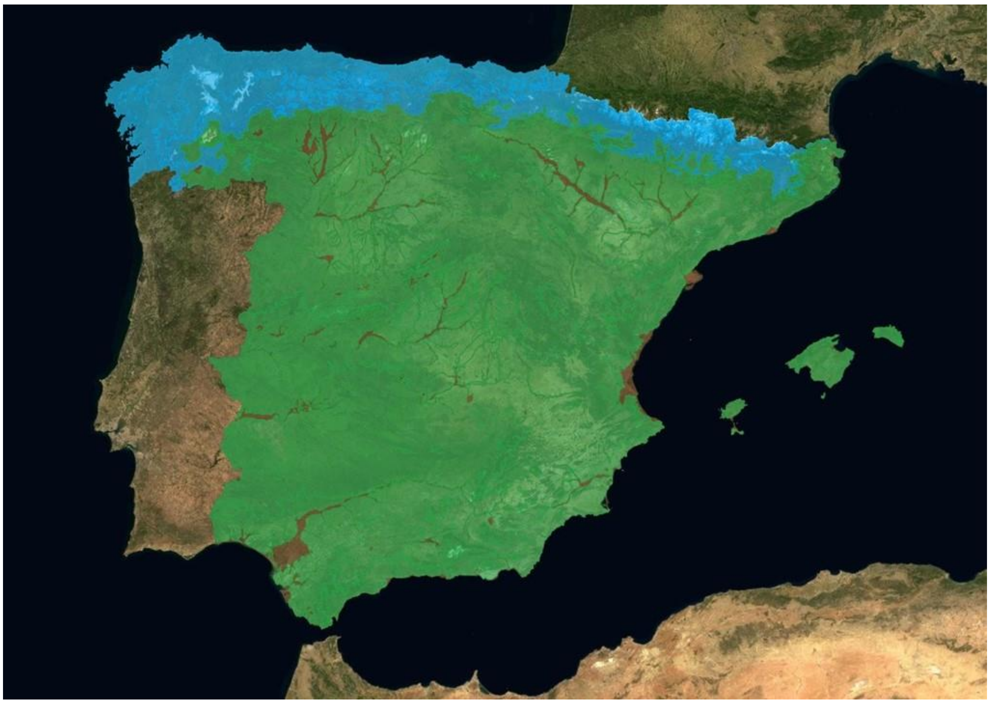

Figure 35. Main biogeographical regions from the Iberian Peninsula: Eurosiberian region (blue), Mediterranean region (green). Modified from ©Meteosierra.

The water regime is the main factor shaping landscapes in warm and/or temperate latitudes. The Mediterranean climate is characterized by a prolonged period of drought in summer, but it also presents variability in precipitation and temperature. The composition of the vegetation is directly affected by the annual precipitation, and it defines different ombrotrophic climate layers (Rivas Martínez 1987). In addition, different bioclimatic zones are distinguished based on several thermoclimatic parameters apart from precipitation, such as: mean annual temperature, mean minimum of the coldest month, mean maximum of the coldest month, mean temperature of the coldest month, thermality index, number of months with potential frosts (Rivas Martínez 1987; Fernández González 1997; Alcaraz et al. 1999; Rivas Martínez et al. 2004). Vegetation is structured within a biogeographical framework, delineated by bioclimatic zones that vary both altitudinally and latitudinally. The typologies commonly employed for the Iberian Peninsula have been defined by Ozenda (1975) and Rivas Martínez (1982, 1987) and Rivas Martínez et al. (2004) and are the Thermomediterranean, Mesomediterranean, Supramediterranean and Oromediterranean (Table 5; Figure 36).

Table 5. Summary of the Mediterranean bioclimatic characteristics in the Iberian Peninsula.

Bioclimatic typology	Altitude (m.a.s.l.)	Annual rainfall (mm)	Annual temperature (ºC)	Vegetation
Thermomediterranean	< 400	200-1,600	17-19	Scrublands of macchia and garrigue. Sclerophyllous forest: *Ceratonia siliqua*, *Olea europea* var. *sylvestris* and *Chamaerops humilis.*
Mesomediterranean	700	300-700	13-17	*Quercus ilex, Quercus coccifera, Quercus suber, Pinus halepensis, Pinus pinea*, and *Pinus pinaster.*
Supramediterranean	900	350-1,600	8-13	Decidous *Quercus, Quercus pubescens, Pinus nigra* subsp. *salzmannii*
Oromediterranean	> 1600	400-700	< 16	*Pinus sylvestris* and *Pinus uncinate, Juniperus thurifera, Fagus sylvatica, Abies alba.*

The Thermomediterranean region is represented in coastal regions below 400 m.a.s.l. Annual temperature range is 17-19ºC and rainfall varies significantly from humid to semi-arid climates (200-1,600 mm). Thermomediterranean vegetation consists of scrublands of macchia or garrigue and sclerophyllous forests. It is characterized by plant species such as *Ceratonia siliqua*, *Olea europea* var. *sylvestris* and *Chamaerops humilis* (Ozenda 1975). The climate and soil diversity in this area contribute to its suitability for various land uses as agriculture (Bernabeu et al. 1993). The Mesomediterranean region is the dominant bioclimatic zone across Iberia. The region experiences an average annual temperature ranging from 13 to 17°C, with cold winters, and an annual precipititation of 300-700 mm. The vegetation in this area is characterized by the presence of holm oak (*Quercus ilex*), which is the most prominent plant species. In semi-arid regions, kermes oak (*Quercus coccifera*) replaces holm oak, while cork oak (*Quercus suber*) grows on siliceous substrates. In the northern Mediterranean region, forests can extend up to 600-700 m.a.s.l. The forests mainly comprise of different species of pine (*Pinus halepensis*, *Pinus pinea*, and *Pinus pinaster*). Although some of these species also occur at the Thermomediterranean level, the most characteristic species of this level cannot withstand the winter frosts typical of the Mesomediterranean (Ozenda 1975). The bioclimatic zone has significant potential for agricultural and livestock purposes: the valleys offer favourable conditions for cultivating cereals, vineyards, olives, and almond trees, while the vegetation also provides pastures suitable for sheep, goats, and pigs (Bernabeu et al. 1993). The Supramediterranean region covers part of the northern sub-plateau and mid-mountains of the Mediterranean area. The average annual temperature is 8-13ºC, with long and harsh winters. Precipitation patterns vary significantly, from dry to hyper-humid, with rainfall ranging between 350-1,600 mm normally at altitudes around 700 m.a.s.l. The vegetation is predominantly oak, both deciduous and pubescent. At higher elevations, pine (*Pinus nigra* subsp. *salzmannii*) is often found. The region is generally unsuitable for agriculture due to the severe winters, which limits the range of vegetal species. However, the vegetation provides excellent pastures during the summer (Bernabeu et al. 1993). This bioclimatic zone is mainly located in the Ebro Valley, covering mid-mountain regions in the Pyrenees and the Iberian System. Finally, the Oromediterranean region occurs above an altitude of 1,600 m.a.s.l. It is similar to the formations found in the mountains of the Eurosiberian region. The vegetation in this area is dominated by conifers, including different species of pine (*Pinus sylvestris* and *Pinus uncinata*), and juniper (*Juniperus thurifera*). Beech (*Fagus sylvatica*) and fir (*Abies alba*) are more prevalent in humid regions. In the alpine zone, the tree layer disappears, and only grasslands and thorny species thrive. These areas are associated with certain livestock activities such as transhumance.

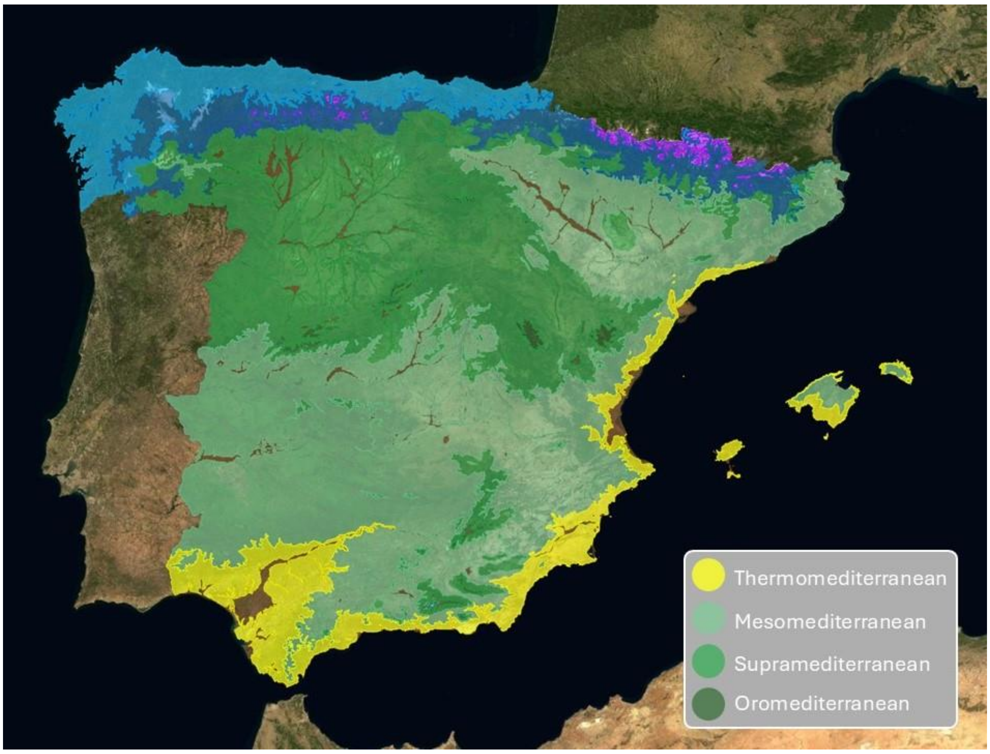

Figure 36. Vegetation structure within a biogeographical framework in the Iberian Peninsula. Modified from ©Meteosierra.

3.2.1. South-East Iberian Peninsula.

3.2.1.1. Cordillera Penibética and La Alpujarra complex (Granada, Andalucía).

3.2.1.1.1. Geography.

Part of the material analysed in this thesis comes from the archaeological site of Cueva de los Murciélagos, located at 450 m.a.s.l on the southeastern Mediterranean coast of the Iberian Peninsula. It is located near the village of Albuñol in Granada although it borders the province of Almería, both in the autonomous community of Andalucía. Geographically it is located in the Cordillera Penibética range which is the southern part of the Cordillera Bética mountain range and runs from Cádiz (Andalucía) in the west to Alacant (Comunitat Valenciana) in the east along more than 500 km. It has a parallel range on the Mediterranean coast (Figure 37). The northern part of the Cordillera Penibética range consists of the Sierra de Lújar, Sierra de La Contraviesa and Sierra de Gádor ranges which compose to the La Alpujarra region.

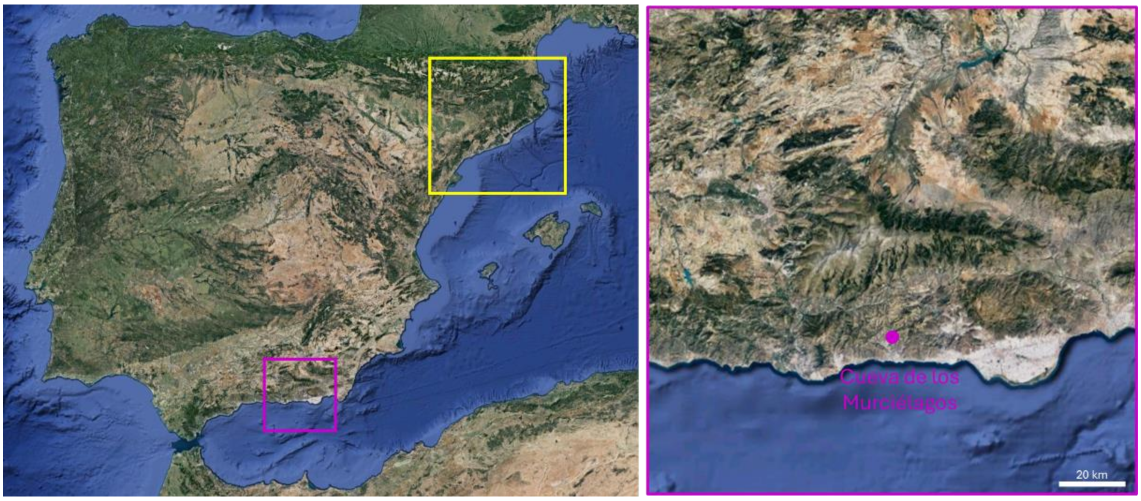

Figure 37. Study area covering the Cueva de los Murciélagos Site in the South-East of the Iberian Peninsula. Modified from ©GoogleMaps.

3.2.1.1.2. Climate.

The climate in the south-eastern region of the Iberian Peninsula is a mixture of different climate types, including Mediterranean, mountain and semi-arid climates. Specifically, the climate profile of the study area in southeastern Iberia is characterised by a combination of Mediterranean and semi-arid climates. This mixture leads to a moderation of extreme continental temperatures due to the influence of the sea. Winters are warm without frost and summers are temperate, with average temperatures not exceeding 30ºC. The climatic conditions in the area have an irregular distribution pattern. Average temperatures are fairly uniform along the entire coast, ranging from 17.2 to 18.4ºC annually, rainfall shows a marked gradient from east to west. Rainfall varies considerably, ranging from 217.5 mm to 474.6 mm, with winter being the wettest season.

3.2.1.1.3. Vegetation.

The vegetation along the southeastern coast of Iberia is influenced by the mountainous terrain in a narrow strip parallel to the coast, reaching up to 500 m. As a result, the ombrotype vegetation varies from semi-arid in the eastern coastal range to dry ombrotype in the western part. However, along the coastline, at altitudes of 200-300 m.a.s.l and with topographic exposures that capture atmospheric moisture, the ombrotype can locally shift from semi-arid to dry. The coastal vegetation primarily falls within the Thermomediterranean bioclimatic zone, transitioning to supra-Mediterranean beyond 300 m.a.s.l. (Rivas Martínez et al. 2004).

Wild woodland formations are rare in the Thermomediterranean region of southeastern Iberia. In the eastern sector, where semi-arid ombrotype and rocky soils are prevalent, the growth of forest tree vegetation is not possible. Instead, the vegetation is predominantly represented by dense shrubs. Holm oak (*Quercus rotundifolia*) and cork oak (*Quercus suber*) are not present in the Thermomediterranean zone on the coast. These kinds of forest masses are present in the Supramediterranean zone in areas like the Sierra de Lújar and the Sierra de La Contraviesa ranges. In the Thermomediterranean zone, remnants of holm oak appear as isolated specimens or small groups in ravine bottoms and shady areas. They are typically found between 200-300 m.a.s.l. in the tributary ravines of the Verde and Guadalfeo rivers. In the eastern sector, holm oaks are found at higher altitudes, usually above 400 m. Pine forests, mainly composed of *Pinus halepensis*, are the primary forest stands on the coast. These forests often result from reforestation efforts or spontaneous regrowth in abandoned agricultural lands. The forests can range from dense formations with sparse undergrowth to clearings accompanied by characteristic thermophilic shrubs such as *Pistacia lentiscus, Osyris quadripartita, Salvia rosmarinus*, and *Ulex parviflorus*.

The coast of Granada is dominated by mastic trees, specifically *Pistacia lentiscus*, which is the most abundant shrub in the area. Under favourable conditions, they can form dense stands, alongside other evergreen species such as kermes oak (*Quercus coccifera*), wild olive (*Olea europaea* var. *sylvestris*), buckthorn (*Rhamnus alaternus*), bayon (*Osyris quadripartita*), and black hawthorn (*Rhamnus oleoides*). Thermophilic shrubs dominate the plant formations on the coast, indicating the alteration and degradation of the natural environment due to repeated clearing, felling, and fires. These periodic disturbances, occurring in conditions of poor soils and dry-semiarid ombrotrophic climates, make it difficult for more stable and mature tree and shrub formations to recover. As a result, scrubland can persist as permanent vegetation.

Scrublands are formations dominated by shrubs that can reach heights of 2-2.5 m in optimal conditions. They correspond to different formations that usually occur in open areas, where five main types of coastal scrub can be identified, depending on the dominant species, such as *Salvia rosmarinus*, *Cistus* sp., *Thymus* sp., *Genista* sp., *Anthyllis* sp. and nitrophilous shrubs (Del Río Sánchez 2023). A characteristic species found in the scrublands on the southeastern coast of the Iberian Peninsula is the dwarf palm (*Chamaerops humilis*), which appears isolated with other scrublands and is the only native palm on the Iberian Peninsula coastline. Scrubland is also common on the south-eastern coast of Iberia and corresponds to a medium type of vegetation, dominated by retamoid species that can form dense formations. There are two main varieties, one dominated by *Genista spartioides* in dry environments and the other by *Cytisus malacitanus* in cooler, more humid environments. The first is the most common, colonising large areas of rocky soil on slopes and ravines, although it can also be accompanied by typical scrub species such as *Rosmarinum officinalis*, *Cistus clusii*, *Satureja ovata*, among others.

Grassland herbaceous formations also predominate in the area. This group defines plant formations with non-woody herbaceous stems, generally dominated by grass species that often colonise bare soils. The first notable formation is characterised by *Stipa tenacissima* (esparto grass), a plant with large tufts that is well adapted to summer droughts and disturbances caused by fires. It prefers dry and deep soils, but also occurs on rocky soils, both acid and alkaline. *Hyparrhenia hirta* also develops on similar soils. Herbaceous formations take the form of numerous small formations with a spring optimum, in a mosaic with shrubs and bushes, formed mainly by annual species or those that lose their aerial part in summer, such as *Glebionis coronaria*, *Ophrys papilionacea* and *Ophrys lutea*, among others (Del Río Sánchez 2023).

3.2.2. North-East Iberian Peninsula.

3.2.2.1. El Priorat (Tarragona, Catalunya).

3.2.2.1.1. Geography.

The archaeological site of Coves del Fem is located in the Montsant mountain range, at an altitude of 530 metres, in the El Priorat region of Tarragona (Catalunya). It is in the lower part of a northern slope, surrounded by peaks reaching 1,000 m.a.s.l. less than 2 km away.

It includes the basin of the river Siurana, between the prelitoral mountain range, opened to the west (Figure 38).

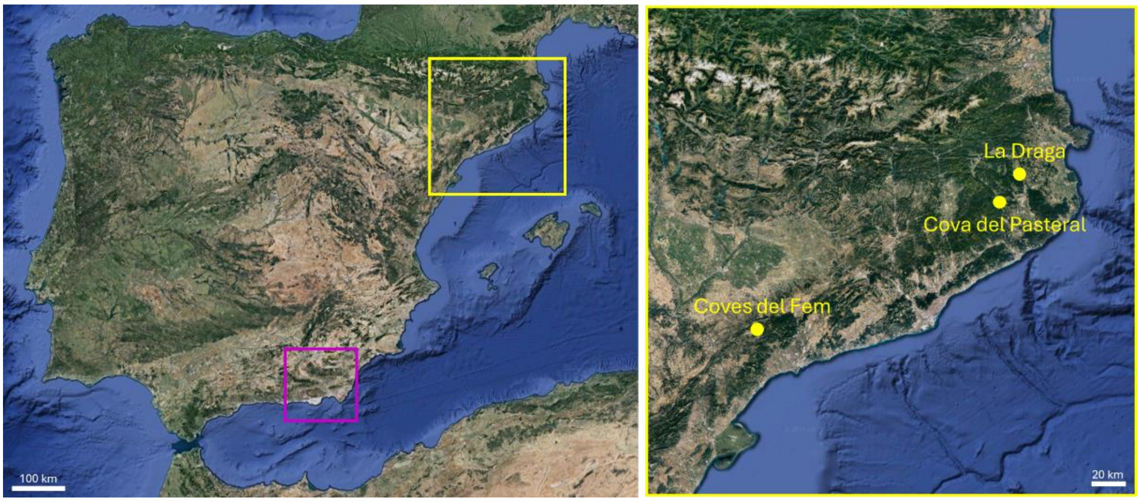

Figure 38. Study area covering the Cova del Fem, La Draga and Cova del Pasteral sites in the North-East of the Iberian Peninsula. Modified from ©GoogleMaps.

The Monstant is the most prominent mountain in the area, with a peak of 1166 m. On the opposite side, the Colldejou (914 m) and Llaberia (912 m) mountains, together with the Puigcerver (922 m) and Argentera (799 m) ranges, define the Baix Camp region. The Prades (1,201 m) and Serra la Llena (1,023 m) mountains mark the border between the Baix Camp, the Conca de Barberà and the Garrigues regions. The River Montsant and its tributary, the Siurana River, which has its source in the Prades mountains, converge after encircling the base of Montsant. After collecting the Guiamets stream, the Siurana flows into the Ebro River.

3.2.2.1.2. Climate

The climate of the Priorat is Mediterranean. 30 km from the coast, it has a continental Mediterranean climate, with mean annual temperature of 12.8ºC (maximum 21.6ºC in July, minimum 4.8ºC in January) and annual precipitation of 622 mm. Despite the arrival of sea breezes, the presence of parallel mountain ranges and ridges along the coast prevents the penetration of humid, temperate sea air. This topography results in very cold winter nights.

Average annual temperatures hover around 15°C in the lower areas, dropping to 12°C on the higher slopes of the Montsant and Prades Mountain ranges. Winters are particularly cold in the northern part of the district, with monthly averages falling below 5ºC in January. Summers are warm, with average temperatures of 22-24ºC in July.

Annual rainfall is around 560 mm, rising to over 600 mm in the mountainous areas. Rainfall follows a bimodal pattern, peaking in November, while snowfall is rare. The region is open to the influences of the Ebro valley, whose climatic effects are moderated by the surrounding high mountains and those of the southern and eastern Mediterranean.

3.2.2.1.3. Vegetation.

The vegetation in the Montsant area is composed of Mesomediterranean vegetation with Eurosiberian mountain influences (Alcolea Gracia 2017). The potential vegetation is dominated by evergreen oak (*Quercetum ilicis galloprovinciale* and *Quercetum rotundifoliae*) and deciduous oak (*Quercetum faginae*) in humid areas and at higher altitudes. Oak woods have dense layers of *Quercus ilex* with undergrowth of *Viburnum tinus*, *Rhamnus alaternus*, *Phillyrea latifolia*, *Ruscus aculeatus*, *Asparagus acutifolius*, *Lonicera implexa* and *Clematis flammula*. In degraded areas there are scrublands dominated by *Arbutus unedo* and *Pistacia lentiscus*. *Pinus sylvestris* and *Pinus nigra* subsp. *salzmannii* can be found at higher altitudes, and *Pinus halepensis* at lower altitudes.

Scrubland and shrubland cover the entire area, replacing the former holm oak and kermes oak forests. Fires, abandonment and exploitation are the main causes of the loss and degradation of the original forest vegetation. The calcareous scrub of rosemary and winter heath is one of the typical shrub formations of the Mediterranean landscape. Rosemary (*Rosmarinus officinalis*), thyme (*Thymus vulgaris*) and lavender (*Lavandula latifolia*), winter heather (*Erica multiflora*), white rockrose (*Cistus albidus*), globe daisy (*Globularia alypum*) and spurge flax (*Thymelaea tinctoria*) are present. Higher up, garrigue can be found, which is considered to be the most advanced stage of recovery of the holm oak forest. This dense and thorny scrub is made up mainly of kermes oak (*Quercus coccifera*) and lentisk (*Pistacia lentiscus*), accompanied by other species typical of coastal holm-oak woods, such as spurge laurel (*Daphne gnidium*) and wild madder (*Rubia peregrina*).

The Montsant River is lined by riparian forests of Populus alba, Populus nigra, *Fraxinus angustifoli*a and various *Salix* sp. (*S. alba*, *S. atrocinerea*, *S. elaeagnos*, *S. purpurea*, *S. fragilis*), which occupy areas that are rarely flooded. Willows (*Salix* sp.) cover an undergrowth of low shrubs and herbs such as brambles (*Rubus fructicosus*), hops (*Humulus* sp.) or wild mint (*Mentha* sp.). The reed beds are formed by species that take root in flooded and shallow banks, such as reed (*Phragmites australis*), cattail (*Typha* sp.) or rushes (different Cyperaceae such as *Scirpus holoschoenus* and *Schoenus nigricans,*, or Juncaceae like *Juncus effuse* and others).

3.2.2.2. Pla de l'Estany and La Selva (Girona, Catalunya).

3.2.2.2.1. Geography.

The archaeological site of La Draga is located on the Estany de Banyoles lakeshore in the city of Banyoles and in the region of Pla de l'Estany in Girona (Catalunya) (Figure 38). This region consists of a plain around the lake at 173 m.a.s.l , 35 km from the Mediterranean Sea and 50 km south of the Pyrenees and it is surrounded by medium-height mountains around 600-1,000 m.a.s.l approximately. It is also located between the Ter and Fluvià rivers. It presents different areas with lacustrine water sources, some intermittent and linked to rainy seasons like the Clot de l'Espolla. However, the most important one is the permanent Estany de Banyoles which has an oval shape; it covers approximately 105 ha with a depth of about 46 m.

The Cova del Pasteral archaeological site is located in El Pasteral, an urban area that corresponds to the town of La Cellera de Ter, in the region of La Selva (Girona) at nearly 170 m.a.s.l. (Figure 38). It is an area with a variety of landscapes due to the great contrasts in its orography. It includes part of the Mediterranean coast and the Guilleries and Montseny mountain ranges, although there is also an orographic depression in the interior. These orographic systems are also known as the Littoral range (up to 512 m.a.s.l.), the Prelittoral range (up to 1,706 m.a.s.l.), and the La Selva depression. There are also three hydrographic sectors corresponding to seasonal small rivers, the basins of the Tordera and Ter rivers. There are also two important estuaries in the interior of the region: the Susqueda estuary and the El Pasteral estuary.

3.2.2.2.2. Climate.

The climate in the north-eastern Iberian Peninsula is classified as variable Mediterranean, influenced by factors such as altitude and proximity to the sea. The relief also plays an important role in shaping the climate of this area. Along the Mediterranean coast, rainfall is low and sporadic, while the average annual temperature is relatively high and moderated by the nearby mountain ranges parallel to the coast. Moving inland towards the humid Mediterranean or sub-Mediterranean zones, rainfall increases and temperatures tend to be colder. In contrast, the continental Mediterranean climate is characterised by low rainfall and extreme temperature, with very warm summers and cold winters.

The climate in the immediate vicinity of Estany de Banyoles is characterised as humid Mediterranean or sub-Mediterranean. It presents an annual rainfall of 750 mm and maintains an average annual temperature of 15°C. During the months of July and August, the average maximum temperature reaches 23°C, while in winter the average minimum temperature drops to 7°C. The lowest monthly rainfall, around 10 mm, is usually recorded in summer and December. This climate pattern in Banyoles is in line with the dynamics of the pre-Pyrenean region, which has higher annual rainfall and lower average annual temperatures than the coastal areas and the southern inland regions.

Otherwise, the area of La Selva is the wettest part of the coast. The presence of the prelittoral elevations (Massís de Montnegre, Massís de Montseny, Guilleries and El Far ranges) means that the moisture carried by the easterly winds causes frequent and intense rainfall on the forested slopes. Summer is dry on the coast, but relatively cool and humid inland. The region therefore has a temperate and humid Mediterranean climate with a maritime influence. The average annual rainfall is 700 mm on the coast and more than 1,000 mm on the higher slopes of Montseny and Guilleries. Autumn is the wettest season, due to the greater frequency of easterly winds. The humidity of the region also comes from the 'marinada' (CAT) phenomenon, a humid wind that blows up when it collides with the mountains of the Prelittoral system, producing fog that covers the slopes, especially from 800 m.a.s.l. upwards.

3.2.2.2.3. Vegetation.

The heterogeneity in the orography and climate of northeastern Iberia is reflected in an extremely diverse landscape. The vegetation in the area of Estany de Banyoles is characterized by the presence of Meso- and Thermomediterranean vegetation along the Mediterranean coastline as well as the continental inland, where evergreen sclerophyllous forests (*Quercus ilex*, *Quercus coccifera*, *Pinus halepensis* and *Pinus sylvestris*) and shrublands (macchia and garrigue) predominate. The Submediterranean area, which reaches the pre-Pyrenean areas from 500 to 1,800 m.a.s.l., is occupied by humid Mediterranean forests (*Quercus humilis*, *Corylus avellana* and *Fagus sylvatica*). Furthermore, boreal conifer forests of *Pinus uncinata* and *Abies alba* are also present in the subalpine zona up to 2,300 m.a.s.l. in the Pyrenees.

Due to the humid climate, the vegetation of La Selva is characterised by large areas of woodland: oak (*Quercus humilis*), cork oak (*Quercus suber*), pine (*Pinus* sp.), chestnut (*Castanea* sp.) and beech (*Fagus sylvatica*). Oak groves and cork oaks would be the natural forests on the sunny lower hills and slopes. Cork oaks are abundant on the sunny lower slopes of the Prelittoral area. The oak forest covers a large area up to 1,000 m.a.s.l., depending on the insolation. Garrigues, scrub and macchia also appear, with pines in the areas of natural oak and cork. On the plain of La Selva there are poplar and banana plantations, favoured by the fertility and humidity of the soil. On the banks of the rivers there are riparian forests with sedges, reeds, and willows. Deciduous forests dominate the humid slopes of the middle and high mountains. Where summers are still slightly dry, oak and chestnut trees also grow. Dense beech forests grow in the wetter and higher areas. Due to the humid climate of La Selva and the presence of fog on many summer days, special vegetation grows here, typical of very humid places, such as beech and oak.

CHAPTER IV - MATERIALS

4. Materials.

4.1. Cueva de los Murciélagos, 7986-3740 cal BC (Albuñol, Granada).

4.1.1. The site and its archaeological record.

The archaeological site of Cueva de los Murciélagos corresponds to a sepulchral cave used during the Mesolithic and Early Neolithic. It is located in the southeast of the Iberian Peninsula at 450 m.a.s.l. and 7 km from the Mediterranean coastline near the village of Albuñol (Granada) (Figure 39). The cave, of karstic origin, is at the beginning of the lowest section of Las Angosturas Gorge or the Aldaya dry riverbed in La Contraviesa mountain range, 170 m from the base of the gorge in grey limestone. Impermeable rocks (chalcoschist and phyllite) are found very close to the base of the stratigraphic column, so the cave is subaerial with a few small globular speleothems (0.5-4 cm). This limited development and growth of the speleothems is due to periods of low rainfall and/or high temperature, giving the cave practically null humidity. The cave is inside a rock shelter 30 m wide and 25 m deep, and has a lens-shaped entrance 17,2 m wide facing east, with direct access to different tunnels and chambers which lead to the main chamber. The cave is 60 m long and 30 m wide, with a drop of about 48 m between the highest and the deepest parts (Figure 40) (Martínez-Sevilla et al. 2023).

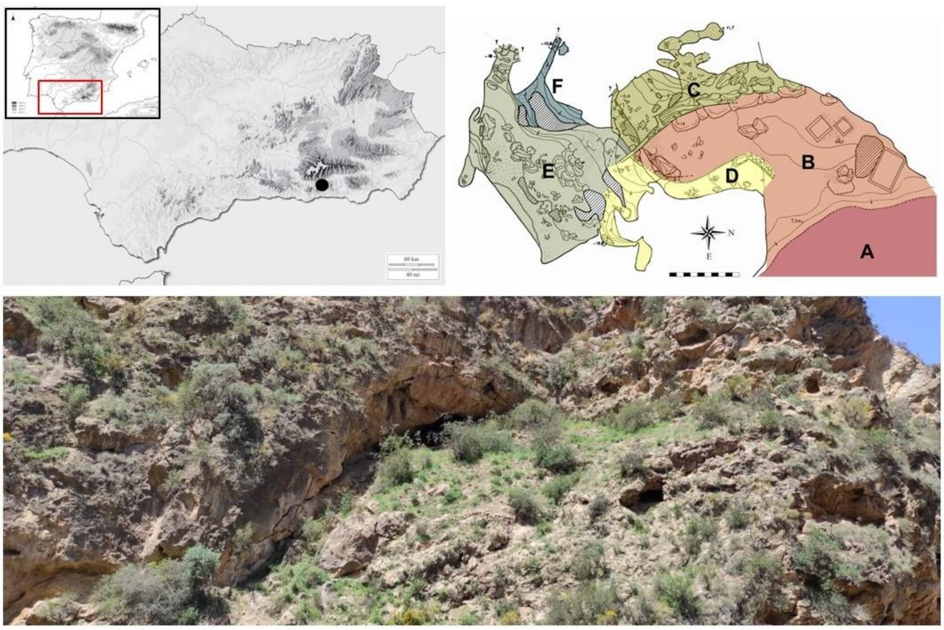

Figure 39. Localisation of the Cueva de los Murciélagos site (Albuñol, Granada - southeastern Iberian Peninsula).

It is said that the cave was first accessed in 1831 by the owner of the surrounding lands who collected the abundant bat guano in the main chamber for fertilizer (de Góngora 1868).

The shelter was also used to keep goats until the identification of a vein of galena (lead) resulted in its exploitation by a mining company in 1857, although earlier mining activities are documented in historical documents. The removal of blocks to access the mineral during these works led to the discovery of a gallery that contained several partially mummified corpses accompanied by different sorts of goods: baskets, wooden tools and other archaeological remains (de Góngora 1868).

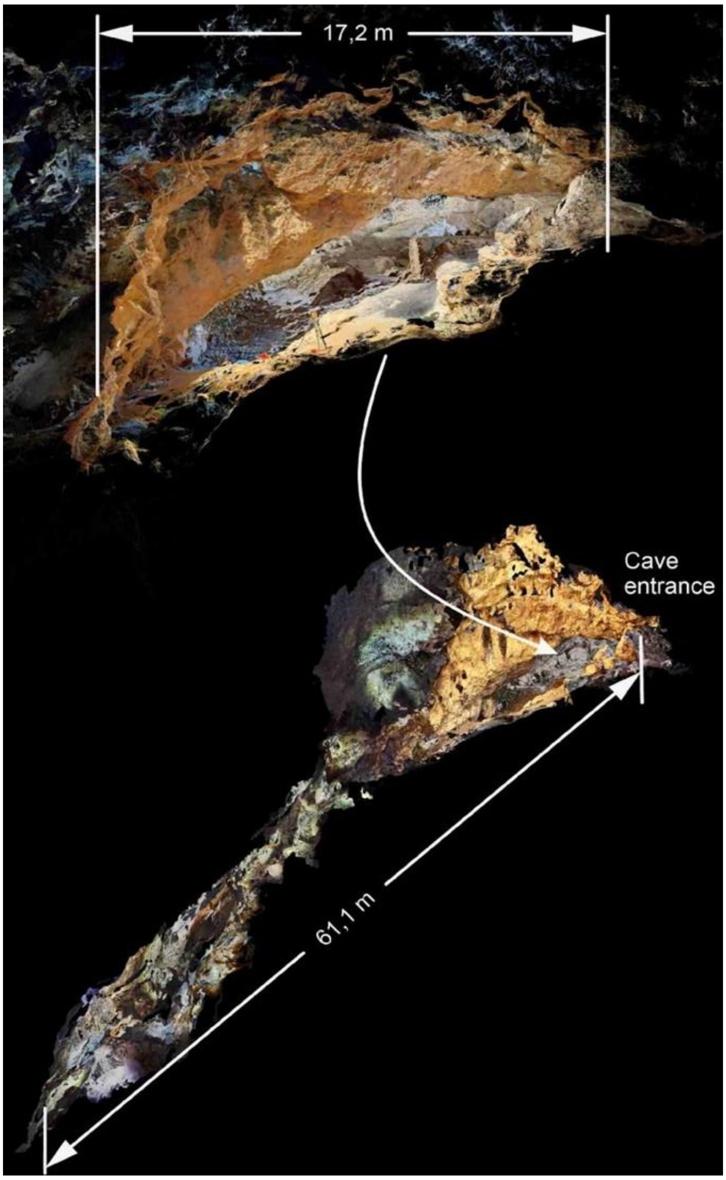

Figure 40. Cueva de los Murciélagos geographic characteristics (MUTERMUR Project).

Plant-based objects were burned and scattered around the immediacies of the cave and the shelter, while other objects were distributed among the Albuñol villagers. Ten years after, the cave was visited by Manuel de Góngora y Martínez who collected the testimonies of the miners regarding the discovery, gathered the archaeological remains and published the first academic review that mentions the site (de Góngora 1868). He described the existence of at least 68 individuals distributed in different chambers and areas of the cave. Most of these human remains have yet to be re-located. De Góngora's publication describes both organic and non-organic archaeological materials associated with the burials (Figure 41). No contextual information about their location is given in his publication either about the association of the objects or their original positions: de Góngora only stated they were recovered from the floor surface in the inner part of the cave. He was the first investigator and the last owner of the remains until they were deposited in the museums. In 2021 the site was included in a research project called MUTERMUR '*De los museos al territorio: actualizando el estudio de la Cueva de los Murciélagos de Albuñol (Granada)* ' (CM/JIN/2021-009). It aimed to re-assess the materials stored in the museums as well as carrying out the first systematic fieldwork at the site.

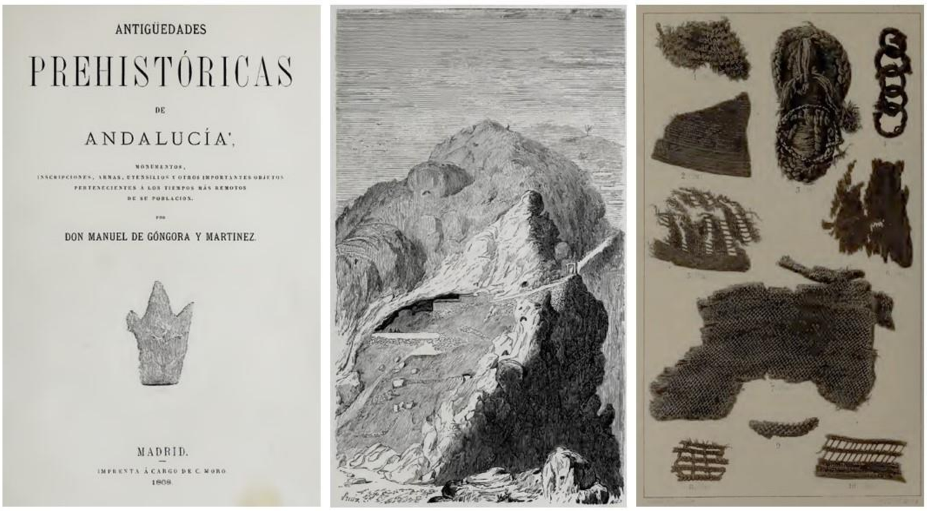

Figure 41. First graphical documentation of the materials from the Cueva de los Murciélagos site (de Góngora 1868).

Numerous critiques were published regarding the authenticity of the materials and their chronology (Gómez-Moreno Martínez 1933, 1949). These doubts remained unresolved until the 1970s, when the first radiocarbon analyses were carried out on a sample of vegetal fibre and one of wood, both yielding Neolithic dates (5200-4850 cal BC) (López 1978). Radiocarbon dates on two more samples confirmed the chronology of the objects in 1996 (Cacho et al. 1996). Two sandals, a basket fragment, a piece of wood and one undetermined object were dated by conventional radiocarbon methods, providing a chronology between 5200 and 4850 cal BC, in the regional Early Neolithic (Cacho et al. 1996). However, another wood sample that provided an earlier chronology (6450-6030 cal BC) was interpreted as a result of the "old wood effect" and so was excluded from the interpretation. The possibility that this earlier date could be related to the use of the cave was previously postulated by some of the authors (Carrasco-Rus and Martínez-Sevilla 2014). The last radiocarbon results obtained in the frame of the MUTERMUR Project confirm that the objects from Cueva de los Murciélagos were deposited during two main chronological phases, separated by around 2,000 years (Figure 42; Table 6). Phase 1 was during the Mesolithic (7680-7100 cal BC) and Phase 2 was related to Early Neolithic chronologies (5380-4050 cal BC) (Martínez-Sevilla et al. 2023). Additionally, the new fieldwork was able to identify older materials from the rock shelter suggesting different uses of the site in earlier chronologies. However, these materials are under study and no further information is available (Martínez-Sevilla 2022).

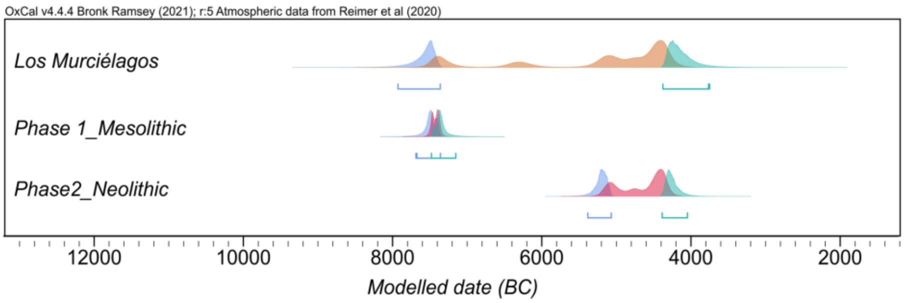

Figure 42. Mesolithic and Neolithic chronological phases from the Cueva de los Murciélagos site (Martínez-Sevilla et al. 2023).

Archaeological materials recovered at the site in the 19th century and nowadays stored in the Museo Arqueológico Nacional (MAN, Madrid), Museo Nacional de Antropología (MNA, Madrid) and Museo arqueológico y etnológico de Granada (MAEG, Granada) include ceramic sherds, flint blades and flakes, quartz, a polished axe head and bone awls, as well as diverse ornaments, such as perforated shells, wild boar tusks and stone and shell bracelets (López 1980; Martínez-Sevilla 2018), a unique gold diadem and human remains (Figure 43). The pottery assemblage comprises globular vessels with impressed, incised and Almagra (red-painted) decorations (Carrasco Rus and Pachón Romero 2009). Regarding the organic record, the cave has yielded an important assemblage of wooden materials and carpological remains, as well as the fibre-based materials that part of this thesis focuses on (Figure 44).

Surveying in the whole shelter and cave was carried out in the first systematic archaeological fieldwork at the site in the frame of the MUTERMUR Project. During this work, new caves were documented as well as a large collection of archaeological materials, such as pottery, lithic, bone tools, animal remains (bone and skins), human remains (bones and hairs), as well as plant remains like wooden fragments and fibre-based objects.

Table 6. Radiocarbon data from Cueva de los Murciélagos site. The dates were calibrated using the OxCal v4.4 programme and the IntCal20 callibration curve (Bronk Ramsey 2021).

Lab code	Object code	Material	Date BP	cal BC 68.3% interval		cal BC 95.4% interval		Method	Reference
CSIC-246	-	Plant fibre	5400 ± 80	-4438	-4262	-4453	-4173	-	López 1978
Beta-627336	MAN624	Plant fibre	5550 ± 30	-4443	-4351	-4447	-4346	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627335	MAN625	Plant fibre	5550 ± 30	-4443	-4351	-4447	-4346	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627337	MAN623	Plant fibre	5570 ± 30	-4443	-4361	-4454	-4348	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627341	MAN615	Plant fibre	5580 ± 30	-4446	-4365	-4484	-4350	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627330	MAN603	Plant fibre	5630 ± 30	-4499	-4371	-4537	-4366	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627331	MAN611	Plant fibre	5640 ± 30	-4533	-4406	-4542	-4367	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627338	MAN475	Wood	5660 ± 30	-4535	-4435	-4552	-4370	AMS-Standard	Martínez-Sevilla et al. 2023
CSIC-1132	MAN616	Plant fibre	5861 ± 48	-4795	-4680	-4844	-4556	-	Cacho et al. 1996
CSIC-1134	MAN609	Plant fibre	5900 ± 38	-4826	-4720	-4886	-4691	-	Cacho et al. 1996
CSIC-1133	MAN598	Plant fibre	6086 ± 45	-5056	-4910	-5206	-4846	-	Cacho et al. 1996
Beta-628427	MAN594	Plant fibre	6150 ± 30	-5187	-5013	-5206	-5001	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627340	MAN479	Wood	6170 ± 30	-5173	-5046	-5210	-5013	AMS-microsample analysis	Martínez-Sevilla et al. 2023
Beta-627342	MAN617	Plant fibre	6210 ± 30	-5156	-5067	-5281	-5041	AMS-Standard	Martínez-Sevilla et al. 2023
CSIC-247	-	Wood	7440 ± 100	-	-	-	-	-	López 1978
Beta-627334	MAN581	Plant fibre	8300 ± 30	-7464	-7356	-7486	-7317	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627333	MAN580	Plant fibre	8320 ± 30	-7469	-7361	-7487	-7332	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-627332	MAN579	Plant fibre	8350 ± 30	-7481	-7361	-7501	-7346	AMS-Standard	Martínez-Sevilla et al. 2023
Beta-628426	MAN626	Plant fibre	8400 ± 30	-7504	-7370	-7531	-7353	AMS-Standard	Martínez-Sevilla et al. 2023

Figure 43. Sample of archaeological materials found in the Cueva de los Murciélagos site (Modified from CERES-MAN).

Figure 44. Sample of organic materials recovered in the Cueva de los Murciélagos site (Modified from CERES - MAN).

The archaeological work carried out at the site in 2022 and 2023 provided the first stratigraphic description of the site (Martínez-Sevilla 2022). Three different test pits were carried out (Figure 45). Test pit 1 was located at the entrance to the shelter and it was excavated to a depth of over 3 m. Different structures for storage and fireplaces were identified. Radiocarbon dates from organic material from Test pit 1 (charcoal and charred seeds) revealed a long tradition of occupation of the shelter from the Palaeolithic (12,254±48 BP) until the nineteenth century, when the cave was mined. An extensive burning area was dated to 5048±46 BP. Pottery, lithics, animal bones, malacofaunal remains, personal ornaments, charcoal and seeds were recovered from this test pit. Test pit 2 was carried out near the current entrance of the cave, where the miners deposited the sediments from their activities. Local people have traditionally recovered archaeological materials from this part. In this case, an inverse stratigraphy was recorded in which the older archaeological materials were found in the uppermost layers, while the modern materials (corresponding to the dates of the mining activities, such as a coin from 1817) were found in the lower layers. Test pit 3 was planned for 2023 after the general survey of the cave in 2022. It is in the deepest part of the shelter where the miners deposited the rocks they extracted. It corresponds to a large area where the extraction of sediments (rocks) allowed the preservation of organic materials, although non-perishable archaeological remains from the prehistoric period have also been found.

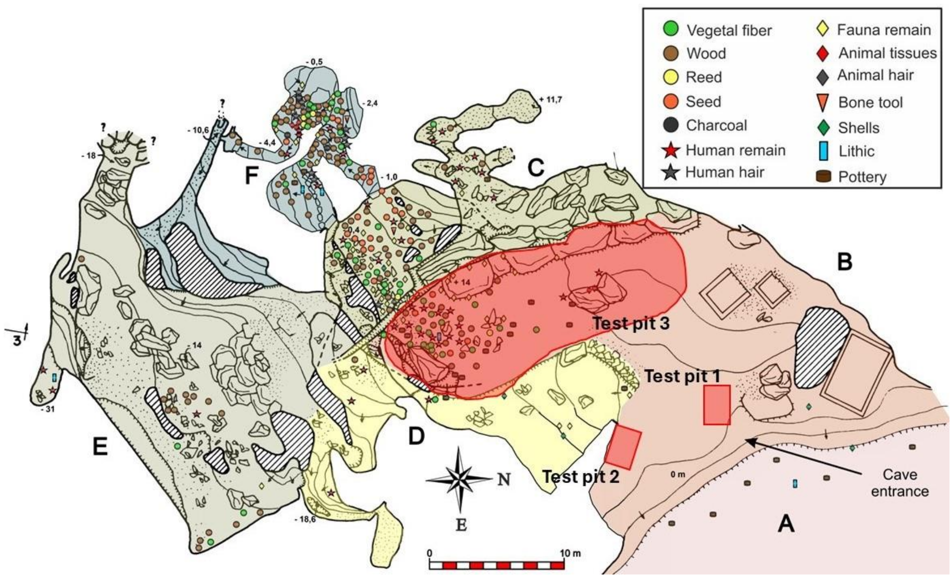

Figure 45. Test pits location location at the Cueva de los Murciélagos site (MUTERMUR Project).

Pottery, lithic, faunal, anthropological and archaeobotanical remains -except for palynology analysis- are still under study, thus no information is yet available and they are not part of this PhD dissertation.

The available palaeoenvironmental data is limited. The palynological analysis carried out on samples taken from Test pit 1 yielded results of limited reliability for the reconstruction of the palaeoenvironment (Revelles 2023). The preservation of pollen remains was inadequate and the samples did not achieve the minimum criteria required for an accurate description of the landscape. Despite being sampled from the entire stratigraphic depth of Test pit 1 over two profiles (east and west), the pollen content did not accurately reflect the pollen distribution during the occupation of the site (Figure 46).

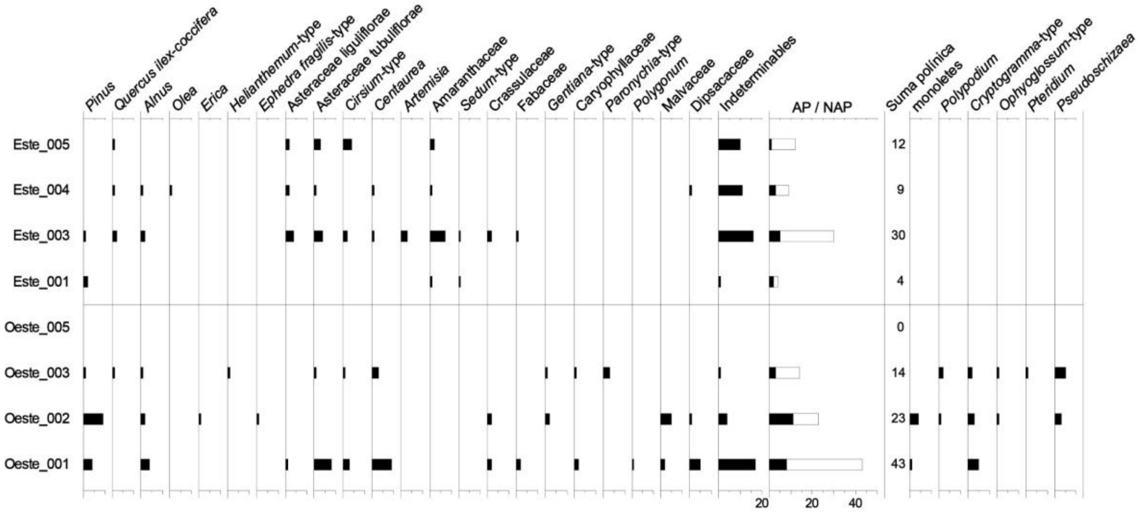

Figure 46. Pollen diagram of the Cueva de los Murciélagos site (profiles East and West). The bars show absolute values (pollen grains) (Revelles 2023).

Within the eastern profile, in the lower layers associated with the Palaeolithic period, the remains included two pollen grains of Pinus sp., one belonging to the Amaranthaceae family, and another resembling the Sedum genus. This period was characterised by the prevalence of pine forests and hardy herbaceous plants adapted to cold and arid conditions which probably dominated the landscape. In the recent prehistoric strata, the presence of holm oak (*Quercus ilex-coccifera*) and olive (*Olea* sp.) trees, both evergreens with a thermophilic nature, indicates a warmer climate. The existence of a riverside species like alder (*Alnus* sp.) suggests the proximity of watercourses during this period. The scarcity of pine pollen implies that holm oak predominated in the cave environment during recent prehistory. In the surroundings, herbaceous plants, particularly Asteraceae (including Liguliflorae, Tubuliflorae, *Cirsium* sp., as well as genera like *Centaurea* sp. and *Artemisia* sp.), together with Amaranthaceae, Crassulaceae, *Sedum*-like plants, Fabaceae, and Dipsacaceae dominated the landscape.

The oldest samples from the western profile contain only Pinus sp. and Alnus sp. pollen grains, along with some of shrubs such as heather (*Erica* sp.) and ephedra (*Ephedra* sp.).

Herbaceous plants include Asteraceae (Liguliflorae, Tubuliflorae, Cirsium-type, and *Centaurea* sp.), Crassulaceae, Fabaceae, *Gentiana*-type, Caryophyllaceae, *Polygonum* sp., Malvaceae, and Dipsacaceae. The presence of ferns (*Polypodium* sp., *Cryptogramma*-type, *Ophyoglossum*-type, and *Pteridium* sp.) and the microfossil Pseudoschizaea (likely of algal origin) were also identified. These are characteristic of periods of desiccation, including ephemeral water and seasonal humidity. The latest samples probably indicate a temperate period towards the end of the Pleistocene, which facilitated the expansion of holm oak-coccifera. The presence of *Pinus* sp., *Alnus* sp., and the shrub *Helianthemum*-type was also documented. Among the herbaceous plants, there are Asteraceae, Tubuliflorae, *Cirsium*-type, *Centaurea* sp., *Gentiana*-type, Caryophyllaceae, and *Paronychia*-type. In this sample, ferns such as *Polypodium* sp., *Cryptogramma*-type, *Ophyoglossum*-type, and *Pteridium* sp., have been identified as well as a significant concentration of Pseudoschizaea.

4.1.2. Study materials.

Cueva de los Murciélagos is one of the best-known sites in Southern Europe for the exceptional preservation of organic materials by desiccation. Although the archaeological organic materials from Cueva de los Murciélagos have been frequently cited as the best-preserved collection of fibre-based archaeological materials in southern Europe, only three publications primarily concentrate on these materials (Alfaro 1980, 1984; Cacho et al. 1996).

Alfaro (1980, 1984) made the first systematic study of the fibre-based materials from the site regarding the technology of their production. Her publications revealed the main typologies of basketry, cordage and sandals, with a detailed catalogue describing each object, adapting the terminology to technical variations. The author specifies that the entire set of fibre-based objects was made from esparto grass (*Stipa tenacissima*) and explains the differences in the appearance of the raw material due to the processing of the fibre through crushing the esparto, as is still traditionally done today. However no microscopic analyses were performed.

In a subsequent publication, researchers detected geometric decorations on seven of the baskets using spectrophotometry analysis (Cacho et al. 1996). For the last two years, these materials have been analysed using an interdisciplinary approach combining geoarchaeology, radiocarbon dating and Bayesian modelling, raw material identification, and analysis of the technological features (Martínez-Sevilla et al. 2023).

Figure 47. Sample of cordage remains from Cueva de los Murciélagos: a) Twisted cord (MAN591b), b) Braided cord (MAN591a).

Figure 48. Sample of sandals remains from Cueva de los Murciélagos: a) Simple type sandal (MAN610), b) Central core type sandal (MAN605).

The current thesis is focused on the materials stored in the Museo Arqueológico Nacional and Museo Arqueológico y Etnológico de Granada. Although new finds have been made in the last archaeological fieldwork, these are currently under analysis in research institutions and are not included in this PhD dissertation. The materials made from fibres found in this cave represent the most extensive and diverse collection of fibre-based materials in southern Europe. The collection includes a variety of objects made using different techniques. There are 65 individual registers of plant-based objects in the museum's collection, although some may correspond to the same object. Cords, footwear, and basketry objects are represented.

4.1.2.1. Cordage and sandals register.

The cord assemblage consists of nine registers, one of which corresponds to a twisted cord. This is approximately 30 cm in length and 6 mm in width and is a fragment of a resultant S-cord, or a 2-ply (S z, z) (Figure 47a). The remaining eight cords are braided (3-ply) and vary in length and width (Figure 47b). Some of the cords resemble the footwear laces depicted in sandals recovered at the site.

Sandals are an important part of the inventory. Alfaro (1980, 1984) distinguished two types of sandals: simple (N=2) and central core (N=20), depending on how the sole is manufactured. The simple type lacks laces (they are not conserved) (Figure 48a), while the central core type features a small group of fibres extending from the base of the sole (Figure 48b), which may be placed between the first and second toes. These fibres are also connected to a braid fixed to the middle of the sandal, which could be tied around the ankle. The footwear presents very clear use traces in the lower part of the sole.

4.1.2.2. Basketry register.

The basketry assemblage is the most diverse and extensive, and the techniques used are well-represented and varied (Figure 49). These include twined (N=10) (Figure 50a), rhomboidal twined (N=6) (Figure 50b), coiled (N=11) (Figure 51a), pseudobraided/*cofín* (N=6) (Figure 51b) and braided (N=1) (Figure 51c) (Alfaro 1980, 1984). The diversity in basketry techniques is showed in Figure 52. In addition, many of the registers display decorations made with dyed fibres that drawing geometric motifs (Figure 50a), which were studied in the 1990s (Cacho et al. 1996), as well as handles reinforced with fragments of animal skins (Figure 50a). De Góngora (1868) reported in his publication that some of the baskets contained different categories of contents, such as *Papaver somniferum* (Figure 44e) capsules and human hair (Figure 49b). It is difficult to know when these contents were placed in the baskets, but some registers still contain human hair and remains of mineral ochre pigments. An undetermined object has also been recovered and it corresponds to a set of four fibre-based rings (Figure 52).

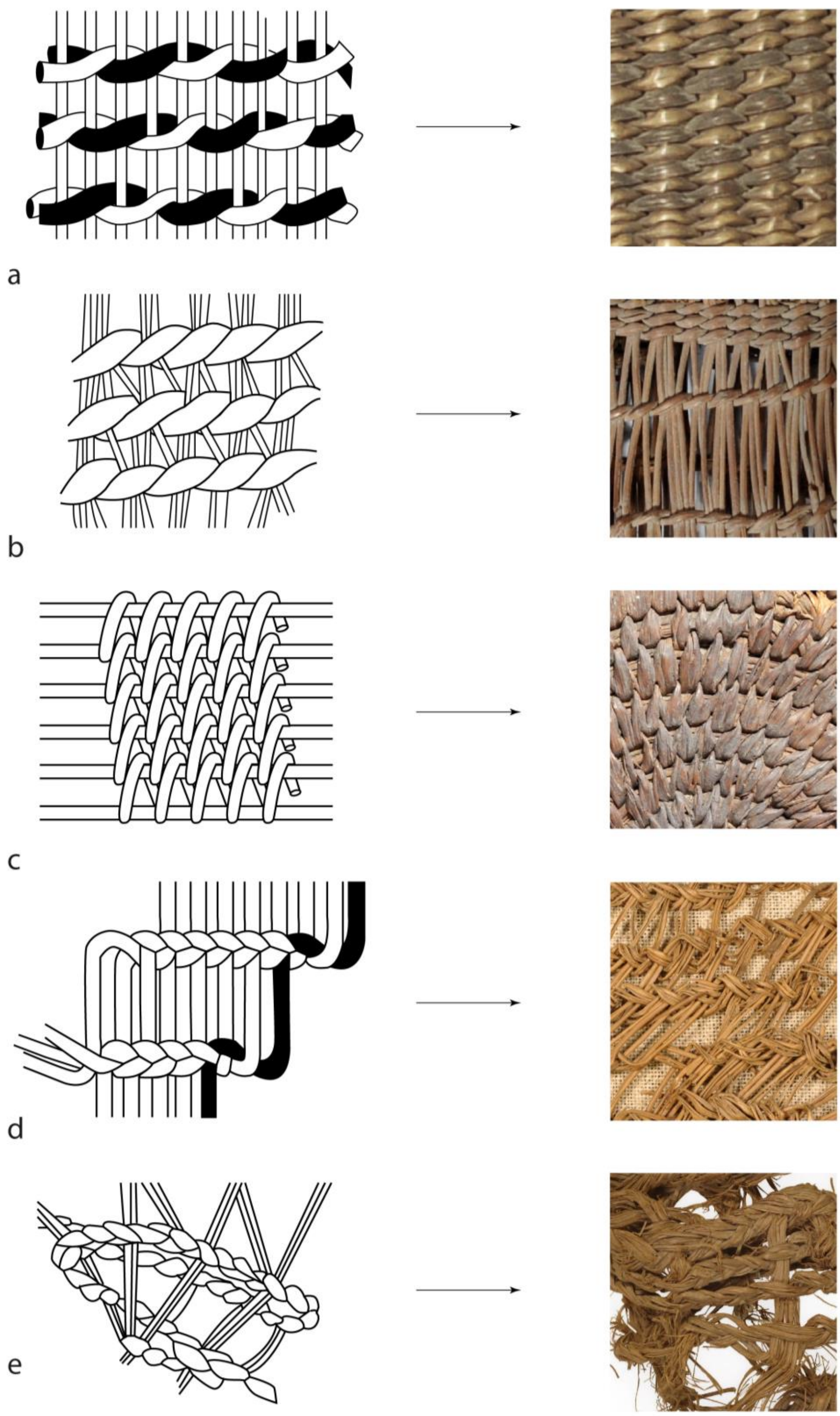

Figure 49. Basketry technological variety in the materials from Cueva de los Murciélagos: a) Twining, b) Rhomboidal twining, c) Coiling, d) *Cofín*, e) Braiding. Drawings modified from Alfaro (1984) by RR.

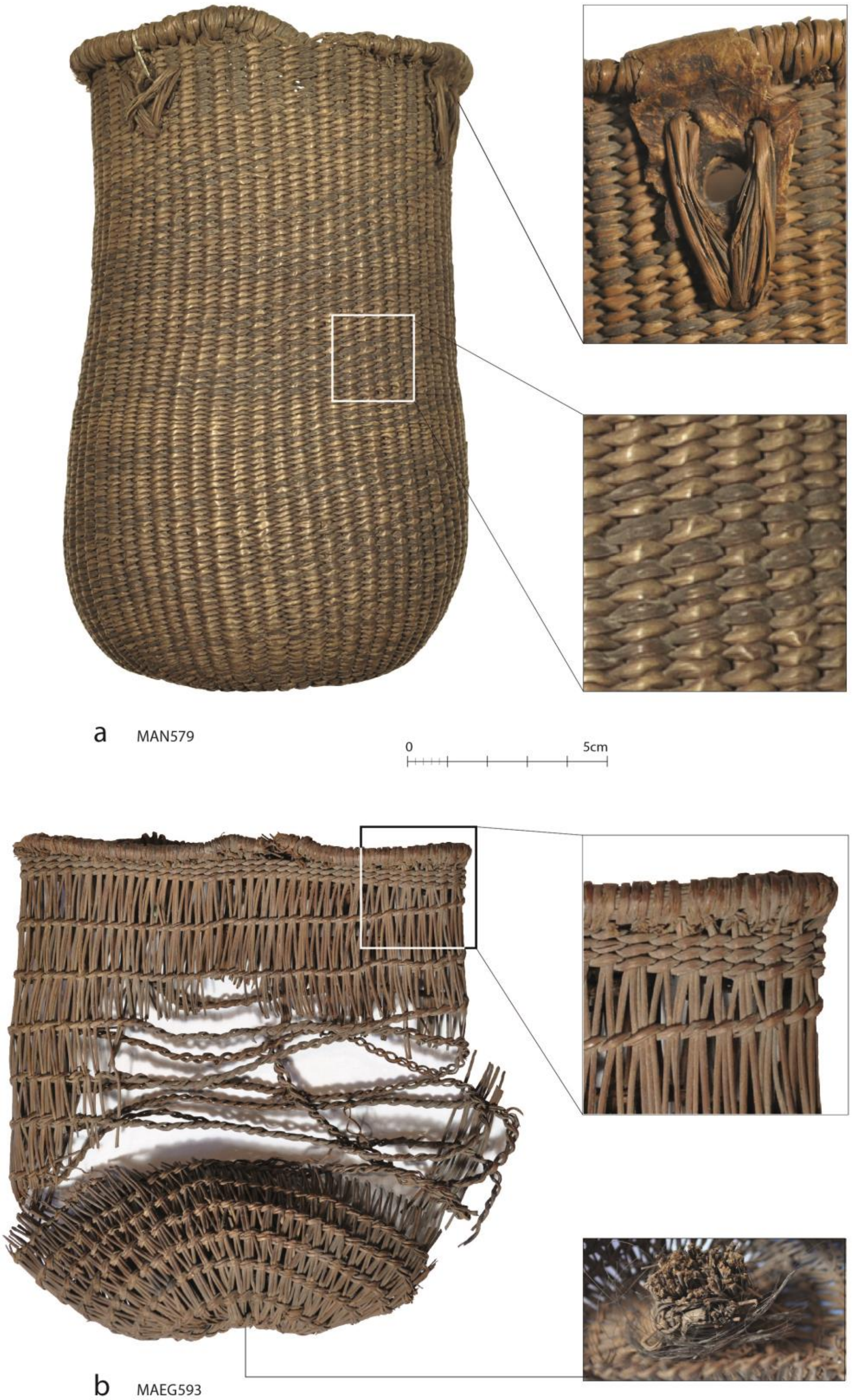

Figure 50. Sample of basketry remains from Cueva de los Murciélagos: a) Twined basketry (MAN579), b) Rhomboidal twined basketry (MAEG593).

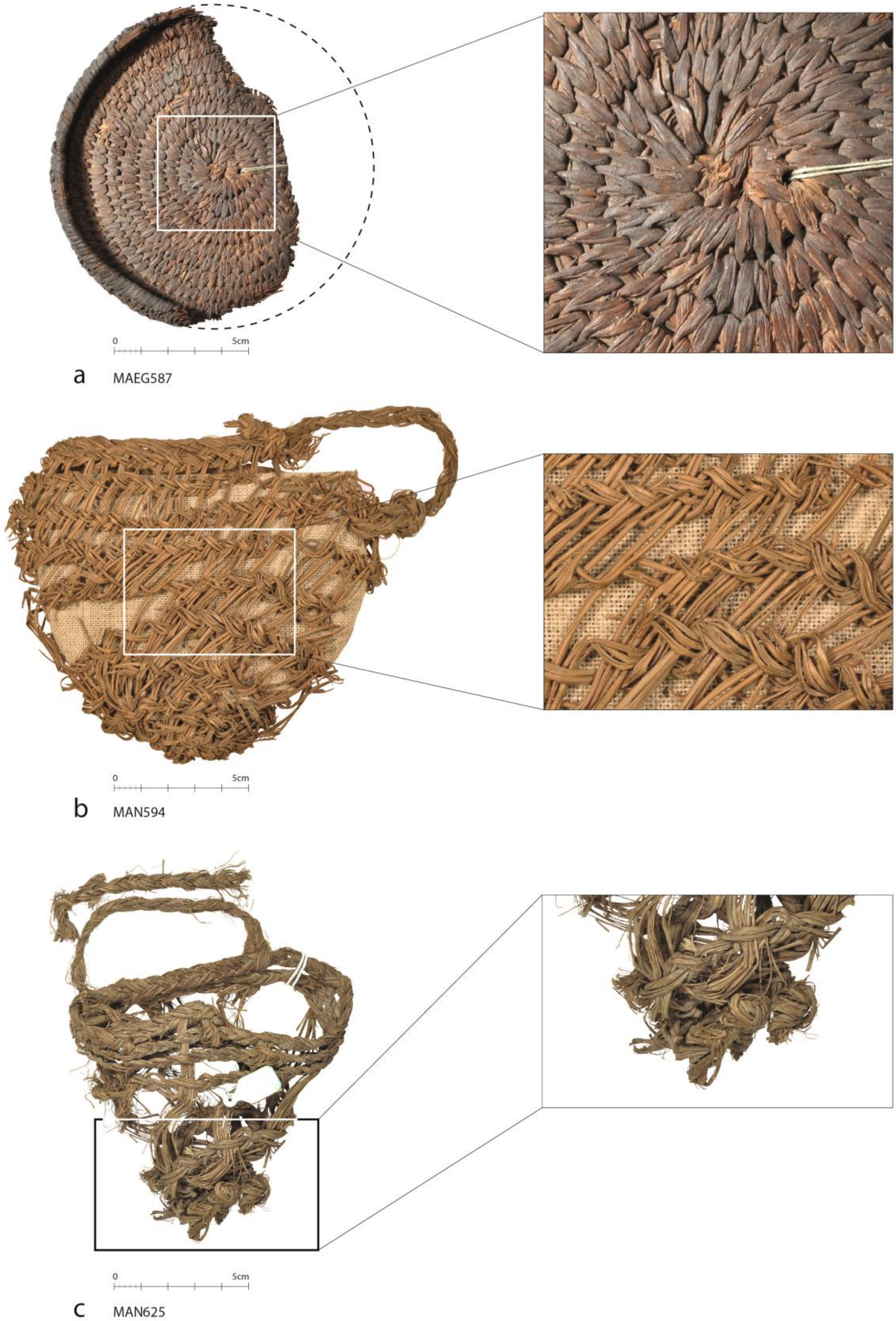

Figure 51. Sample of basketry remains from Cueva de los Murciélagos: a) Coiled basketry (MAN588), b) Pseudobraided/*cofín* basketry (MAN694), b) Braided basketry (MAN625).

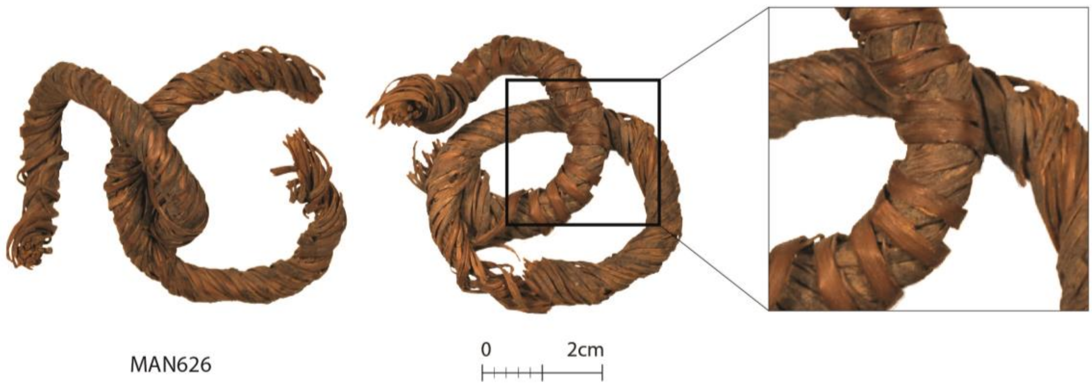

Figure 52. Set of four fibre-based rings from Cueva de los Murciélagos (MAN626).

4.2. Coves del Fem, ca. 6065-4545 cal BC (Ulldemolins, Tarragona).

4.2.1. The site and its archaeological record.

The archaeological site of Coves del Fem is situated near Montsant river and mountain range at about 530 m.a.s.l. at the Serra de Montsant Natural Park in the Northeast of the Iberian Peninsula (Ulldemolins, Tarragona) (Figure 53). Although the name of the site refers to a set of caves, it alludes to a rock shelter formed by river erosion of the natural conglomerates, depositing sediments in the cave. It faces northeast with a surface of 250 m^2 approximately of which 58 m^2 have been totally/partially excavated in two different sectors (1 and 2), in which part of the archaeological levels are currently preserved by rocks fallen from the roof of the shelter (Palomo et al. 2018). The site has been traditionally visited by inhabitants of the area, but it was discovered archaeologically in 1997 and looted on several occasions. The site has been excavated since 2013 and dated chronologically between 6065-4545 cal BC (Table 7). It thus covers different periods: the Mesolithic (6065-5718 cal BC); the first Early Cardial Neolithic phase (5667-5476 cal BC); and the Early Epicardial Neolithic (4941-4545 cal BC) (Bodganovic et al. 2017; Piqué et al. 2021a). The excavations revealed the existence of an archaeological stratigraphic package at least 140 cm thick in some points of the site (Bodganovic et al. 2017; Palomo et al. 2018). Surveying at the site in 2020 revealed portable art of Palaeolithic style in the form of an engraved slab with seven zoomorphic figures (Domingo et al. 2023). The site covers the transitional period from the last hunter-gatherers to the first farming human groups in northeastern Iberia, permitting the characterisation of a chronological gap of archaeological knowledge in the area.

Sector 1 was excavated in 2013, 2015 and from 2019 to 2021 (Figure 54). It presented the most complete diachronic stratigraphic sequence in the central part of the shelter, where the excavation currently occupies 39 m^2 (Palomo et al. 2018). The Mesolithic phase is documented under a sterile level. The archaeological material found within this phase consists of lithics such as tools made of local flint, which is very common in the area, charcoal, and some faunal remains. The first Early Neolithic phase in Sector 1 corresponds to the Cardial Ware Culture related to the earliest pottery tradition in northeastern Iberia decorated with cardial impressions. The Early Epicardial Ware Culture is also represented in the site, with pottery characterised by globular shapes with plastic decoration, incisions and channelling (Figure 55a). Diversity in domestic structures has also been identified during that phase such as postholes, fireplaces, and pits whose construction affected the Cardial Neolithic and Mesolithic layers.

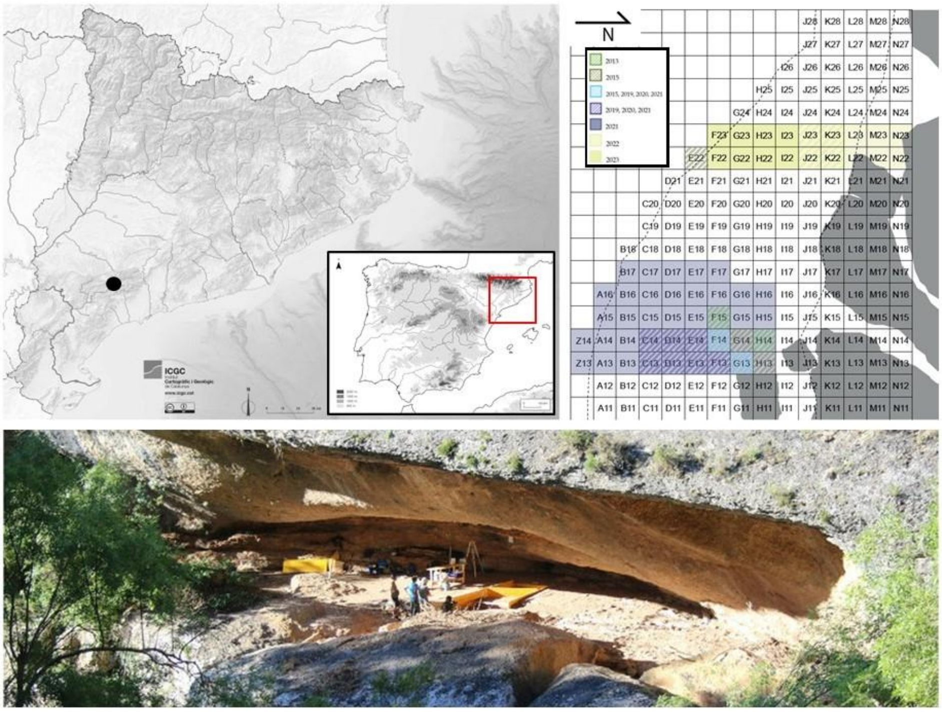

Figure 53. Localisation of the Coves del Fem site (Ulldemolins, Tarragona - northeastern Iberian Peninsula).

In both Cardial and Epicardial Neolithic phases, the lithic assemblage is abundant and characterized by the presence of laminar cores, flint blades and geometrics (Figure 55b, c) made by indirect percussion, as well as the presence of grinding stones used for food or pigment processing. Flint heat treatment was often applied to core preforms (Minguell et al. 2023). The presence of ornaments like perforated shell beads, herbivore teeth (Figure 55d) and slate clasts are also recorded. Faunal remains from Sector 1 revealed the consumption of medium and small prey, such as red deer (*Cervus elaphus*), rabbit (*Oryctolagus cuniculus*), Iberian ibex (*Capra pyrenaica*) and turtles. In the Neolithic levels, domesticated species are represented by Iberian ibex and other undetermined ovicaprids, as well as wild boar (*Sus scrofa*). Worked deer antler has been also found, as well as bone implements such as spatulas and awls (Figure 55e) (Palomo et al. 2020; Piqué et al. 2021c).

Table 7. Radiocarbon data from Coves del Fem site. The dates were calibrated using the OxCal v4.4 programme and the IntCal20 callibration curve (Bronk Ramsey 2009, 2021).

Lab code	Sector or square	Material	Date BP	cal BC 68.2% interval		cal BC 95.4% interval		Method	Reference
SUERC-50640	G12 and G13	Seed	5772 ± 27	-4683	-4587	-4699	-4545	AMS-Standard	Bogdanovic et al. 2017
SUERC-50641	G12 and G13	Seed	5840 ± 27	-4767	-4683	-4785	-4614	AMS-Standard	Bogdanovic et al. 2017
Beta-42864	E21	Bone	5970 ± 30	-4898	-4797	-4941	-4779	AMS-Standard	Bogdanovic et al. 2017
SUERC-53025	H13 and G13	Bone	6342 ± 32	-5364	-5299	-5461	-5221	AMS-Standard	Bogdanovic et al. 2017
Beta-42865	G13	Charcoal	6570 ± 30	-5535	-5483	-5607	-5476	AMS-Standard	Bogdanovic et al. 2017
Beta-42868	G13	Charcoal	6630 ± 30	-5614	-5538	-5623	-5509	AMS-Standard	Bogdanovic et al. 2017
Beta-42866	G13	Bone	6700 ± 30	-5642	-5567	-5667	-5556	AMS-Standard	Bogdanovic et al. 2017
Beta-42867	G13	Cone of pine	6900 ± 30	-5803	-5732	-5844	-5718	AMS-Standard	Bogdanovic et al. 2017
SUERC-50642	F14	Charcoal	7157 ± 29	-6049	-6005	-6065	-5988	AMS-Standard	Bogdanovic et al. 2017

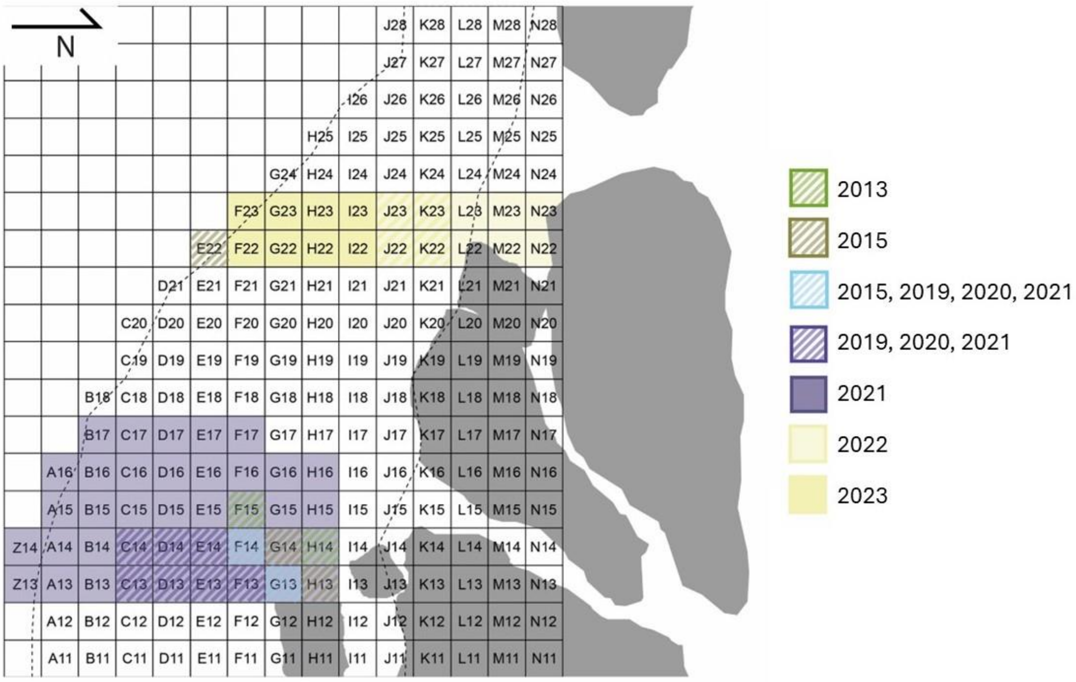

Figure 54. Excavated area and their corresponding archaeological campaigns years from Coves del Fem site.

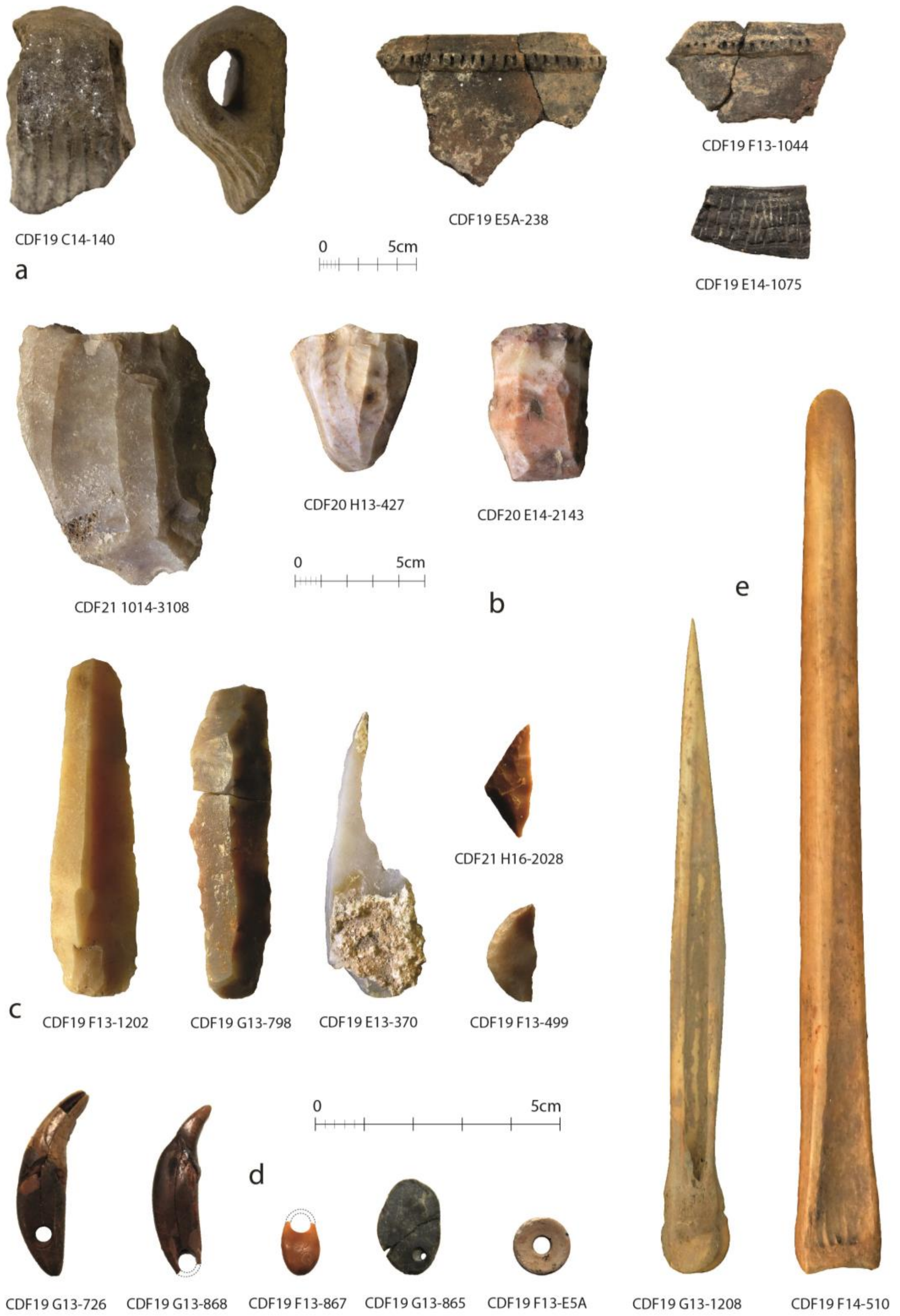

Figure 55. Sample of archaeological materials found in the Coves del Fem site: a) Pottery fragments with plastic decoration, incisions and channelling, b) Laminar cores, c) Flint blades and geometrics, d) Bead made of perforated herbivore teeth, e) Bone-based tools.

The archaeological levels provide good preservation of archaeobotanical remains. The preservation of organic remains in the site is basically by carbonisation but also dehydration, such as some examples of worked wooden remains determined as *Pinus sylvestris* with tool-marks to shape a pointed end (Palomo et al. 2020; Piqué et al. 2021a). The earliest Neolithic levels has provided carpological remains of acorns (*Quercus* sp.) and wild grapevine (*Vitis vinifera* var. *sylvestris*), and domesticated species like barley (*Hordeum vulgar*e) and other undetermined cereals (Garay-Palacios 2021).

Sector 2 is in the western part of the rock shelter, and was excavated in 2022 and 2023 (Figure 54). At the moment it presents an area of 19 m^2. The fieldwork documented a more modern use of the cave than in Sector 1, expanding the use of Coves del Fem to ca. 6065 cal BC to 2200 BC approximately. However, no results of the analysis of the materials from this sector are yet available.

Palynological data revealed that deciduous oak and holm/kermes oak expanded in the area in ca 6550 BC (Pérez-Obiol et al. 2011), even though the pollen record from the site is affected in different levels and sectors, and it has only been possible to describe the vegetation in the Epicardial Neolithic phase (Palomo et al. 2018). The pollen analysis has revealed a landscape predominated by *Pinus* sp. since the Mesolithic, with a greater representation of deciduous trees like *Corylus* sp. in the Mesolithic and deciduous *Quercus* sp. and *Betula* sp. in the Early Neolithic Cardial phase, and a slight expansion of sclerophyllous (*Quercus ilex-coccifera* and *Olea* sp.) in the Epicardial period. Pollen shows higher values of deciduous *Quercus* in early stages of the Epicardial phase, and later the decline of mesophilous vegetation is clear (Figure 56).

In general, the pollen diagrams show how dense forests existed, although in some samples the percentages of non- arboreal pollen are higher due to the input of plants in the context of human activities. This could be the case of *Cirsium* or *Cerealia* type in different places in the cave. The pollen record from Coves del Fem provided information about landscape evolution from the Mesolithic to Epicardial Neolithic (8005-4545 cal BC), showing how deciduous trees regressed during the Early Neolithic Epicardial (4950 cal BC onwards) (Piqué et al. 2018, 2021b).

In the charcoal record, the most abundant carbonized species is pine (*Pinus sylvestris-nigra*) in all levels. The earliest levels also present juniper (*Juniperus* sp.), oak (deciduous *Quercus*) and holm/kermes oak (evergreen *Quercus*). Oak gains importance in the most recent layers, where it appears with other deciduous species, like maple (*Acer* sp.), and riparian taxa such as the Salicaceae family, ash (*Fraxinus* sp.) and elm (*Ulmus* sp.) although pine continues to be intensively exploited (Alcolea 2017). The findings derived from charcoal data revealed that during both Mesolithic and Early Neolithic occupation phases at Coves del Fem there were pine and oak forests near the site. Nonetheless, during the earliest phases, the exploitation of oak and riparian taxa for carbonizing purposes becomes recurrent, suggesting a significant impact on the deciduous forests, indicating heightened pressure during this period. Pine is also represented in the carpological register by a scale and a whole pine cone (*Pinus* sp.) in Mesolithic levels, but it also appears in Early Neolithic strata.

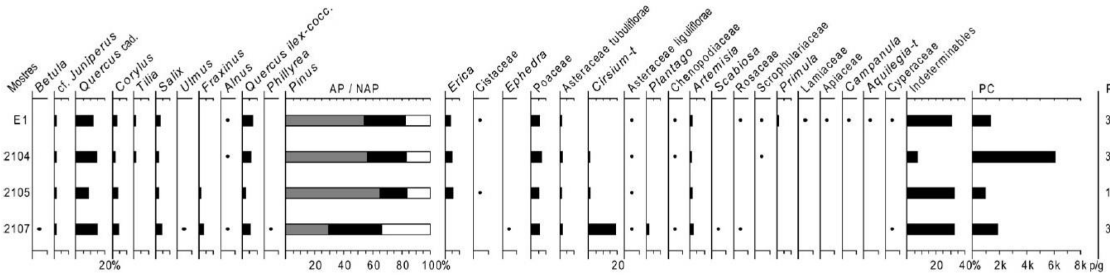

Figure 56. Pollen diagram of the Coves del Fem site (section 4) (Palomo et al. 2018).

4.2.2. Study materials.

The materials analysed from Coves del Fem in the current thesis correspond to a single fragment of a cord and a set of basketry fragments. These materials have been analysed morphotechnically by Romero-Brugués (2021) and Romero-Brugués et al. (2021a).

These materials were recovered during archaeological fieldwork in 2019 in Early Neolithic or Epicardial levels. They were found inside a pit in contact with the bottom as if they were lining a storage structure, such as a bin or silo and were considered a substructure (E5A) (Figure 57). While basketry fragments were recovered during the excavation, the cord fragment was recovered after during the sediment triage. Although part of the structure was affected by looting activities and water streams before its excavation, it has been interpreted as part of a domestic area (Rosillo et al. 2019). Structure E5A has an oval-shaped plan with an irregular section and a maximum depth of 40 cm. Different categories of archaeological materials were discovered, including thermoaltered lithic and pottery remains, fauna, and cereal materials mainly of *Triticum aestivum/durum/turgidum* (Garay-Palacios 2021). The base of structure E5A was supposed to be lined with plant fibres.

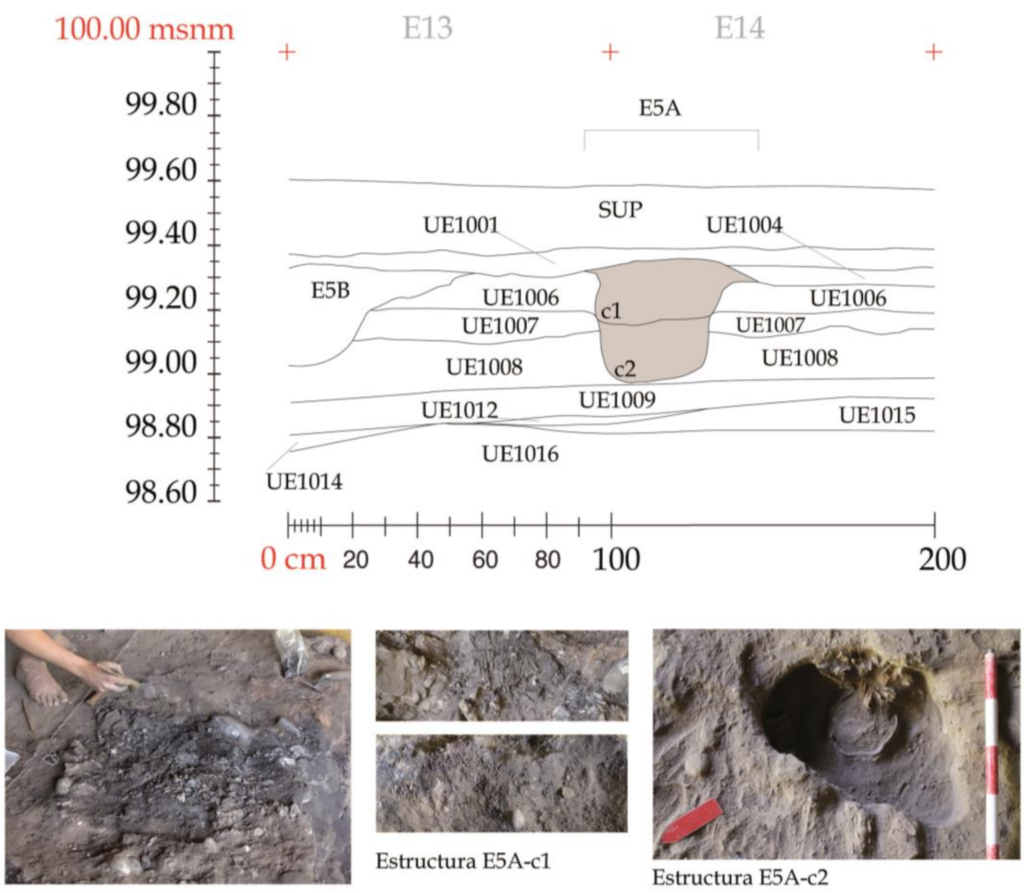

Figure 57. Structure where the materials studied in this thesis came from (Romero-Brugués et al. 2022)

4.2.2.1. Cordage register.

During the triage of sediments from inside Structure E5A, water-sieved with a 2 mm mesh, a single fragment of twisted cord was discovered. The carbonized cord measures 6.6 mm in length and 1.6 mm in maximum width, with fragmented edges and a smooth surface without coatings. It corresponds to an S-spun fragment of a Z-cord, or a 2-ply (Z s, s) cord with a torsion angle of 20-25º (Figure 58).

4.2.2.2. Basketry register.

There are 52 fragments of basketry remains of varying sizes. These fragments are mainly preserved through carbonization, although some fibres are conserved desiccated (Figure 58).

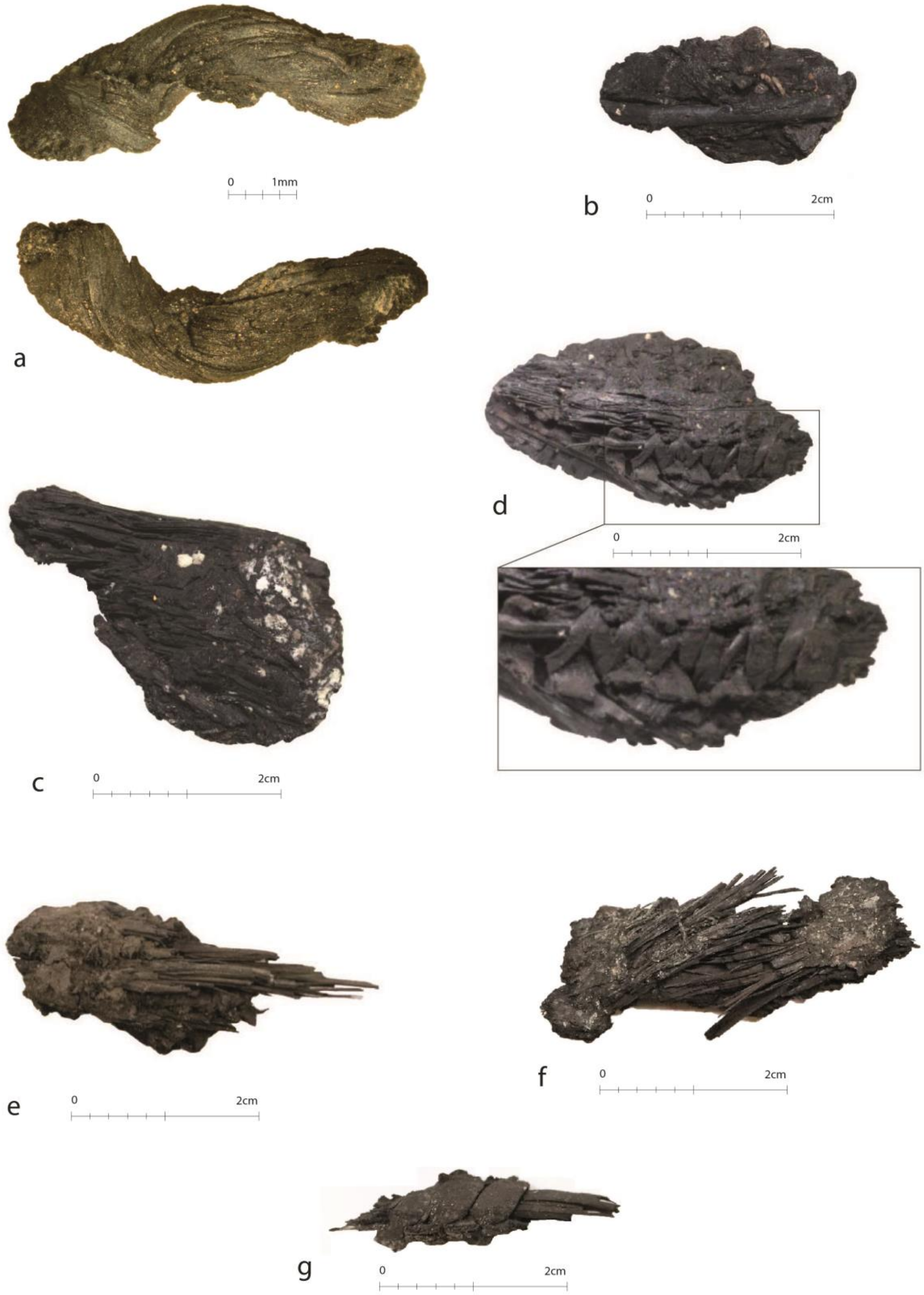

Figure 58. Cordage and basketry remains from Structure E5A from the Coves del Fem site: a) Twisted cord fragment, b-g) Coiled basketry fragments.

Additionally, some fragments contain reddish sediment particles, as well as white particles that correspond to calcareous disaggregated and calcined rock. Although highly fragmented, all the fragments have been considered part of the same object due to similarities in size and morphology. The morphotechnical study was based on the analysis of 12 fragments regarding their recognizable features, measurements and state of preservation (Table 8). The basketry technique used to produce this basket was coiling (coiled basketry). Some of the fibre bundles showed slight torsion to the right due to the production process. The 12 fragments included fibre bundles, stitches, rims, and indeterminate pieces (Figure 58). Variations in the production process are evident in the measurements of bundle thickness and stitch types. The stitching pattern is simple, with two variations: interlocking stitch and the split stitching pattern. The curvature of the basket and spiral spacing could not be determined.

Table 8. Technological aspects of the coiled basketry fragments registers from Coves del Fem (Extracted from Romero-Brugués 2021).

Inventory number	Fragment description	Measures (mm)	Bundle width (mm)	Stitch width (mm)	Number of conserved bundles	Spacing	Coiled stitch typology
CDF19-261	Bundle	45x21	17-19	ND	Indet.	ND	Indet.
CDF19-261	Shapeless	18x9	Indet.	4-5	Indet.	ND	Indet.
CDF19-261	Stitch	10x6	Indet.	2-3	Indet.	ND	Indet.
CDF19-261	Stitch	8x5	Indet.	3-5	Indet.	ND	Indet.
CDF19-261	Stitch	7x2	Indet.	1-2	Indet.	ND	Indet.
CDF19-261	Bundle	31x8	3-4	5-6	1	ND	Simple interlocking
CDF19-261	Bundle	27x9	6-9	ND	Indet.	ND	Indet.
CDF19-261	Bundle	35x3	ND	ND	ND	ND	ND
CDF19-261	Bundle	47x16	9-19	Indet.	Indet.	ND	Indet.
CDF19-261	Base/rim	38x23	4-6	4-5	Indet.	Indet.	Simple split
CDF19-261	Base/rim	39x24	Indet.	Indet.	Indet.	Indet.	Indet.
CDF19-E5A	Base/rim	34x27	Indet.	Indet.	Indet.	Indet.	Indet.

4.3. La Draga, 5324-4977 cal BC (Banyoles, Girona).

4.3.1. The site and its archaeological record.

The archaeological site of La Draga is located on the eastern shore of Lake Banyoles at 172 m.a.s.l. in northeastern Iberia (Banyoles, Girona) (Figure 59). Discovered in April 1990 during the preparation work for the 1992 Summer Olympics in Barcelona, the site has been excavated for more than thirty years and it is considered the only evidence of a Neolithic Lake dwelling in the Iberian Peninsula (Palomo et al. 2014; Terradas et al. 2017). Although it is suggested that the real site covers an area of about 15,000 m^2, the archaeological fieldwork has focused on an area of 3,000 m^2 approximately of which 1,000 m^2 have been excavated and three different sectors have been identified (Bosch et al. 2000, 2006, 2011; Palomo et al. 2014, 2016).

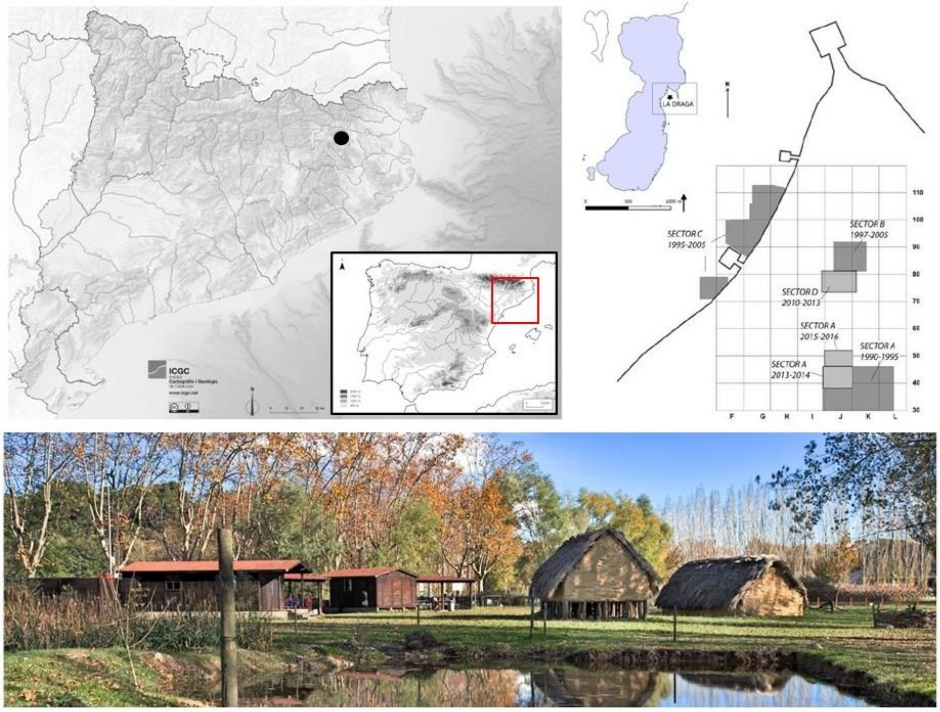

Figure 59. Localisation of the La Draga site (Banyoles, Girona - northeastern Iberian Peninsula).

Sector A was excavated in multiple seasons from 1991 to 1995, 2013 to 2016 and 2019 to 2021 and it is above the water table. In Sector B the archaeological level is in the phreatic layer, and it was excavated from 1997 to 2005, 2023 and 2024. Excavations from 2010 to 2013 were focused on a different sector called Sector B-D, located in the south of Sector B with very similar preservation conditions (Figure 60). Sector C is currently under water but was exposed in prehistoric times (excavated from 1997, 2005 and from 2019 to 2022). These three sectors present differences in the preservation of the organic materials: archaeological layers in Sector A contain charred organic materials, only the ends of the piles have been preserved under the water table. In contrast, the lowest archaeological layers of Sectors B-D and C have preserved perishable materials because of the anaerobic conditions due to the permanent presence of ground water (Bosch et al. 2000, 2006, 2011; Palomo et al. 2014, 2016).

Two different constructive occupations are detected at the site, corresponding to the Early Neolithic, precisely within the late Cardial Neolithic according to the pottery chronocultural adscription. The first period is called Phase I (Level VII sediments) and the latest chronological studies dated it in 5309-5247 cal BC (Table 9) (Andreaki et al. 2022).

It is related to the use of wooden platforms and their successive repairs which have been preserved in anoxic circumstances. It is characterized by the construction of dwellings above wooden piles whose situation and morphology are difficult to determine (López Bultó 2015, Bultó and Piqué 2018). The waterlogged part of this phase presents excellent preservation of organic matter, and it provided the richest collection of bioarchaeological materials from the Early Neolithic period in northeastern Iberia. The second occupation period - Phase 2 - is associated with pavements formed by travertine slabs and is dated in 5207-4862 cal BC (Andreaki et al. 2022). The preservation of organic materials is less common, and it basically takes place when materials are carbonized.

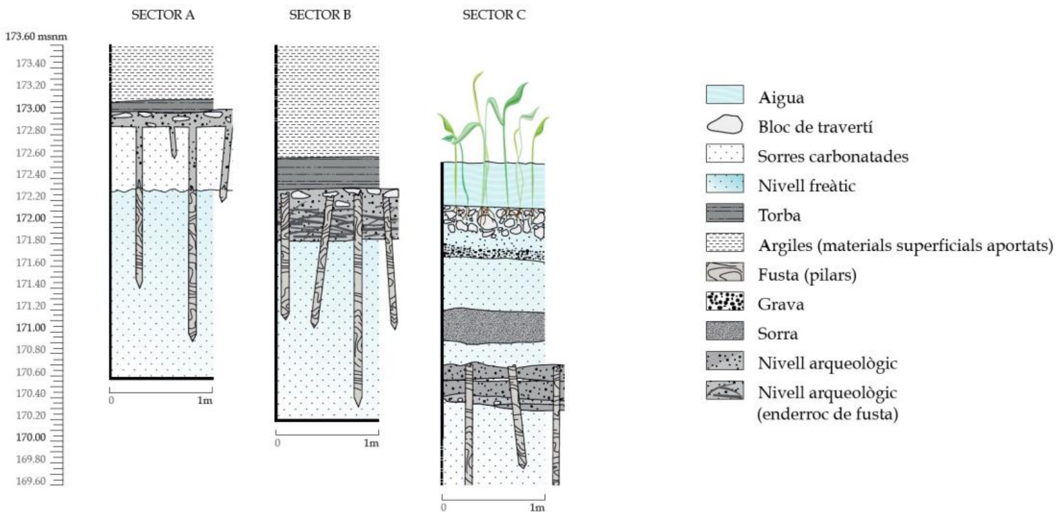

Figure 60. Water table level on each of the sectors described at the site (Sector A, B, C and D).

The pottery remains from La Draga appeared in a highly fragmented state, and are among the most damaged materials from the site. In Sector A, the edaphological conditions, together with fluctuations in the water table, had a serious impact on the pottery, altering the surface or even disaggregating the fragments until they became a clay mass. In Sectors B and C, the state of preservation of the ceramics is slightly better. The globular profile is the most representative and different shapes can be described. Hemispherical, spherical and cylindrical vessels are described as simple forms with variations in size and depth, while composite forms are represented by necked vessels with different depths (Figure 61a). A high percentage of decorated vessels is recorded (almost 70-80%), and the most common technique is Cardial impression using Mediterranean bivalves of *Cerastoderma* sp. and/or *Acanthocardia* sp. Other imprinting elements or drags over the surface are also represented, as well as the application of clay reliefs. Several vessels show a combination of decorative techniques. The complete decorative motif can only be reconstructed with some certainty on a small number of vessels (Bosch and Tarrús 2011, 2017).

Table 9. Radiocarbon data from La Draga site. The dates were calibrated using the OxCal v4.4 programme and the IntCal20 calibration curve (Bronk Ramsey 2021).

Lab code	Sector/ square	Material	Date BP	cal BC 68.2% interval		cal BC 95.4% interval		Method	Reference
Beta-505895	C	Peat	5060 ± 30	-3956	-2800	-3955	-3783	AMS-Standard	Piqué et al. 2021a
Beta-505896	C	Peat	5360 ± 30	-4320	-4070	-4328	-4054	AMS-Standard	Piqué et al. 2021a
Beta-425198	A	Fauna	5920 ± 30	-4836	-4727	-4888	-4716	AMS-Standard	Piqué et al. 2021a
Beta-481573	A	Fauna	5980 ± 30	-4904	-4800	-4984	-4784	AMS-Standard	Piqué et al. 2021a
Beta-422869	A	Fauna	5990 ± 30	-4935	-4805	-4987	-4791	AMS-Standard	Piqué et al. 2021a
Beta-298438	D	Fauna	6010 ± 40	-4951	-4839	-5002	-4793	AMS-Standard	Piqué et al. 2021a
Beta-422872	A	Fauna	6050 ± 30	-4997	-4905	-5036	-4846	AMS-Standard	Piqué et al. 2021a
Beta-428247	A	Fauna	6060 ± 30	-5006	-4905	-5198	-4847	AMS-Standard	Piqué et al. 2021a
HD-15451	A	Cereal	6060 ± 40	-5023	-4856	-5203	-4841	AMS-Standard	Piqué et al. 2021a
Echo-2448.1.1	B	Cereal	6090 ± 90	-5207	-4850	-5292	-4791	AMS-Standard	Piqué et al. 2021a
Beta-422871	A	Fauna	6100 ± 30	-5200	-4952	-5208	-4907	AMS-Standard	Piqué et al. 2021a
ETH-88872	D	Cereal	6116 ± 26	-5203	-4995	-5208	-4945	AMS-Standard	Piqué et al. 2021a
OxA-20232	B	Cereal	6121 ± 33	-5206	-4991	-5209	-4946	AMS-Standard	Piqué et al. 2021a
OxA-20234	A	Cereal	6128 ± 33	-5206	-4996	-5209	-4953	AMS-Standard	Piqué et al. 2021a
Beta-315049	D	Cereal	6130 ± 40	-5207	-4996	-5210	-4952	AMS-Standard	Piqué et al. 2021a
ETH-88873	D	Cereal	6131 ± 26	-5205	-5000	-5210	-4991	AMS-Standard	Piqué et al. 2021a
Beta-438952	A	Cereal	6140 ± 30	-5206	-5005	-5210	-4997	AMS-Standard	Piqué et al. 2021a
OxA-20235	A	Cereal	6143 ± 33	-5207	-5006	-5210	-4996	AMS-Standard	Piqué et al. 2021a
ETH-88874	D	Cereal	6152 ± 26	-5208	-5037	-5209	-5010	AMS-Standard	Piqué et al. 2021a
OxA-20231	B	Cereal	6163 ± 31	-5208	-5048	-5212	-5011	AMS-Standard	Piqué et al. 2021a
Beta-278256	C	Fauna	6170 ± 40	-5208	-5054	-5217	-4997	AMS-Standard	Piqué et al. 2021a
OxA-20233	A	Cereal	6179 ± 33	-5178	-5065	-5216	-5011	AMS-Standard	Piqué et al. 2021a
Beta-315050	D	Cereal	6180 ± 40	-5208	-5061	-5286	-5003	AMS-Standard	Piqué et al. 2021a
Beta-0000	B	Fauna	6184 ± 27	-5174	-5072	-5216	-5038	AMS-Standard	Piqué et al. 2021a
Beta-425194	A	Wooden post	6200 ± 30	-5212	-5072	-5292	-5046	AMS-Standard	Piqué et al. 2021a
Beta-505901	A	Wooden post	6210 ± 30	-5215	-5082	-5297	-5050	AMS-Standard	Piqué et al. 2021a
Beta-315051	D	Cereal	6210 ± 40	-5216	-5066	-5302	-5041	AMS-Standard	Piqué et al. 2021a
UBAR-1293	B	Wooden post	6220 ± 45	-5291	-5071	-5306	-5044	AMS-Standard	Piqué et al. 2021a
UBAR-1248	B	Wooden post	6240 ± 35	-5302	-5081	-5306	-5066	AMS-Standard	Piqué et al. 2021a
UBAR-1308	B	Wooden post	6270 ± 45	-5309	-5211	-5332	-5064	AMS-Standard	Piqué et al. 2021a
Beta-481571	A	Wooden post	6270 ± 30	-5303	-5215	-5318	-5084	AMS-Standard	Piqué et al. 2021a
Beta-315052	D	Cereal	6270 ± 30	-5303	-5215	-5318	-5084	AMS-Standard	Piqué et al. 2021a
Beta-278255	C	Fauna	6270 ± 40	-5307	-5213	-5323	-5071	AMS-Standard	Piqué et al. 2021a
Beta-425195	A	Wooden post	6280 ± 30	-5305	-5216	-5324	-5132	AMS-Standard	Piqué et al. 2021a
Ua-62942	D	Wooden post	6285 ± 39	-5307	-5217	-5363	-5083	AMS-Standard	Piqué et al. 2021a
UBAR-1247	B	Wooden post	6295 ± 45	-5312	-5217	-5372	-5079	AMS-Standard	Piqué et al. 2021a
Ua-62941	B	Wooden post	6308 ± 39	-5318	-5218	-5368	-5212	AMS-Standard	Piqué et al. 2021a
Beta-481572	A	Wooden post	6320 ± 30	-5322	-5220	-5363	-5216	AMS-Standard	Piqué et al. 2021a
Beta-425196	A	Wooden post	6320 ± 30	-5322	-5220	-5363	-5216	AMS-Standard	Piqué et al. 2021a
Beta-453513	A	Wooden post	6401 ± 38	-5470	-5321	-5475	-5310	AMS-Standard	Piqué et al. 2021a

The site documented a diverse range of lithologies used for daily sustenance and artisanal endeavours. The archaeological record revealed three primary categories of tools: chipped tools crafted from siliceous rocks, such as flint and quartz; adzes frequently made from metamorphic rocks such as amphibole and corneal schists; and larger grinding implements like querns, typically hewn from basalt, porphyric rocks, and granites. Sandstone and limestone pebbles were commonly used for polishing and burnishing respectively. The materials were sourced from a wide geographic range from local to tens of kilometres away (Figure 61b) (Palomo et al. 2011; Terradas et al. 2017). Functional analysis of lithic remains from La Draga revealed that some were used for woodworking and plant fibre processing, and others for butchering meat (Palomo et al. 2013).

Archaeozoological and archaeobotanical data indicate intensive activities of farming and cultivation (Antolín and Saña 2022). The archaeozoological studies carried out to date have provided a detailed picture of the various processes involved in livestock activity at La Draga, from the breeding and maintenance of the herds to the processing of the food obtained (Figure 61c). The results underline a differentiated management of the four main domestic species, with evidence of intensive herding, probably with animals moving closer to the settlement, especially during winter or the breeding season. The four main domestic species are sheep (*Ovis aries*), goat (*Capra hircus*), pig (*Sus domesticus*) and ox (*Bos taurus*), as well as wild species. However, the exploitation of at least 51 different animal species is documented at the site, with 3% wild and 97% domestic, the latter being the main supplier of animal products. The most hunted species were red deer, wild boar, roe deer and wild goat. Other species such as rabbit and small carnivores like badger, gull, marten and wildcat were also caught, although in smaller numbers, probably for fur (Saña 2011, 2013; Navarrete and Saña 2013; Navarrete 2017). In addition, ornithological remains have also been identified and associated with their consumption. 18 different bird families and/or species were recorded (*Phalacrocorax* sp., *Phalacrocorax carbo*, *Phalacrocorax aristotelis*, Anatinae, *Aythya* sp., *Aythya nyroca*, *Bucephala clangula*, *Pandion halietus*, *Perdicinae*, *Alectoris graeca-rufa*, *Grus grus*, *Crex crex*, *Fulica atra*, *Scolopax rusticola*, *Columba livia-oenas*, *Columba palumbus* and a small passeriform), both from lacustrine environments and associated with harvesting sites. Their exploitation is poorly represented compared to other faunal remains (Garcia Petit 2011).

Fishing and gathering aquatic resources were activities practiced on a daily basis at the site. Fishing is documented by the presence of remains of *Ictalurus* punctatus (catfish), *Amphilius platychir* (mountain barbel) and *Anguilla anguilla* (eel) (Antolín et al. 2017). Malacofaunal gathered remains have been identified in the archaeological register of La Draga, such as marine valves and bivalves (*Acanthocardia* (*Rudicardium*) *tuberculata*, *Callista chione*, *Cerastoderma glaucum*, *Chamelea* (*Venus*) *gallina*, *Clamys varia*, *Donax* sp., *Glycimeris glycimeris*, *Glycimeris violascens*, *Glycimeris bismaculata*, *Mactra corallina*, *Mytilus galloprovincialis*, *Ostrea edulis*, *Pecten* sp., *Spondylus* sp.), gastropods *(Cerithium vulgatum*, *Collumbella rustica*, *Sphaeronassa* (*Nassarius*) *mutabilis*) and scaphopods (*Dentalium vulgare*) from the Mediterranean coast. Most of the remains were consumed, but some were collected after the organism was dead. The use of malacofauna for personal ornamentation is also well documented at the site (Figure 61d) (Oliva Poveda 2011). There is also evidence of turtle (*Emys orbicularis*) consumption, and its shell was also used as a container (Tarrús 2008; Antolín et al. 2017).

Figure 61. Sample of non-organic archaeological materials found in La Draga site: a) Pottery fragments, b) Lithic and macrolithic materials, c) Faunal remains, d) Personal ornalments, e) Bone-based tools.

The archaeological record at the site includes an extensive and diverse range of bone tools (Figure 61e). These tools were made from different skeletal elements, mainly from domestic animals such as sheep and goats, including tibiae and metapodials, as well as bovine ribs. Regarding their production processes, different techniques such as percussion, abrasion and polishing have been recorded to produce a variety of tools, in particular awls and spatulas (Figure 61e). The functional analysis of these tools has revealed their use in different tasks, such as drilling and sewing animal skins or leathers, indicating the usefulness of needles and awls in textile production processes as well as in basketry (Legrand-Pineau 2011; De Diego et al. 2017, 2018). Smooth bivalves were used for skin working. However, mussel shells were collected alive, primarily for consumption as a food source, and later used for crafting purposes such as cutting, opening and stretching plant fibres (Clemente and Cuenca 2011; Palomo et al. 2013).

The archaeological excavation at La Draga uncovered at least 18 types of personal ornaments (Figure 61d). The most common ones were beads, circular pendant-beads, and oval-rhomboidal pendant-shaped beads, all made from shell fragments. Marine scaphopod beads, circular calcite beads, and globular beads made from volcanic rock, bone, and cherry stones were also discovered. The settlement produced rings made from antler, bone, shell, and marble, which were categorized by their diameter and shape for comfortable finger wear. Additionally, fragments of primarily marble bracelets have been found, as well as rectangular horn and perforated clay plaques. The number of beads found in various stages of production provides evidence of the settlement's craftsmanship (Oliva Poveda 2011, 2017).

Furthermore, the archaeological site of La Draga is considered the best palaeobotanically-described archaeological site in southern Europe due to its extended archaeobotanical record. The analysis of wooden implements (Figure 62a, b) also registered the use and exploitation of deciduous, riparian, and Mediterranean forests (López-Bultó and Piqué Huerta 2018). Deciduous *Quercus* sp. and Buxus sempervirens were the most often used raw materials to manufacture tools, but many other taxa were used for specific implements: *Corylus avellana*, *Laurus nobilis*, *Acer* sp., *Arbutus unedo*, *Clematis* sp., *Cornus sanguinea*, *Fraxinus* sp., *Juniperus* sp., *Pinus* sp., evergreen *Quercus* sp., *Rosaceae/Maloideae*, *Salix* sp., *Sambucus* sp., *Taxus baccata* and *Ulmus* sp. Moreover, during Phase I, large numbers of trees preserved in waterlogged conditions were felled to build the huts, of which over 95% consisted of oak (Piqué et al 2021b, 2021c). More than 1,271 vertical piles and 494 horizontal architectonic timbers were documented and their analysis determined that their acquisition was preferably in winter, although it seems that wood for the platforms was cut down in summer and autumn (López-Bultó 2015; Piqué et al. 2021c). In addition, tool marks were found on the surface of three *Laurus nobilis* piles, with new wood growing over the wounds. This was associated with an incipient management of the forest, including sorting, knowledge and control of tree growth (López-Bultó et al. 2023). The study of charcoal and wooden artefacts indicates extensive use of wooden materials that were acquired mainly locally.

Carpological remains are abundant at La Draga (over 300,000) and recovered thanks to the systematic procedure of recovering and wet-sieving sediment from the site (Figure 62d) (Antolín 2013; Piqué et al. 2021c). Most of this sort of material belongs to charred cereal remains including different species, but also in an uncharred state. Although no significant differences in terms of families consumed as food are seen between the two occupational phases at La Draga, there are differences in the conservation conditions owing to the lack of waterlogging in Phase 2, which means that organic material appears only carbonized. The cereal cultivated species are basically naked wheat (*Triticum durum/turgidum* type) and 2-row barley (*Hordeum distichon*, possibly the naked one). Slighter amounts of emmer (*Triticum dicoccum*), einkorn (*Triticum monococcum*) and Timopheev's wheat (*Trtitcum timopheevi*) are also present. Opium poppy (*Papaver somniferum*) has been also detected on the site as a probably cultivated plant. Plants gathered as food include acorns (*Quercus* sp.), hazelnuts (*Corylus avellana*), crab apples (*Malus sylvestris*), sloes (*Prunus spinosa*), bramble (*Rubus fructicosus*) and wild grape (*Vitis vinifera* subsp. *sylvestris*).

Remains of other non-alimentary plants have also been identified mainly in Phase I. Plant from aquatic/shoreland ecosystems are abundant, including a wide list of species such as *Alisma plantago-aquatica*, *Apium nodiflorum*, *Chara* sp., *Cladium mariscus*, *Cyperus fuscus*, *Iris pseudacorus*, *Lycopus europaeus*, *Mentha aquatica*, *Najas marina/intermedia*, *Nymphaea alba*, *Phragmites australis*, *Polygonum lapathifolium*, *Potamogeton* sp., *Ranunculus aquatilis*, *Ranunculus sceleratus*, *Scirpus lacustris*, *Typha angustifolia* and *Typha latifolia*. Ruderal plants (*Eupatorium cannabinum*, *Plantago major*, *Urtica dioica* or *Verbena officinalis*, among others) and species from woodland areas such as remains of *Alnus glutinosa* and fruit stones from *Cornus sanguinea*, *Crataegus monogyna*, *Taxus baccata* and *Tilia platyphyllos* have been recovered, some related to their use as food or infusions, and medical economic value (Antolín and Buxó 2011). Additionally, probable *Prunus avium* fruit stones modified into beads have also been detected. To date, a single case of Underground Storage Organs (USO) has been identified in the record from La Draga and identified as *Cyperus* sp. (Berihuete-Azorín et al. 2018a). Remains of tree leaves were also recovered from La Draga Specifically, 17 samples of *Laurus nobilis* leaves were identified, distributed throughout the excavation site, as well as *Buxus sempervirens* leaves and one sample corresponding to an undetermined species (Figure 62c) (Castells et al. 2020).

Figure 62. Sample of organic archaeological materials found in La Draga site: a, b) Diversity of wooden tools, c) In situ *Laurus nobilis* leaf, d) Carpological remains.

Due to the exceptional waterlogged conservation of organic materials in La Draga, 86 remains of fungal fruit bodies are also represented in Sectors B and C. Six different taxa were identified as *Skeletocutis nivea*, *Coriolopsis gallica*, *Daedalea quercina*, *Daldinia concentrica*, *Ganoderma adspersum* and *Lenzites warnieri*. Some of them show evidence of manipulation as partially charred and physical modifications (Girbal 2000, 2011; Berihuete-Azorín et al. 2018b). Additionally, exuded vegetal matter used as adhesives was identified as a mixture of birch bark tar with fat as a decoration or assembling adhesive in ornamental remains such as a fragment of marble bracelet (Piqué et al. 2021b).

Palynological studies have been performed on the sediments from the site (Sectors A and B) as from the lake sediments. The results revealed the early vegetal landscape was characterized by deciduous forests (deciduous *Quercus* sp. and *Corylus* sp.) and conifers (*Pinus* sp. and *Abies* sp.) in the proximate mountains. Low values of evergreen sclerophyllous taxa (*Quercus ilex-coccifera*, *Olea* sp. and *Phillyrea* sp.) suggest their existence regionally despite being scarce locally. In the surroundings of the site, riparian forests (*Ulmus* sp., *Fraxinus* sp. and *Salix* sp.) developed around the lakeshore, like hygrophyte plants (Cyperaceae, *Typha latifolia*, *Typha-Sparganium*, *Juncus articulatus* type, *Juncus effusus* type, *Cladium mariscus* and *Mentha* cf. *aquatica*) and aquatic species (*Potamogeton coloratus*) (Revelles et al. 2014, 2015, 2016, 2017; Revelles and van Geel 2016; Piqué et al. 2021b). A decrease in *Quercus* sp. values is recorded during the Neolithic occupation of La Draga (Pérez-Obiol and Julià 1994; Burjachs 2000; Revelles et al. 2016) and in the lakeshore peat deposits (Pérez-Obiol and Julià 1994; Revelles et al. 2014, 2015). That was when non-arboreal pollen like Poaceae expanded, as did other herbs (Asteraceae, *Artemisia* sp., Apiaceae, Chenopodiaceae, *Erica* sp. and *Plantago* sp.) and shrubs such as *Buxus* cf. *sempervirens* colonized the space left by oak forests, also recorded by anthracological analysis (Piqué 2000; Caruso-Fermé and Piqué 2014). Such trees as *Pinus* sp., *Corylus* sp. and *Tilia* sp. gained importance in the nearby mountains.

The charcoal analysis identified 18 tree and shrub taxa systematically used as firewood (Caruso-Fermé and Piqué 2014), in which deciduous *Quercus* sp. was the dominant taxa. Shrubs were represented in small proportions with the most represented taxa being *Buxus sempervirens* and Rosaceae/Maloideae, together with *Acer* sp., *Taxus baccata*, *Pinus sylvestris/nigra*-type and *Juniperus* sp. The riparian forest was also represented, mainly by *Laurus nobilis*, as well as *Ulmus* sp., *Fraxinus* sp., *Corylus avellana*, *Salix* sp. *Alnus glutinosa*, *Sambucus* sp., *Populus* sp., *Clematis vitalba* and *Cornus sanguinea*. Mediterranean vegetation was evidenced by the limited presence of evergreen *Quercus* sp. and *Arbutus unedo*.

4.3.2. Study materials.

The archaeological site of La Draga is the best described archaeobotanical site in the Iberian Peninsula, due to the excellent preservation of the organic material it contains, which has led to a long tradition of archaeobotanical analysis. In terms of plant fibre-based materials, both cords and basketry remains have been found at the site.

Both cords and basket remains were recovered directly in the field or during subsequent wet sieving, then cleaned and restored using the lyophilisation method (Bosch et al. 2006, Piqué et al. 2014). This consisted of polyethylene glycol (PEG) impregnation, freezing and drying by sublimation (Chinchilla et al. 2017). Lyophilisation can alter the surface characteristics of the remains, such as texture and colour. Preliminary descriptions of the fibre-based remains were published in the monographic volume on the site, where the pieces were described metrically, although a systematic technological description was absent (Bosch et al. 2000, 2006). It also provided very generic raw material identification based on macroscopic features; only one single piece was identified by Schoch. The materials are currently stored in the Museu Arqueològic Comarcal de Banyoles.

4.3.2.1. Cordage register.

The cordage assemblage analysed here was recovered during archaeological fieldwork from 1998 to 2005 in Sector B (Phase I), where organic remains were preserved by waterlogged conditions. Piqué et al. (2018) published the first technological analysis and an approach to the raw material used was carried out for some of the remains based on microscopic images. The total sample consists of 75 remains, including twisted fibres (N=35), twisted cords (N=33) (Figure 63a-e), a braided cord (Figure 63f) (N=1), single fibres (N=2), a knot (N=1), indeterminate remains (N=2) and unprocessed liana rolls (N=2). Although the lianas have not been studied in the current work. Taking into account the similarities between the fragments regarding their morphology and technology, as well as their position in the site, several associations were made, resulting in 22 different registers (Romero-Brugués 2021). Each register corresponds to either a single cord element or a group of fragments with similar characteristics that have been associated. Although small cord fragments can be separated from larger ones, it was not always possible to associate them with a specific cord element.

Even in the fragmentary state of preservation, several morphological and technical features of the remains could be observed (Table 10). Measurements such as cord and strand length and width, and angle of torsion, were taken to describe the process of their production and the associations between the fragments. The measurements taken from the cords show differences in their thickness, which varies between 4 and 16 mm, and the angle of torsion, which is variable between 10 and 45º. This angle is related to the stiffness of the cord. The length of the cords is influenced by the taphonomic effects they have undergone. The fragments are all shorter than 90 mm, except for one register that corresponds to a roll of cord almost 2,000 mm long. The results of this study showed that most of the cords from La Draga were made by twisting, and the dominant pattern was the 2-ply S twist (S z,z), but it seems that the 3-ply Z pattern (Z s,s,s) was also recorded, as well as a single case of braided cord (Romero-Brugués 2021).

Table 10. Technological aspects the individualized coiled baskets from La Draga (Extracted from Romero-Brugués 2021).

Inventory number	Fragment description	Technique	Number of conserved fragments	Angle of torsion (º)	Length (mm)	Width (mm)
D98 JF83-4	ND	Indet.	1	ND	ND	ND
D98 JF86-13	Cord	Braided	1	15-20	53	16
D01 JJ87-22	String	S	1	20	5-37	8/2-4
D01 JJ87-7	String	Z S	5 6	10-15 20	21-55 17-52	1-3 2-8
D01 JJ87-43	Fibre	Indet.	1	ND	ND	ND
D01 KA87-13	String	S	3	30-40	39-69	7-9
D01 KA87-22	String	S	6	25-35	24-45	4-5
D01 KA87-27	Cord String	Z s,s,s S	1 3	40-45 15-20	67 28-65	11 5-6
D01 KA87-32	ND	Indet.	1	ND	ND	ND
D01 KB87-15	String	S	1	30	36	6
D02 JI88-15	Fibre	Indet.	1	ND	ND	ND
D02 KA88-14	Cord	S z,z	1	15-20	35	5
D02 KA88-15	String	S	1	20	52	8
D02 KA89-21	String	S	3	20-25	18-37	2-8
D02 KA89-5	String	S	1	20	48	4-5
D02 KA89-8	String	S	1	20	28	5-7
D02 KB90-7	String	S	1	20-25	56	7
D03 JH85-6	String	S	3	15-20	15-22	4-6
D04 JI92-9	Roll of cord Knot Cord	S z,z - S z,z	1 1 29	ND ND 30	1,916 10-13 ∑ 1,150	4-5 7 4-5
D05 JJ92-16	Cord	S z,z	1	25-30	90	4-5

Piqué et al. 2018 also worked on the raw materials used in a sample of four of the registers (references D01 JJ87-22, D02 JI88-15, D04 JF72-1 and D04 JI92-9) using optical and electron microscopes (Figure 64). They identified the use of bast stem fibres, lime tree bark fibres (*Tilia* sp.) and *Clematis* sp. corresponding to a roll of liana, which was not included in the current study. However, this part of the analysis is fully developed in the current thesis and will be developed in the next chapters.

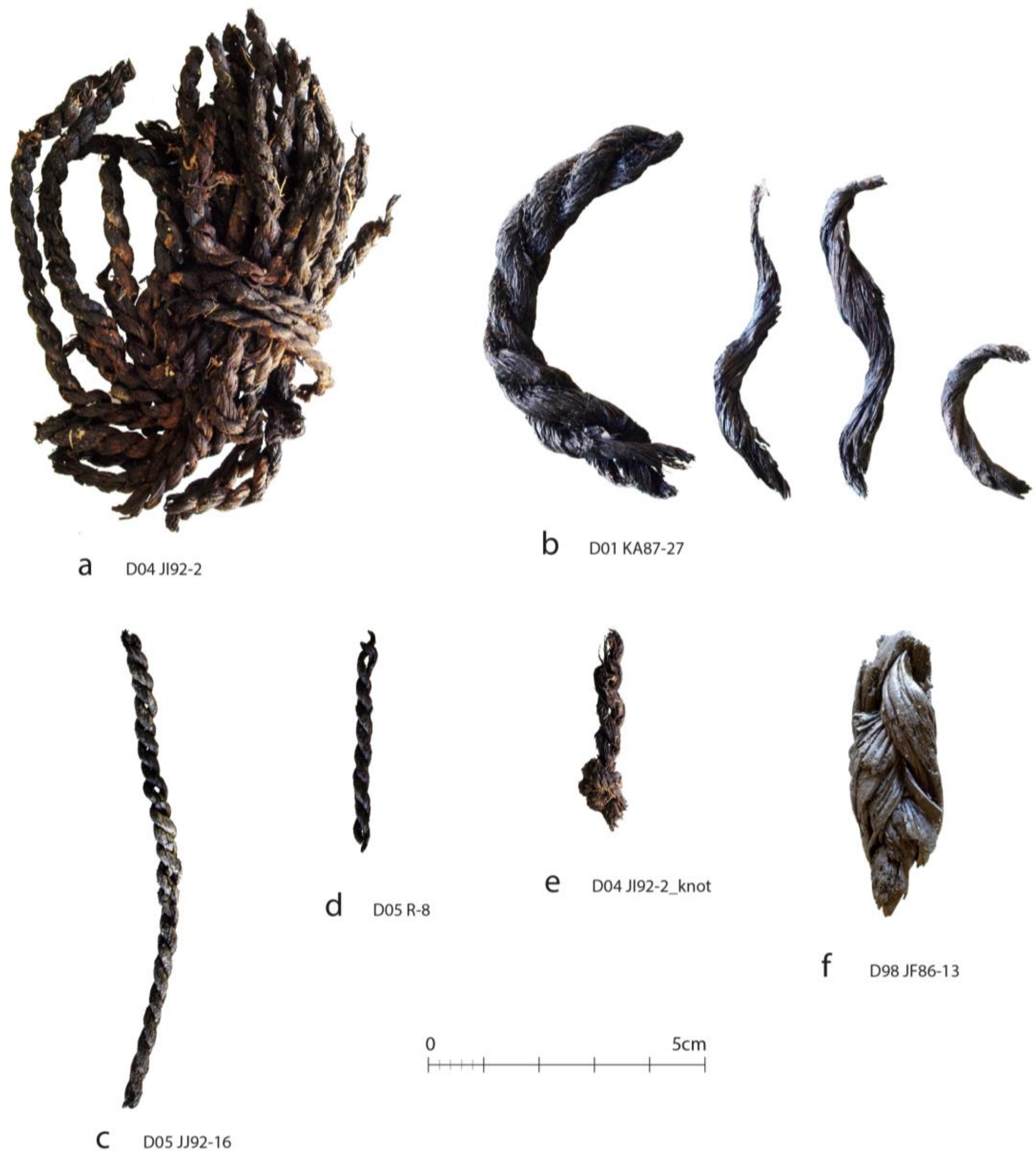

Figure 63. Cordage remains from La Draga : a-e) Twisted cords, f) Braided cord.

4.3.2.2. Basketry register.

The basket remains at La Draga were recovered during the archaeological fieldwork from 1990 to 2005, in Sectors B and C (Phase 1). Although they were all waterlogged, only a few of them were preserved organically and most of them were carbonized.

The morphological and technical description classified the 34 basketry fragments as bases, handles, knobs, and bundles of at least eight individualized items (Figure 65) (Romero-Brugués et al. 2021b, Romero-Brugués 2021). Two artefacts exhibit cereal grains attached to them (Figure 65c). Furthermore, it has been determined in four pieces that rigid or semi-rigid elements (such as branches or rods) were stitched to a beam (Figure 65g). These elements serve to reinforce the basket internally, enhancing its structural integrity.

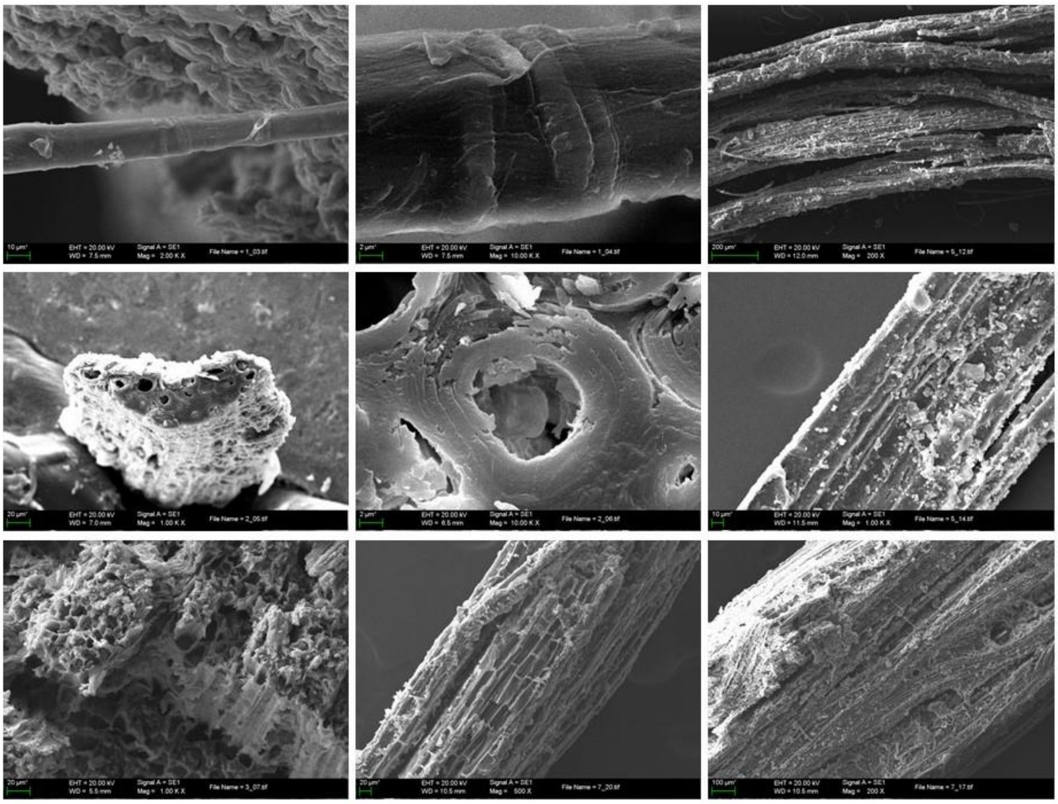

Figure 64. Cord raw material determination from La Draga made by Piqué et al. 2018 using scanning electron microscopy (SEM): a) Sample JI-92 (9), b) Sample JJ 88 (15), c) Sample JJ-87 (22).

Most of the 34 remains are small fragments ranging in length between 14.55 and 221.6 mm, in width between 6.01 and 35.1 mm, and in thickness between 3.6 and 19.61 mm. Therefore, the high fragmentation of the assemblage does not allow the original size of the baskets to be calculated. Despite the high fragmentation, three pieces stand out for their larger size. The fragmentation of the set makes it challenging to establish clear morphological categories or draw conclusions about the represented morphotypes.

Regarding manufacturing techniques, the whole sample is determined as coiled basketry with variations in the type of stitches (Romero-Brugués et al. 2021b; Romero-Brugués 2021). The thickness of the bundles and the width of the stitches vary considerably between objects. While most of the bundles are 4-8 mm thick and the stitches 2-4 mm thick, showing some consistency in their production, there are notable exceptions. One piece stands out for its size, with a single bundle 17.13-19 mm thick. However, it is important to acknowledge that some of the bundles are not well preserved, showing material loss or deformation due to carbonisation or post-depositional processes. Therefore, the sizes of the bundles are approximate estimates.

In terms of stitch typology, it has been observed that all instances use simple stitches, with five variations (Figure 66) (Romero-Brugués 2021). The predominant technique at La Draga employs V-shaped double simple stitches (N=18). The remaining four categories consist of simple interlocking stitch (N=4), simple non-interlocking stitch (N=4), simple split stitch with simple interlocking stitch (N=1), and simple split stitch with simple non-interlocking stitch (N=4). In three cases, the stitch type could not be determined (Table 11). Additionally, four pieces showed the use of a combination of stitch types, such as simple split stitch with simple interlocking and non-interlocking. Overlapped stitches were observed in a single case, where simple split plus simple split overlapping was used.

To determine the section of the basket, criteria such as the presence or absence of vertical and horizontal curvature, as well as the visibility of stitches from the last preserved bundle, have been used. The presence of handles and edges, along with some fragments exhibiting vertical curvature, suggests that they originated from baskets. Measurements of horizontal and vertical curvatures provide insights into the original size of the objects or the specific part of the objects.

The measurements of horizontal and vertical curvature provide information about the original dimensions of the objects or the specific section of the basket or mat from which the fragments originate. In most cases (N=27), the fragments show horizontal curvature, indicating their association with the base of the basket (Romero-Brugués 2021). It is worth noting that two pieces still retain the foundational element. Vertical curvature has been measured in only five fragments. Only four pieces exhibit concavity in terms of vertical curvature. One of these fragments (D98 JG84-27(4)) may belong to a handle or knob. The remaining three fragments show curvatures that suggest they were part of the rims or walls of the containers.

The original size or diameter of the objects could not be determined due to their small size. However, the minimum width or diameter of the base has been estimated using the horizontal curvature, while the minimum diameter of the rim has been inferred from rim fragments, and the opening from the handle or knob. Horizontal curvature measurements have been recorded for 29 pieces (Romero-Brugués 2021). The two basket bases with a circular coiled foundation have diameters of 28.8 cm and 11 cm. The smallest objects have minimum diameters ranging from 11 to 13 cm, while three fragments come from bases with minimum diameters exceeding 30 cm, with the largest estimated at 42 to 46 cm in diameter. It is important to note that in many cases, the curvature is minimal or absent, indicating that they may have originated from large objects, or alternatively, that they were asymmetric, possibly oval in shape.

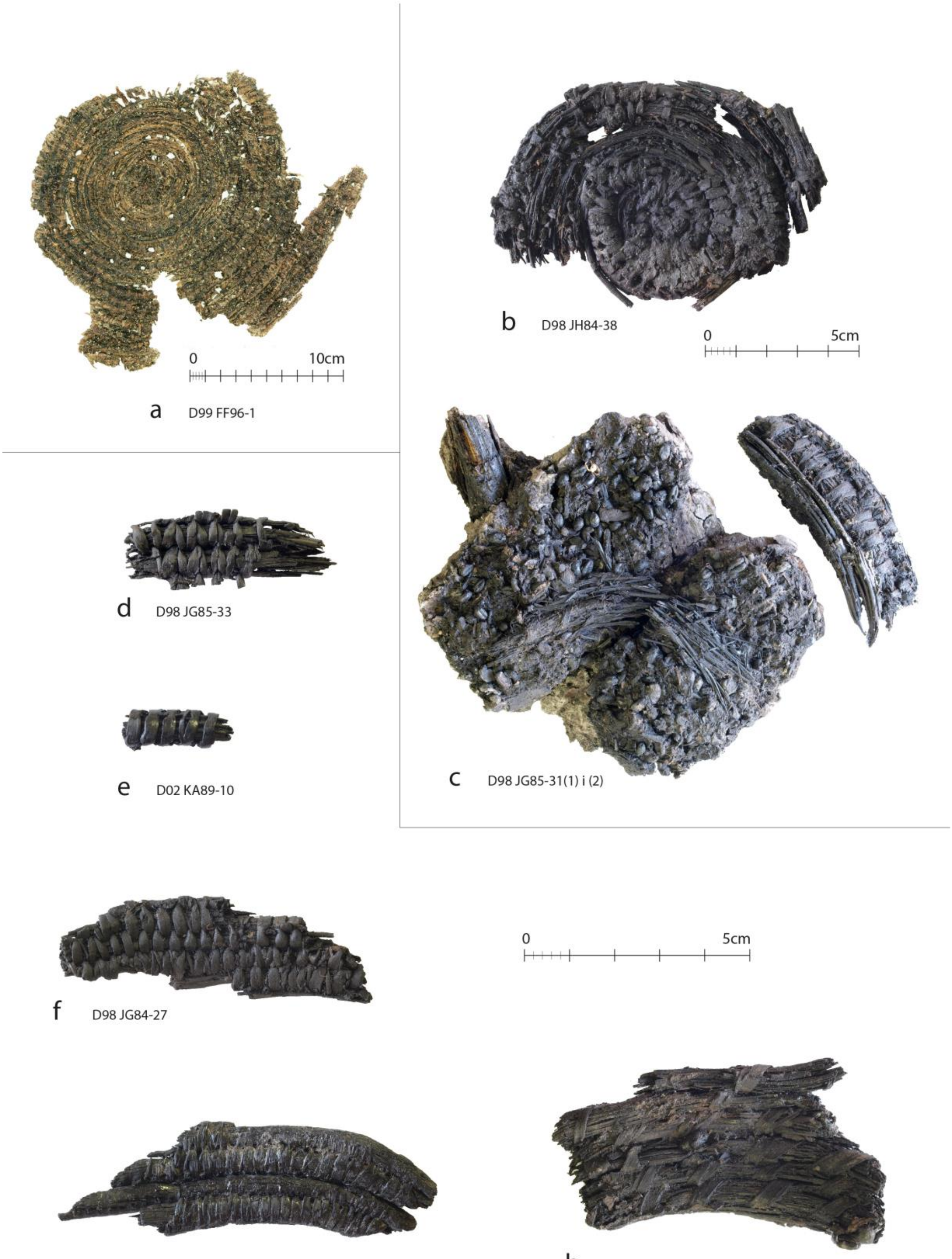

Figure 65. Basketry remains from La Draga.

Additional data facilitate the connections between fragments, particularly when remains were discovered spatially proximate and recorded together during excavation. The criteria used to propose the association of objects include similarities in bundle thickness, fibre composition, texture, raw material, stitch type, measurements, and the presence of fundamental elements. According to these criteria, it is believed that the La Draga assemblage corresponds to at least eight individual objects. Each individual has been assigned a letter (A, B, C, D, E, F, G, and H) (Table 9).

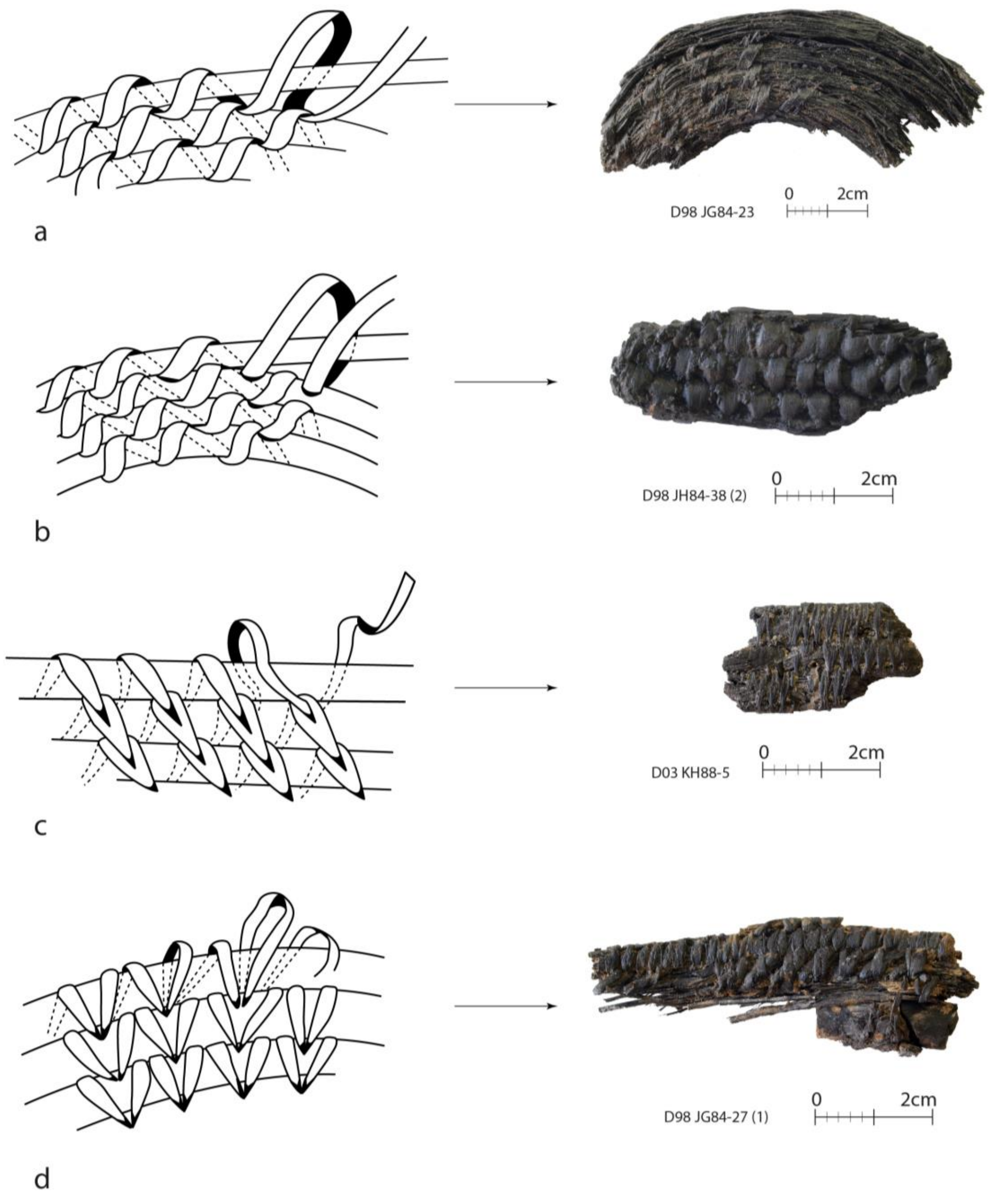

Figure 66. Coiled basketry variations identified in La Draga basketry fragments: a) Interlocking stitch, b) Non-interlocking stitch, c) Split stitch, d) V-shape or double stitch. Drawings modified from Romero-Brugués (2021) by RR.

Table 11. Technological aspects of the coiled basketry fragments registers from Coves del Fem (Extracted from Romero-Brugués 2021) (*Continues).

Individual	Reference number	Kind of rest	Horizontal curvature	Vertical curvature	Minimum length bundle	Maximum length bundle	Minimum length stitch	Maximum length stitch	Number bundles preserved	Measures	Shape	Spacing of foundation or coil	Type and form of stitch
A	D/97 FF-96/1	BASE	288,14	/	9,68	12,75	2,96	3,46	12	221*158*3	Circular base	Close	Simple split
B	D/04 EJ-73/3 (1)	BUNDLE	140-160	/	14,83	15,4	4,44	6,12	1	56*26*9	Not have	Not preserved	Simple split?
	D/04 EJ-73/3 (2)	BUNDLE	200-240	/	8,92	9,5	/	/	1	55*11*8	Not have	Not preserved	Not preserved
C	D/02 KA-89/10 (1)	INDET.	180-220	220-260	5,99	6,92	3,77	3,92	2	47*12*5	Indet.	Close	Simple split
	D/02 KA-89/10 (2)	HANDLE OR KNOB	/	/	8,02	9	2,8	3,71	1	24*8*6	Indet.	Not preserved	Simple non-interlocking
	D/02 KA-89/10 (3)	INDET.	60-100	/	6,22	7,67	2,12	3,41	2	27*13*7	Indet.	Close	Simple split
	D/02 KA-89/10 (4)	INDET.	180-220	160-200	2,54	5,1	2,46	3,29	3	32*12*3	Indet.	Close	Simple split
	D/02 KA-89/10 (5)	HANDLE OR KNOB	/	/	6	/	2,2	3,3	1	14*6*4	Indet.	Not preserved	Simple non-interlocking
D	D/02 KC-90/6 (1)	BASE	500-560	/	4,36	7,49	1,43	2,23	4	81*21*6	Oval base	Close	Simple split
	D/02 KC-90/6 (2)	BASE	very weak	/	4,49	6,69	2,2	2,92	2	59*11*6	Oval base	Close	Simple split?
	D/02 KC-90/6 (3)	RIM	/	/	6,9	7,7	2,58	2,91	2	31*13*6	Indet.	Close	Simple split
E	D/98 JG-84/23	BASE	110-130	/	8,9	10,02	3,2	4,8	5	95*41*7	Oval base	Close	Simple interlocking
	D/98 JG-85/24 (2)	BASE	140-180	/	17,13	19	3,01	4,45	1	92*17*8	Only one bundle	Not preserved	Simple interlocking
	D/98 JH-84/38 (4)	BASE	120-140	/	5,1	6,6	3,8	6,6	6	72*35*8	Oval base?	Close	Simple interlocking
F	D/98 JG-84/27 (2)	BASE	380-420	/	3,53	6,49	2,51	4,54	4	95*25*8	Oval base?	Close	Simple split + simple non-interlocking
	D/98 JG-85/24 (1)	BASE	very weak	/	5,41	6,79	2,61	2,98	2	57*13*6	Indet.	Close	Simple split
	D/98 JG-85/31 (2)	BUNDLE	300-340	/	9,4	21,47	3,4	5,1	3	92*31*19	Associated with fragment of *Corylus*	Close	Simple split

Continuation of Table 11.

Individual	Reference number	Kind of rest	Horizontal curvature	Vertical curvature	Minimum length bundle	Maximum length bundle	Minimum length stitch	Maximum length stitch	Number bundles preserved	Measures	Shape	Spacing of foundation or coil	Type and form of stitch
G	D/98 JG-84/27 (3)	RIM	400-520	/	5,9	8,45	2,6	3,21	3	67*23*6	Indet.	Close	Simple split + simple non-interlocking
	D/98 JH-84/38 (2)	RIM	400-500	/	6	7	3,3	4,3	3	48*19*8	Indet.	Close	Simple split + simple non-interlocking
	D/98 JH-84/38 (5)	BASE	111,36	/	5,7	10,75	3,2	4,2	5	110*73*8	Circular base	Close	Simple split + simple non-interlocking
H	D/98 JG-84/27 (4)	HANDLE OR KNOB	/	400-500	7,38	7,67	3,4	3,9	2	29*14*6	Indet.	Close	Simple split
	D/98 JG-84/27 (5)	INDET.	140-180	/	9,16	10,67	3,7	4,9	2	45*20*9	Indet.	Close	Simple split
	D/98 JG-85/33	BASE	very weak	/	6,67	7,32	1,8	4,88	2	46*16*5	Indet.	Close	Simple split
	D/98 JH-84/38 (3)	RIM	/	160-180	4,3	5,7	1,7	1,9	3	50*15*7	Indet.	Open/ Close	Simple split + simple split overlapping
	D/98 JH-84/41	INDET.	420-500	/	8,91	11,09	3,16	6,5	3	56*23*9	Indet.	Close	Simple split
	D/98 JH-85/28	BASE	420-460	/	6,2	6,5	2,98	3,13	9	86*21*8	Oval base?	Close	Simple split
	D/03 JH-88/5	BASE	very weak	/	6,24	6,78	2,13	2,62	3	33*18*4	Indet.	Close	Simple split
G or H	D/98 JG-84/27 (1)	HANDLE?	400-500	/	4,1	4,4	3,5	3,8	2	65*20*8	Indet.	Open/ Close	Simple split + simple interlocking
	D/98 JG-84/48	INDET.	200-220	/	6,65	9,59	2,3	4,23	2	43*15*8	Indet.	Open/ Close	Simple split
	D/98 JG-85/31 (1)	INDET.	300-340	/	/	/	4,1	5,3	1	116*9	Indet.	Not preserved	Not preserved
	D/98 JH-84/23 (1)	HANDLE	200-240	/	11,86	13	3,4	4,5	1	49*11*9	Indet.	Not preserved	Simple non-interlocking
	D/98 JH-84/23 (2)	HANDLE	/	/	9,63	10,5	4,04	6,33	1	22*11*9	Indet.	Not preserved	Simple non-interlocking
	D/98 JH-84/37	SHAPELESS FRAGMENT	/	/	/	/	1,9	2,7	/	66*26*9	Not have	Not preserved	Not preserved
	D/98 JH-84/38 (1)	INDET.	240-280	/	2,3	9,26	2,1	5,2	3	73*15*13	Indet.	Not preserved	Simple interlocking?

4.4. Cova del Pasteral, ca. 5000-3000 BC (El Pasteral - La Cellera de Ter, Girona).

4.4.1. The site and its archaeological record.

The archaeological site of the Cova del Pasteral refers to a series of natural interconnected caves nearly 300 m in length, in El Pasteral (La Cellera de Ter) in the northeast of the Iberian Peninsula, 20 km west of Girona (Figure 67). The caves are found in an outcrop of limestone on the northern side of a hill called Muntanya de Canet or Puig de Gria. The formation of the limestone began 450 million years ago by calcium carbonate precipitation in the sea. The sediments became lithified and originated a calcareous formation of huge thickness folded on itself. Rainwater percolated through the calcareous rocks and shaped rounded cavities. Then, 300 million years ago, magma from this volcanic area entered these chambers and its contact with the calcareous elements produced a mineralogical rearrangement producing the formation of marble, a metamorphic rock (Ferrer 2021).

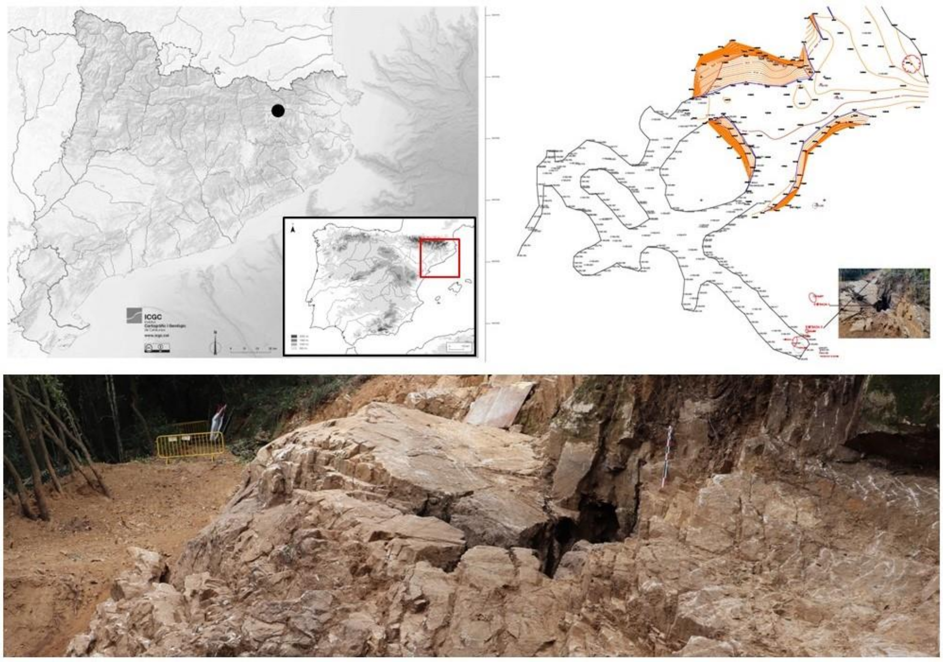

Figure 67. Localisation of the Cova del Pasteral site (La Cellera de Ter, Girona - northeastern Iberian Peninsula).

The discovery of the site took place at the end of the 20th century when the area was exploited as a marble quarry. During those works, a sepulchral cave with different archaeological materials related to Neolithic chronologies was found. However, the natural prehistoric entrance must have been blocked at the end of the Neolithic period due to the lack of modern materials in the site.

The site was visited numerous times by residents from the area who recovered archaeological materials from it. Riuró (1942) published the first description of the cave and the materials recovered by the teacher from El Pasteral. These materials are currently stored in the Museu d'Arqueologia de Catalunya (MAC, Barcelona). The sporadic recoveries and the destruction of the cave by mining activities resulted in fragmented contextual information. In the 1980s, speleologists made new and interesting finds in the cave, and the first archaeological analysis of the materials was published. Bosch (1985) carried out a study of the materials recovered from the site and attributed the materials to two chronocultural periods: the Epicardial Early Neolithic (Montboló culture) and the Late Neolithic/Chalcolithic. Moreover, the anthropological analysis of the human remains identified at least 23 individuals (9 for the early phase of the site, and 14 for the latest) (Campillo and Vives 1985).

Systematic archaeological work started in 2020 when the cave became municipal property in the framework of a project focused on the reappraisal of the cave regarding its geological and archaeological interest as well as its biodiversity. For the first time, the site is being excavated archaeologically and studied and this fieldwork has led to the discovery of several entrances and a new gallery as well as documenting the stratigraphic sequence of the site which is currently being described (Figure 68). Since the discovery of a possible natural entrance to the cave in the archaeological work in 2020 (García 2020), the annual fieldwork at the site from 2021 to 2023 confirmed the existence of this access as well as its richness in archaeological materials from prehistoric periods. The pottery record from the excavations has confirmed the chronocultural adscriptions made by Bosch (1985). Together with the first radiocarbon results, this dates the Cova del Pasteral site in ca. 5000-3000 BC.

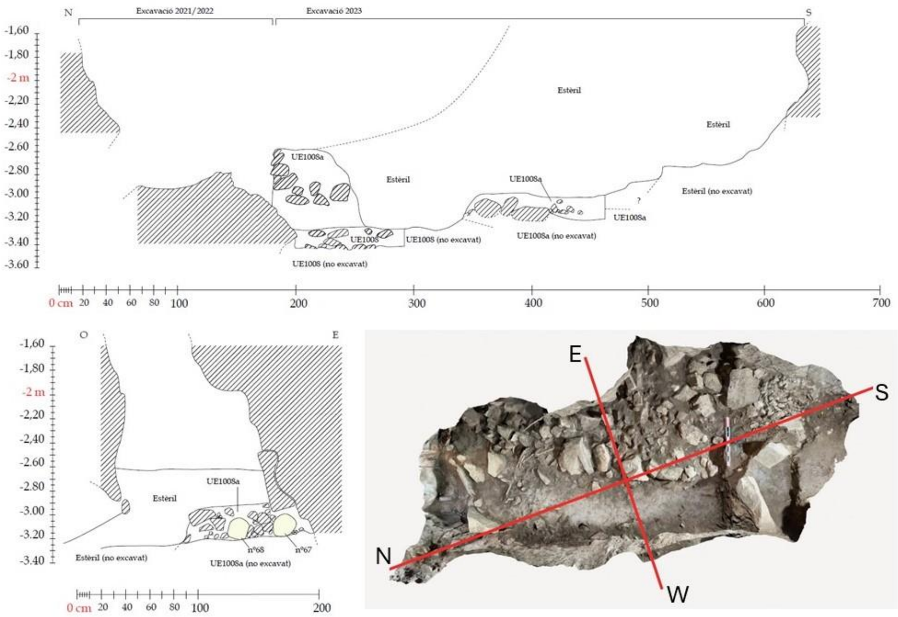

Figure 68. Fieldworks section from the Cova del Pasteral site.

Figure 69. Sample of archaeological materials found in the Cova del Pasteral site: a) Pottery examples; b) Lithic materials d) Machrolithic materials e) Glycimeris sp. bracelet and stone collar beads.

The archaeological materials from the site include an important assemblage of pottery fragments (Figure 69a) and an abundant representation of human remains including both unintentional secondary depositions and in situ inhumations. Whereas the lithic record

(Figure 69b-d) is not very extensive a dagger was find (Figure 69b), but also ornamental element such as beads of different materials (stone, bone, and shell) and a *Glycimeris* sp. bracelet (Figure 69e). These materials are currently deposited in the Universitat Autònoma de Barcelona (UAB, Bellaterra) for their analysis. To date, no archaeobotanical studies have been performed at the site, although its proximity to the archaeological settlement of La Draga means that the palaeoenvironment data from La Draga can be used to form an idea of the past vegetation profile.

4.4.2. Study materials.

The material from the site studied in this research was recovered in the Early Epicardial Neolithic layer (UE1008), which is characterized by the high concentration of pottery fragments chronologically ascribed to this chronological phase and dispersed human remains (Rosillo et al. 2021a; 2021b; 2023). No burials have been found in the site corresponding to the Early Neolithic phase. However, anthropological studies have established that at least twelve individuals were deposited in the cave during this period, representing all age groups. In addition, the analysis of the remains has identified degenerative arthritis of the vertebrae, calcification of the anterior ligament of the joints and infectious pathologies in the mouth, such as caries (Agustí Farjas 2024).

Dental calculus analysed in this PhD dissertation was collected from two isolated teeth from the Epicardial Neolithic layers. As both teeth were isolated no further information about the individuals is available. Besides being adult teeth with different wear patterns, no other pathologies were present. Supragingival tartar deposits from buccal surfaces were extracted from a maxillary right first premolar (Tooth 14) and from a maxillary lateral incisor (Tooth 22) (Figure 70).

Figure 70. Teeth from the Cova del Pasteral site studied in the current research: Tooth 14 (left) and Tooth 22 (right).

CHAPTER V - METHODOLOGY

5. Methodology.

5.1. The creation of a specific modern reference collection.

Although various techniques can be applied to study plant fibres used as raw materials for the manufacture of utensils, a fundamental part of their study - similar to other branches of archaeobotanical research - is the creation of a reference collection. Such collections comprise modern materials that allow archaeological remains to be compared with current species in order to propose taxonomic identifications. The reference material must be specific to the material to be studied, taking into account both chronology and place of origin. In the case of the current PhD dissertation, the reference collection for the study of plant fibres used as raw materials include species traditionally utilised in such fibre-based crafts. Ethnographic studies and traditional knowledge are essential, together with previous archaeobotanical analyses of the study area, to build the reference collection.

The analysis of reference materials is focused on the microanatomical features of different parts of the plants used in fibre-based productions. The description of the anatomical features is an ongoing process, which will be expanded as the study progresses, and is supported by specialized literature. There are freely accessible online reference collections, such as the Fiber Reference Image Library (FRIL) run by Ohio University (fril.osu.edu) and the Fibers in Ancient European Textiles (FIBRANET) created by the Centre for Textile Research at Københavns Universitet (netlearning.gr/fibranet). However, the best or the ideal way to work and compare archaeological specimens is to create one's own reference collection specific to the area and chronology of the study. This has been done in the current research, as explained in this chapter.

5.1.1. Brief review of vascular plant anatomy.

5.1.1.1. Vascular plant histology. Tissue systems.

In order to compare archaeological material with modern references, specific characteristics of the plants should be taken into account. Since plant fibres are generally leaves and stems of monocotyledonous - both whole and fragmented - as well as fibres from the inner part of woody dicotyledonous species, plant or plant histological concepts must be clear. These microanatomical characteristics are key for plant identification. To clarify some histological concepts and to make the reading of this thesis a little more accessible, a brief overview of the anatomical and histological organisation of vascular plants is given below.

The organisation of vascular plants is the result of evolutionary processes, adaptation and specialisation from aquatic habitats to the colonisation of terrestrial environments. New morphological and physiological adaptations were adopted in each part of the vascular system, leading to the differentiation of plant organs (Troll 1937; Arber 1950). After long botanical discussions, the number of plant organs was reduced or summarised to three: stem, leaf and root (Eames 1936), although the first two are usually treated together under the term 'shoot' due to a close structural and developmental relationship (Evert 2006). Moreover, each of these organs represents a structural and functional organisation of the tissues of which it is composed, and although they continue along the body of the plant, their arrangement indicates specific interactions and specialisation of functions. Botanists have proposed a classification of tissue systems (Sachs 1875; Haberlandt 1914; Foster 1949) based on the topographical continuity of tissues, resulting in three distinct systems: the dermal, the basal (or ground) and the vascular tissue systems:

Dermal tissue system. Complex tissue corresponding to the primary outer protective layer of the plant body, usually one cell layer thick, and comprising the epidermis and the peridermis.

Fundamental (or ground) tissue system. This is the simplest tissue and contains cells with different degrees of specialisation, such as the parenchyma with living cells (most common in the ground tissue), the collenchyma with thicker walls and the sclerenchyma with lignified cell walls.

Vascular tissue system. It is also a complex system composed of two conducting tissues, the xylem, which transports water, and the phloem, which transports nutrients to the different parts of the plant.

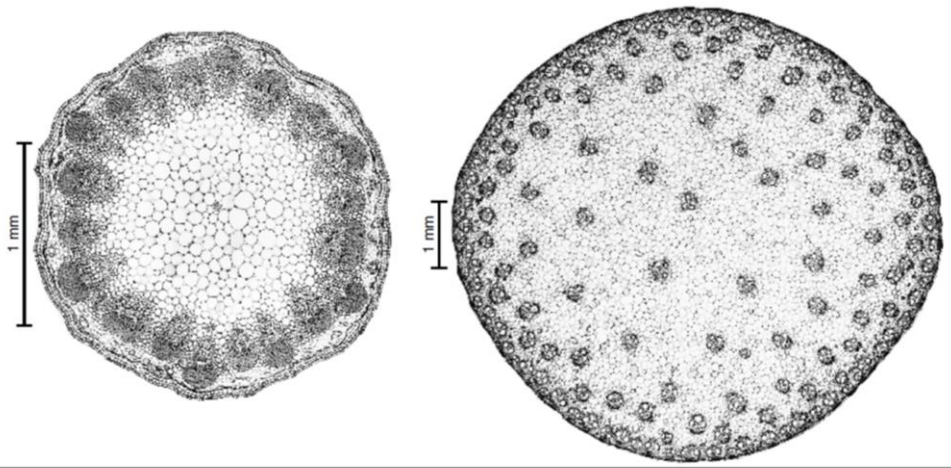

Figure 71. Dicotyledonous (left) and monocotyledonous (right) transversal section.

As mentioned above, the organisation of these tissue systems along the plant body is different and allows the plant taxon to be determined. The one that exhibits the most important differences is the vascular system. For example, in the stems and leaves of monocotyledons they are scattered along the whole unit, embedded in the ground tissue, but in the case of dicotyledons they form a ring located under the cortex, leaving a pith of medulla in the centre (Figure 71). These tissues are developed and explained below. The descriptions of the concepts are based on Esau's Plant Anatomy (Evert 2006).

5.1.1.2. Vascular plants tissues.

5.1.1.2.1. Epidermis.

The epidermis is the outermost layer of cells on all parts of the primary plant body, including roots, stems, leaves, flowers, fruits, and seeds. Organs that exhibit little or no secondary growth usually maintain the epidermis, although in woody species the longevity of the epidermis varies depending on the moment the secondary growth occurs. The functions of the epidermis include reducing water loss by transpiration, mechanical protection, and it also facilitates gas exchange through stomata (Evert 2006). This multiplicity in functions is reflected in the variety in cell typology, such as the epidermal cells (Figure 72) (also known as ground cells, pavement cells or unspecialized cells), or the guard cells of the stomata and appendixes (trichomes and root hairs). The spatial distribution or patterning of the stomata and trichomes in the leaf epidermis is considered non-random and it can be used for taxonomical purposes.

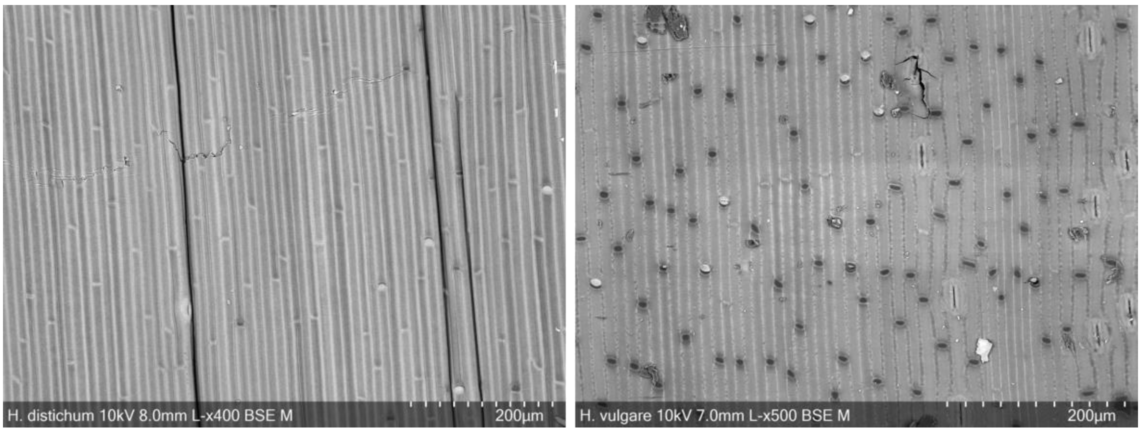

Figure 72. Variability in epidermal cells in different taxonomical families or species: *Hordeum distichum* stem epidermis (left), *Hordeum vulgare* stem epidermis (right).

Stomata, or stomatal pores (Figure 73), are openings in the epidermis bounded by two specialised cells - the guard cells - that change in shape to open or close a central pore. In some species, stomata are surrounded by cells that are indistinguishable from other epidermal cells and are known as neighbouring cells. The main function of stomata is to regulate the exchange of water vapour and CO2 between internal tissues and the external environment (Hetherington and Woodward 2003). For this reason, stomata are found on all aerial parts of the plant body, although they are more abundant on leaves. Their density varies greatly in photosynthetic leaves, differing on different parts of the same leaf (adaxial and abaxial surfaces) and on different leaves of the same plant.

Trichomes (Figure 73) are variable epidermal appendages that occur on all parts of the plant and persist throughout the life of the individual, although they can survive death and carry out a wide variety of functions, such as protection. They vary in structure between families and can even be used for taxonomic identification (Uphof and Hummel 1962; Theobald et al. 1979). Trichomes can be classified into several morphological categories, including papillary, simple, multicellular, stellate, dendritic, and others. A comprehensive glossary of plant trichome terminology has been compiled by Payne (1978).

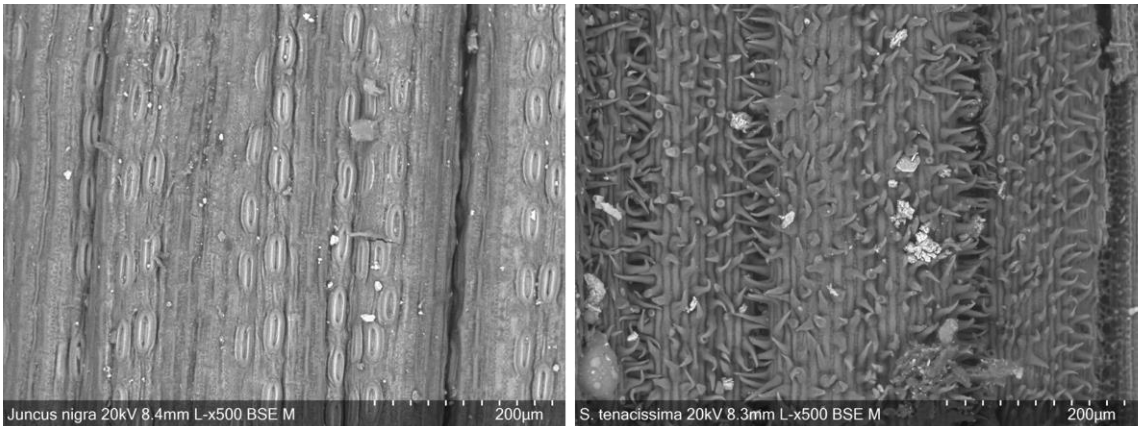

Figure 73. Left: *Schoenus nigricans* stomata cells on the stem epidermis. Right: *Stipa tenacissima* trichome on the abaxial leaf epidermis.

5.1.1.2.2. Peridermis.

Periderm is a protective tissue of secondary origin that replaces the epidermis in stems and roots undergoing secondary growth, resulting in increased thickness. The term 'periderm' should be distinguished from the non-technical term 'bark'. Although 'bark' is often used loosely and inconsistently, it is useful when properly defined. Bark most appropriately refers to all tissues outside the vascular cambium. In the secondary state this includes the secondary phloem, any remaining primary tissue outside the secondary phloem, the periderm and the dead tissue outside the periderm.

5.1.1.2.3. Parenchyma.

The parenchymatic tissue is generally considered to form part of the basic ground tissues of plants (Figure 74). It is based on living cells of different physiology and morphology, although it usually presents polyhedral cells involved in different vegetative functions of the plant. The parenchyma appears in the different organs of the plant, embedding other structures such as vascular bundles. It has reproductive cells and is in fact the main site where essential functional activities of the plant take place, including photosynthesis, assimilation, respiration, storage, secretion and excretion. However, its cells have a slightly different role depending on the organ of the plant. For example, in the vascular tissues (xylem and phloem) they play an important role in transporting water and nutrients along the plant. In terms of their cells, they are relatively undifferentiated morphologically and physiologically, which allows them to change or combine functions, although they can also be specialised for specific functions such as photosynthesis.

5.1.1.2.4. Collenchyma.

This is a living tissue composed of a single elongated cell type with thickened walls but without lignification (Figure 74). Parenchyma and collenchyma cells are physiologically and structurally similar, but the main difference between them is that collenchyma cells have thicker walls and are usually more elongated in shape. Because of the similarities between the two tissues and the structural and functional variability of both, collenchyma is generally considered to be a thick-walled type of parenchyma, structurally specialised as a supporting tissue. Collenchyma has relatively soft, pliable, non-lignified primary walls and has a supportive function in growing organs and in mature plant organs slightly modified by secondary growth. Roots rarely contain collenchyma, but collenchyma may occur in the cortex (Guttenberg 1940). The peripheral location of this tissue is highly characteristic, as it may appear just below the epidermis, or it may be separated from the epidermis by one or more layers of parenchyma. In addition, in many plants, the parenchyma is found in the outermost phloem and innermost xylem, as part of a vascular bundle or surrounding the entire vascular bundle, and has a thick primary wall.

5.1.1.2.5. Sclerenchyma.

The sclerenchyma tissue is composed of cells with a secondary wall, often lignified, which provides mechanical support to other softer cells in the plant. Its cells appear in groups or bundles between other plant tissues and have a secondary wall, which is why they usually appear lignified (Figure 74). They are usually divided into two categories: fibres and sclereid. The former are described as long cells, whereas sclereids are shorter in length, although they can vary in the same individual. Sclereids have more pits on their walls than fibres, but this difference is not constant: the real difference comes from their origin, since sclereids come from parenchyma cells, while fibres come from meristematic processes.

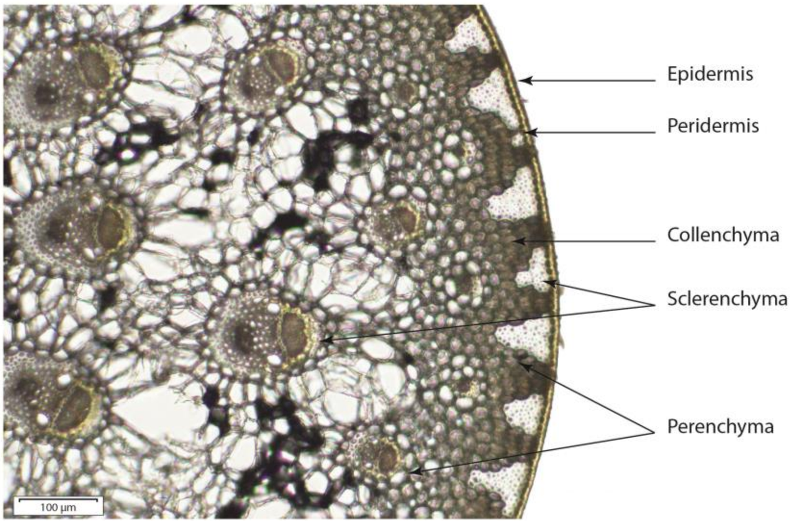

Figure 74. Epidermis, peridermis, collenchyma, sclerenchyma and parenchyma tissues visible in a *Juncus effusus* transversal section.

As mentioned above, fibres are typically long, spindle-shaped cells with more or less thick secondary walls, and they usually occur in strands, which are the fibres used in the manufacture of plant fibre products. Retting processes allow their extraction and result in the separation of fibre bundles from some plants (mainly dicotyledons). The fibres overlap and give strength, hardness and flexibility to the fibre bundles. Sclerenchyma fibres are widely distributed throughout the plant body: they can be found in separate strands in the cortex and phloem, or even as sheaths or bundles associated with the vascular bundles. The fibres are arranged differently in the stems of monocots and dicots (Schwendener 1874; de Bary 1884; Haberlandt 1914; Tobler 1957). In monocots, e.g. Poaceae, the fibres form a system in the form of a ribbed hollow cylinder, with the ribs connected to the epidermis, or they may appear to be fused with other sclerenchyma structures. In monocots, dispositional fibre patterns can vary at different levels of the stem or leaf between species, but also within the same plant (Murdy 1960). Fibres are prominent in leaves where they form sheaths enclosing the vascular bundles (Figure 74), or strands extending between the epidermis and the vascular bundles, or subepidermal strands not associated with the vascular bundles (Evert 2006). For example, palm leaves have isolated vascular bundles with massive, radially extending fibre sheaths (Tomlinson 1961). In angiosperm stems, fibres often occur in the outermost part of the primary phloem. Dicots have complete cylinders of fibres close to the vascular tissue and close to the innermost layer of the cortex. Roots show a similar distribution of fibres to stems and may have fibres in the primary and secondary body. There is a more detailed classification of fibres in terms of their location and origin, but this is beyond the scope of this thesis. In fact, and although the term 'fibres' is widely used and applied to materials that, in the botanical sense, include other types of cells, it corresponds to plant fibres with a commercial purpose.

Sclereids are typically short cells with thick secondary walls, heavily lignified and with numerous simple pits. Some sclereids have relatively thin secondary walls, making them difficult to distinguish from sclerified parenchyma cells. The secondary wall typically appears multilayered, reflecting its helical construction (Roland et al. 1987, 1989).

5.1.1.2.6. Xylem.

The xylem (Figure 75) is the main water-transporting tissue in vascular plants, although it is also involved in the transport of solutes, e.g. minerals, and together with the phloem, forms the vascular tissue system. The xylem is composed of a continuous system of components called tracheary elements along all parts of the plant, which have hard, rigid cell walls. Primary and secondary xylem can be distinguished on the basis of histological differences, although the classification must be considered broadly, relating these two components of xylem tissue to the development of the plant as a whole (Evert 2006).

The cellular components of the xylem tissue include: tracheary elements, sclerenchyma fibres and parenchymatic cells, forming a complex tissue system. The tracheary elements are essentially the tracheid and the vascular elements, which are the actual conducting cells of the xylem. Both are elongated cells with lignified walls that are not alive at maturity. The latter present perforation plates, which are perforations or pits basically on the end walls, although they can also be present on the lateral walls. Tracheids also have perforations, but they are less abundant and therefore less effective in conducting water (Wang et al. 1992; Becker et al. 1999). These perforated plates are the means by which different vascular elements are connected to form long, continuous columns called vessels. In fact, the vessel elements lack a perforated plate at their upper end, creating a unidirectional movement of water and solutes from vessel to vessel, from the bottom to the aerial parts, occurring through the pit pairs in their common walls. It is a passive process that does not consume any energy.

5.1.1.2.7. Phloem.

The phloem (Figure 75) is considered to be the nutrient conducting tissue of vascular plants, derived from photosynthesis. A wide range of substances are transported along the phloem, not only nutrients but also hormones, so it is also involved in inter-organ communication in the plant (Crawford and Zambryski 1999; Thompson and Schulz 1999; Ruiz-Medrano et al. 2001; van Bel and Gaupels 2004). It is structurally related to the xylem. It can also be divided into primary and secondary. Both contain the same cell types, the sieve elements and other different parenchyma cells, as well as sclerenchyma fibres and sclereids. The sieve elements are the main elements of the phloem and have pores in their walls and can be divided into sieve cells and sieve tube elements. They also present some companion cells that offer resistance to the phloem structure, which are a kind of specialised parenchyma cells and are arranged in companion cell strands. Transport by the phloem is an active process from the upper parts to the rest of the plant.

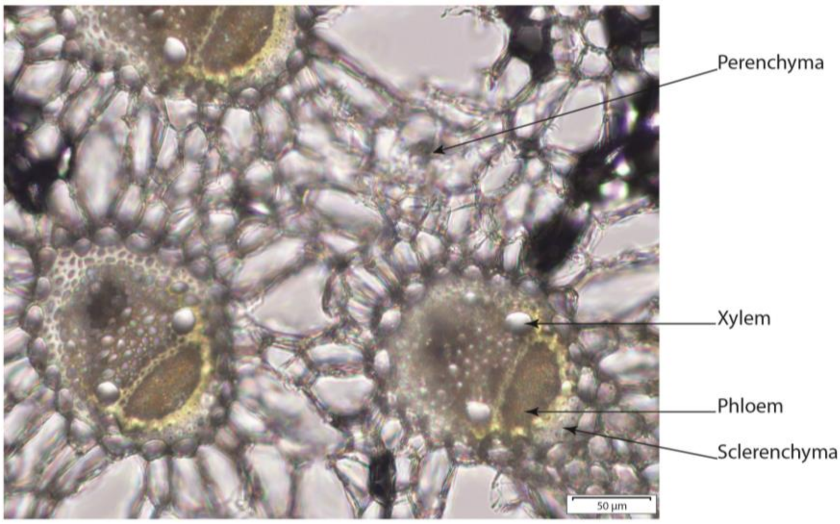

Figure 75. Xylem and phloem distribution in a *Juncus effusus* transversal section.

5.1.2. Species selection and specimens obtaining.

As mentioned at the beginning of this chapter, the fibre specimens used to create the reference collection included in this thesis were selected on the basis of traditional and ethnographic knowledge of fibre-based crafts in Europe and the Iberian Peninsula. To this end, some publications have been consulted, as well as popular knowledge through oral tradition learned from artisans in different parts of the study area. Dialogues were established with different artisans from the northeastern part of the Iberian Peninsula, who basically specialised in working with hard branches such as *Salix* sp., but also from the central and southern part of the Iberian Peninsula, where they are more used to working with *Stipa tenacissima*, Avena sativa or Chamaerops humilis. Furthermore, other plants have been selected and included, despite not being traditionally utilised in the region. From the artisans' perspective, these plants can also be employed in this type of production due to their resemblance to other plants used or their morphological attributes.

Finally, archaeobotanical studies from the sites included in this thesis were also consulted and taken into account in the selection of plants that could have been used in the production of fibre-based objects in the different areas and sites.

Once the species have been selected as part of the modern material to be compared, it is also important to select the parts of the plants that could have been used for this type of craft. This was achieved through the same traditional ethnographic knowledge and the experienced point of view of the artisans, together with the bibliography. As a result, both leaves and stems from different monocots can be employed, and are typically used, while in the case of dicots, bark and bast strips from the stems are utilised.

The collection of these plants was carried out directly in the field when they were available, but when they were not, thanks to the collaboration with the Jardí Botànic de Barcelona - Museu de Ciències Naturals de Barcelona (NAT, Barcelona) and the Archaeobotany Lab Hemmenhofen Herbarium (Landesamt für Denkmalpflege Baden-Württemberg, Germany). It should be mentioned that some of the plants can be difficult to collect because of the complexity in their correct identification.

Monocotyledonous usually do not require lengthy processing to be used. In most cases (some cereals, sedges, rushes and cattails) it is sufficient to wet the fibres (stems or leaves) by placing them in water and wrapping them in a damp cloth. The length of time in water depends on the plant, the environment, the temperature of the water and the preferences of the artisan. When there is no physical processing, these fibres are known as 'raw'. In some cases, such as esparto grass (*Stipa tenacissima*), monocots can be used in different ways or at different stages of processing. Esparto grass can be used raw, as explained above, but it can also be used 'cooked', which means that the fibres remain in water for up to three or four weeks (depending on the preference of the artisan), causing a kind of fermentation or maceration that makes them more malleable. They can then be dried and moistened again before use. Both raw and macerated esparto grass can also be physically processed by beating the fibres with a hard piece of wood to break the more 'woody' parts and make the fibres more malleable. In the case of dicotyledonous plants, they undergo a retting process in which the fibres are immersed in water. This causes the natural breakdown of organic matter by fermentation, allowing the sclerenchyma tissue to be separated from the plant.

The processing required for the use of those plant fibres should also be considered in the preparation of a reference collection, as their distinctive features can change during physical or chemical processing to make them malleable. Consequently, these processes were also replicated in order to create the reference collection, from the physical crushing of some species, such as *Stipa tenacissima*, to the retting of such other plants as *Linum usitatissimum*, *Urtica dioica* and *Tilia* sp. Table 12 give details of the species selected for the reference collection, the part of the plant and its processing.

Table 12. Species and parts of the plant included in the reference collection of this thesis.

Specie	Family	Class	Part of the plant	Processing	Localisation
Avena sativa	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Carex pendula	Cyperaceae	Monocotyledoneae	Stem	Raw	Hemmenhofen Herbarium (Germany)
Chamaerops humilis	Arecaceae	Monocotyledoneae	Leaf	Raw	Zacatín (Granada)
Cladium mariscus	Cyperaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Cyperus fuscus	Cyperaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Hordeum distichum	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Hordeum vulgare	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Juncus effusus	Juncaceae	Monocotyledoneae	Stem	Raw	Jardí botànic de Barcelona - NAT
Juncus inflexus	Juncaceae	Monocotyledoneae	Stem	Raw	Jardí botànic de Barcelona - NAT
Juncus maritimus	Juncaceae	Monocotyledoneae	Stem	Raw	Jardí botànic de Barcelona - NAT
Lygeum spartum	Poaceae	Monocotyledoneae	Leaf	Raw	La Contraviesa (Granada)
Phragmites australis	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	El Bages (Barcelona)
Schoenus nigricans	Cyperaceae	Monocotyledoneae	Stem	Raw	Montsant (Tarragona)
Scirpus holoschoenus	Cyperaceae	Monocotyledoneae	Stem	Raw	El Bages (Barcelona)
Stipa gigantea	Poaceae	Monocotyledoneae	Leaf	Raw	Almería
Stipa tenacissima	Poaceae	Monocotyledoneae	Leaf	Raw Processed	La Contraviesa (Granada)
Triticum aestivum	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Triticum dicoccum	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Triticum durum	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Triticum monococcum	Poaceae	Monocotyledoneae	Leaf Stem	Raw Raw	Hemmenhofen Herbarium (Germany)
Typha angustifolia	Typhaceae	Monocotyledoneae	Leaf	Raw	Hemmenhofen Herbarium (Germany)
Typha latifolia	Typhaceae	Monocotyledoneae	Leaf	Raw	Hemmenhofen Herbarium (Germany)
Cannabis sativa	Cannabaceae	Dicotyledoneae	Bast fibres	Processed	Lejre (Denmark)
Linum usitatissimum	Linaceae	Dicotyledoneae	Bast fibres	Processed	Lejre (Denmark)
Tilia cordata	Malvaceae	Dicotyledoneae	Bark strips	Processed	Vallès Oriental (Barcelona)
Tilia platyphyllos	Malvaceae	Dicotyledoneae	Bark strips	Processed	Vallès Occidental (Barcelona)
Urtica dioica	Urticaceae	Dicotyledoneae	Bast fibres	Processed	Lejre (Denmark)

5.1.3. Sampling and preparation.

In the case of the specimens to be examined under the light microscope, both transverse and epidermal sections were prepared from the raw fibres, while the processed fibres were mounted directly, corresponding to the longitudinal views. Thin slides were prepared as follows.

In order to obtain thin sections, it is necessary to hydrate the samples. The first step was to place a small piece of each plant (leaf and/or stem) in water for an indefinite period of time until it was rehydrated enough to be cut.

Translucent sections were then cut with a razor blade using very gentle movements to obtain a flat and clean surface, particularly for the transverse section. Although a microtome could be employed, it was not used for the current research as the cuts obtained were of sufficient quality to be observed. In addition, the thin sections for the epidermis were obtained by peeling the samples. Although this is a relatively simple process, it can be difficult with some plant parts - such as leaves - as they can be very thin.

The specimens were then mounted for light microscopy using Euromex PB5265 Entellan as a permanent mounting medium, although some were also mounted with pure glycerine and sealed with transparent nail polish.

The samples were examined using an Olympus BX43 optical microscope with a polarized polarizing filter coupled with an Olympus DP26 camera linked to Olympus cellSens software. The polarized filter was used in bast fibre observation (dicotyledonous) as it allows the internal microfibrillar structure to be examined. The preparation of the samples and their microscopic observation was performed in the Archaeobotany Laboratory of the Prehistory Department at the Universitat Autònoma de Barcelona (UAB). In fact, this was the first reference collection of plant fibres to be created there.

In the case of scanning electron microscopy images of the reference collection materials, a Hitachi TM4000Plus benchtop microscope linked to the Hitachi TM4000Plus benchtop SEM workflow software was used without metallisation of the samples. This microscope was used during the overseas secondment to the Archaeobotany Laboratory of the Landesamt für Denkmalpflege Baden-Württemberg in Hemmenhofen (Germany).

5.2. Archaeological materials.

5.2.1. Plant fibres direct evidence: fibre-based crafts.

As mentioned above, various analytical techniques can be used to identify raw materials employed in the manufacture of plant fibre products. The choice of method depends on factors such as the state of preservation and conservation of the materials, the feasibility of sampling - often a destructive process - the objectives and development of the study, and the availability of the necessary infrastructure. Techniques range from those readily available to researchers and laboratories to more complex analyses requiring sophisticated, specialised facilities. These methods are not mutually exclusive: the use of multiple techniques can provide more detailed and accurate results. In this research the identification is based on microscopic observation - optical, scanning and digital - of the samples and, as mentioned above, comparison with specific reference materials.

In recent years, the identification of raw materials has been revised in order to improve or clarify the results, whether due to a lack of materials to compare, methodological issues, or an increase in archaeobotanical knowledge and the development of the science. An example is the textile specimens from Çatalhöyük (Turkey), which were initially identified as flax or wool based, but were recently re-analysed and the raw material was microscopically identified as bark strips from oak (Quercus sp.) and Poaceae leaves (Rast-Eicher et al. 2021). The researchers highlight that tree liber has been overlooked in the identification of plant fibres, with the exception of some species such as lime, especially in northern Europe. It also highlights the need or importance of studying fibre-based materials with the most recent and innovative technologies. Another example of re-studying archaeological materials is the case of Cueva de los Murciélagos, which is studied here, as it is the first time that a systematic and microscopic analysis of these raw materials has been carried out (Martínez-Sevilla et al. 2023) after preliminary work forty years ago (Alfaro 1980, 1984).

5.2.1.1. Sampling archaeological plant fibres.

Sampling archaeological material is by nature a destructive method. In the case of fibre-based objects, the loss of archaeological material is even more negative due to the rarity of this type of perishable material, and can be a limiting factor in the research to be considered.

However, due to the fragility, the complexity of recovering, the restoring and storing processes of these materials, small fragments of fibres often break off naturally and can then be used as samples. When possible, these fragments were sampled to prevent further damage to the objects and to ensure that the archaeological artefacts remained intact. However, in some cases it was not possible to determine the origin of these fragments (the archaeological object from which they came), then small pieces of fibres were obtained from the materials.

Typically, one or two samples were taken from each archaeological object, depending on its size. However, it is important to consider the sampling process in relation to the type of object, the technique used to make it, and the types of elements it contains. For example, in coiled baskets - the most common basketry technique among the materials in this research - there are two distinct elements: the coils and the stitches. In these cases, both elements were sampled separately in order to identify differences in the raw materials used.

It is important to note the minimal size required for microscopic observation, which is a significant advantage of this method and research. Fibre-based objects are typically sampled using tweezers and a blade cleaned with 96% ethanol between each object to prevent cross-contamination for future molecular studies, although such studies are not part of this thesis. The samples are carefully labelled with the material inventory number and placed in plastic Eppendorf tubes. This simple protocol was used to prevent contamination of the samples (Figure 76), although most of the material analysed here has been excavated, restored and stored for almost 40 years and has been handled by countless people.

Figure 76. Sampling proceeding of fibre-based artifacts.

5.2.1.2. Microscopic anatomical description and taxonomical identification.

Identifying plant fragments often involves studying their microscopic characteristics. Microscopy - both optical and electronic - is the most commonly used technique for identifying raw materials. This allows to observe the histological characteristics of the cross-section and the epidermis described in section 5.1.1.1 (Vascular plant histology. Tissue systems). The botanical identification of plant fibres based on the variations in the anatomy of the different tissues. Since the recognition of a single feature rarely establishes the identity of a plant, it is usually necessary to identify a unique combination of features.

In plant fibres, the determination will be based on the observation of the surface of the fibres - where the epidermis and the tangential section will be visible - and the transverse section. The aim is to obtain sufficiently clean and clear surfaces oriented according to these two anatomical planes: transverse and surface. This orientation allows detailed observation of the microanatomy and cell arrangement, which is essential for the taxonomic identification of the specimens). By studying these anatomical planes, researchers can determine the species and characteristics of the raw materials used in archaeological objects.

Although the microscopic observation of anatomical features is carried out on each fragment regardless of its state of preservation, it is evident that diagnostic features are more readily visible under certain conditions, such as charring. These features are also visible in dehydrated specimens, but their observation in waterlogged specimens is hindered more by the brightness caused by the residual water in the specimens than by the preservation of the internal structures of the fibres. Thus, the state of preservation and the conditions of the samples over time significantly influence the quality of the key features to be observed and identified, as well as the methods used to study them.

For cross-section observation, the best technique to obtain a good quality surface in charred fragments is to break the specimens mechanically by hand or with tweezers using a dry cutting method. In the case of dehydrated specimens, a razor blade is used to obtain good quality surfaces as these specimens do not break easily by hand. It is important to make minimal movements with the razor blade to avoid creating brightness lines. Although a microtome could be used, it was not necessary for the current research. Dry cutting methods, either by hand or with a razor blade, are effective for analysing charred and dehydrated remains, but observing a cross-section in water-saturated materials is more complex.

For epidermal observation, both charred and dehydrated elements are relatively similar to observe. In this case, cutting is unnecessary, but some cleaning with a thin, gentle synthetic brush is required to remove soil or sediment particles. Once clear surfaces had been prepared, the samples were placed on a support using materials such as small seeds (e.g. amaranth seeds), salt or sand, depending on the researcher's preference. These supports help to position the samples correctly for microscopic observation (Figure 77). In contrast, for waterlogged specimens, as with cross-sections, it may be helpful to immerse the specimens in water and minimise water movement. This will reduce the brightness caused by microscope light reflecting off the wet surface. Furthermore, it sometimes requires the creativity of the researcher to find a way of observing the features, such as adding a few drops of hydrogen peroxide (H2O2) to clean and clarify the structures, although this does not always work properly. Regardless of the material used, the support must meet two key requirements: it must properly support the fragment and allow the plane of observation to be positioned and maintained horizontally (Alcolea-Gracia 2017).

To view the surfaces of opaque specimens at different magnifications, a microscope with reflected light illumination using bright field (BF) and dark field (DF) contrast methods is required. The magnification, ranging from 40x to 500x, is chosen according to the anatomical plane being observed and the level of detail required. In the cross section, we observe primarily the arrangement and characteristics of the vascular tissue (xylem and phloem), accompanied by sclerenchyma fibres and parenchymatic tissue. In the epidermis, we examine the epidermal cells and stomata involved in cellular transpiration. Identifications and histological descriptions are based on comparisons with reference collections of modern material and specialist literature on plant physiology and histology.

The optical microscopy (OM) analyses for this research were carried out using a reflected light microscope for opaque specimens and a transmitted light microscope for specimens mounted on slides in the Archaeobotany Laboratory of the Prehistory Department at the Universitat Autònoma de Barcelona (UAB). An Olympus BX51 microscope was used, coupled with an Olympus DP26 camera and linked to Olympus cellSens software (Figure 77).

Figure 77. Optical microscopy in the Archaeobotany Laboratory of the Prehistory Department at the Universitat Autònoma de Barcelona (UAB).

Scanning electron microscope (SEM) analysis was carried out at the Microscopy Services of the same university. Scanning electron microscopy is useful for charred and dehydrated samples and provides higher quality images than optical microscopy. However, in some cases it is necessary to metallise samples, which is a destructive process, especially when samples are scarce. This metallisation consists of positioning the stubs using double-sided carbon tape and coating them with a 15 nm layer of gold using a sputter coater. The last analysis, such as in anthracology, non-metallised electron microscopy is therefore preferred to preserve samples for further studies, although specialists note that images are superior in quality when samples are metallised. For this reason, researchers often combine both types of microscopy: optical and scanning. For example, the work of Borojevic and Mountain (2013) and Martínez-Sevilla et al. (2023) focuses on dried remains, while Aura Tortosa et al. (2019) and Herrero-Otal et al. (2021, 2023) study carbonised remains. Romero-Brugués et al. (2021) examine both dried and carbonised remains, with some of these studies included in the current work. For waterlogged materials, however, SEM cannot be used due to the vacuum conditions required by these instruments, making optical microscopy the preferred method. An example of this is the study of the remains of fishing nets, probably made of stinging nettle (cf. *Urtica* sp.), from the Mesolithic site of Zamostje II in Russia (Berihuete-Azorín et al. 2023).

In some cases, where materials could not be extracted from the museums, more detailed images were taken using a portable digital microscope (Dino-Lite Edge Digital Microscope AM7915MZT) with a magnification range of 20x to 220x.

As proposed by several authors, the combination of optical microscopy and scanning electron microscopy was used in the current research. The latter allows clear observation of structures due to the high magnification and resolution of the images. This dual approach enhances the ability to analyse the micro-anatomy and cell arrangements in the samples, providing a comprehensive insight into their characteristics.

However, as anatomical features often overlap between species of the same family or genus, not always was possible to identify at specie level. The nomenclature used in this work follows the guidelines established in Flora Europaea (Tutin et al. 1980) and Flora Ibérica (Castroviejo 1986-2012). When it was necessary to clarify the level of classification, the following conventions were considered:

- When taxonomic identification was made at the family level, the term referring to the family was used (e.g. Cyperaceae).
- When taxonomic identification was made at the genus level, the term referring to the genus followed by 'sp.' was used (e.g. *Typha* sp.).
- When the analysed remains could belong to two genera or species that could not be objectively distinguished, a '/' was used regardless of the level determined (e.g. Cyperaceae/Juncaceae, *Typha domingensis/latifolia*).

- When the recognition of a taxon was highly probable but not objectively certain, the mention 'cf.' was placed before the name of the category concerned, regardless of the level determined (e.g. probably/cf. Poaceae, cf. *Tilia* sp.).
- When the determination was limited to the most basic distinction, the Class term Monocotyledoneae or Dicotyledoneae were used.
- Remains without any proposed attribution were classified as 'non-determined' if a determination could not be ventured despite the preservation of sufficient diagnostic characters; or 'indeterminate' if the absence of characters or poor state of preservation did not allow any attribution.

5.2.2. Other methodologies used for plant fibres analysis.

Ongoing technological advances in science have made it possible to apply methods not originally developed for plant fibre identification to this purpose, allowing older studies to be updated and supplemented in recent years. It is important to remember that fibre-based materials are rare in the archaeological record, as has been emphasised throughout this work, so it is crucial to study them whenever direct evidence is found and recovered. In addition, it is equally important to look for indirect evidence of plant fibres in non-organic remains using these new technologies. Although the analytical techniques for direct and indirect evidence are different, both approaches provide valuable insights into the use of plant fibres in the past.

Phytoliths. First, one field of study related to optical and electronic microscopy is the determination of phytoliths present in the plants. Phytoliths are silicified plant cells with a biomineralisation origin that remain intact after plant death and survive in soils and other materials for long periods of time because they are inorganic and do not decompose with organic material (Pearsall 2015). In fact, they have been recorded in acidic or aerobic conditions, where other fossil remains such as pollen are rarely preserved (Piperno 2006). The analysis of phytoliths in archaeology is very useful as it allows the identification of plants that were present at a site with no visible contemporary evidence (Shoada et al. 2024). It has been documented that monocotyledons produce more phytoliths than dicotyledons, and some families that produce a larger amount of these elements are Poaceae, Cyperaceae, Cucurbitaceae, Asteraceae and Palmae (Shoada et al. 2024).

Their recovery can shed light on the use of plants by human groups in relation to activities carried out in specific areas - such as crop cultivation - but also on the use of plant fibres for the manufacture of various objects. In fact, these are the cells that are visible on the epidermis of the monocot fibres that have been described previously. Ryan (2011) and Wendrich and Ryan (2013) analysed phytoliths associated with storage structures, such as pits, at the Neolithic site of Çatalhöyük (Turkey). The researchers found that at least four different plant species were used for the production of domestic fibre-based artefacts, which were also subsequently used in burial contexts. Some of the plants identified could be assigned to families (Cyperaceae, Panicoideae and Poaceae), while a single species, Phragmites australis, could be identified. The authors also noted that there may be an under-representation of fibre-based materials through the study of phytolith remains, as dicotyledonous plants are also used for their fabrication but produce few or none of such remains.

Computed tomography. Computed tomography (CT), or more precisely micro-computed tomography (micro-CT), consists of obtaining three-dimensional images using X-rays to scan the internal part of objects, slice by slice, on a very small scale with high resolution images. These images are obtained in slices of variable nanometre width - depending on the specimen to be scanned - which are then rotated to produce the same process until arriving at a 360° scan of the specimen completely. The images are computed into a reconstruction to be analysed in 3D models. This method does not alter or destroy the specimens as it is non-destructive, both during the preparation of the specimens and during the test itself. This makes it a good technology for the study of valuable materials such as archaeological remains, especially those based on organic materials such as fibre-based products. It obtains high-resolution reconstructed images providing information about the internal part, avoiding the need to cut the samples as required in microscopy, for example. In the analysis of plant fibres, it is very useful because it is able to obtain real images of the internal part of the fibres, allowing the internal histological structure to be seen together with the morphology - dimensions, shape and internal structures - and their variation along the whole plant part, as some researchers state (Dierick et al. 2014; Andonova 2021). In addition, the degradation of the fibres could be studied and documented. Nevertheless, it is important to have access to a micro-CT with a detector powerful enough to reach the micro-level to see the inner part of each fibre. This could be a very useful technique for the technological study of fibre-based products, such as the footwear from Cueva de los Murciélagos (Albuñol, Granada), in order to really understand how they are made, and in particular the central core type, to know how the fibres are represented in it.

Synchrotron. A synchrotron is a powerful research instrument that accelerates particles to produce high-intensity light, which is used in a wide range of scientific studies to reveal detailed information about the structure and properties of matter. The technology can produce detailed images of the internal structures of organisms, such as proteins and cells, and is also effective in chemical analysis, including the identification of elements and compounds. In archaeological research, high-resolution synchrotron-based microtomography is particularly valuable as it constitutes a non-destructive 3D analysis technique. It is useful for studying various aspects of fibre-based objects, such as morphotechnical parameters that are not visible through manual analysis, similar to the benefits offered by micro-CT. However, it is important to note that such imaging techniques have certain limitations (Iacconi et al. 2023).

Proteomics. Proteomics has made it possible to study plants in greater detail using mass spectrometry-based analysis. It involves the study of proteins, including their structure, function and interaction with other biological compounds. Plants produce a wide variety of proteins, many of which are specific to particular species, genera or families. By analysing the proteins present in plant fibres, researchers can identify their taxonomic origin (Solazzo et al. 2014). It is important to note that proteomics is a relatively new technique in the field of archaeology, and methods and protocols for its use are still being developed (Hendy et al. 2018).

Impressions on durable materials. Impressions left by plant fibre objects on non-perishable items such as ceramics or clay have become a way of studying fibre-based production in recent years (Andonova and Nikolov 2021). These impressions may have been made by placing moist ceramic vessels on fibre-based mats during their manufacture (Walker 1990, Papí 1992-1994, Rovira 2006, Guerra-Doce et al. 2024), or by waterproofing the durable objects (Hollander and Schwartz 2000). Alternatively, they can be decorative motifs on the surface, as observed on certain Corded Ware ceramics (Hole 1959), where impressions made with braids (Ibáñez et al. 2012) or pressed textile patterns (Watson 1991) are observed. Although these studies make it easy to determine the technique used to produce the fibre-based object - cords or baskets - the identification of the raw material is complex. In this sense, by analysing the morphology and measurements of the impressions left by the fibres, researchers can approximate the families of plants that could have been used, although these results are often not very precise. Studies have been published on the coiled basketry imprints from the Early Bronze Age site of Cova Fonda (Salomó, Tarragona), where the raw materials were probably made from monocotyledonous plants, along with the use of unspecified dicotyledonous bark for sewing the same objects (Romero-Brugués et al. 2022; Piqué et al. 2024), and on remains from the Chalcolithic/Bronze Age sites of the Villafáfila lagoons in central Iberia, more specifically the sites of Molino Sanchón II (ca. 2500-2000 cal BC) and Santioste (ca. 2400-1500 cal BC), where coiled basketry was also made with both monocotyledonous and dicotyledonous plants (Guerra-Doce et al. 2024). In both cases, experimental archaeology was part of the methodology to understand both the ceramic imprints and the raw materials.

5.2.2.1. Other evidence of plant fibres: Dental calculus samples.

In the search for plant fibres in non-perishable materials, dental calculus samples were analysed in the current research. Due to the lack of standardised methods, a methodological approach was developed to ascertain the best protocol for plant fibre extraction from dental calculus. First it was tested how different reagents used for disaggregating the dental calculus could affect the conservation of plant fibres. This approach was applied to various modern plant fibres used in fibre-based production, which are also included in the reference collection of this thesis. Secondly, the approach was tested on medieval dental calculus samples in order to control the procedure, the selection of this material as a control is due to the major availability and the abundance of dental calculus in these samples which minimize the risk of destroying this evidence. Finally, the method of extraction was applied to Neolithic samples for the case study.

5.2.2.1.1. Methodological approach applied to modern plants.

In order to establish the methodological approach used in this part of the current thesis, a bibliographic review of dental calculus analysis was carried out in order to select different solvents, concentrations and reaction times for testing their effects on plant fibres.

Firstly, a selection of different plants documented for craft purposes in North-east Iberia and surrounding areas in prehistory was made. This selection aimed to be representative of the different types of plant fibres traditionally used in basketry and textile production in the study area. Differences in the typical physical processing of these plants were also taken into account. Table 13 summarises the taxonomic classification, parts used and processing methods of the species included in this study.

Table 13. Species used in the reference collection for the methodological approach in dental calculus analyses.

Division	Class	Order	Family	Genus	Specie	Plant part	Processing state
Angiospermae	Monocotyledoneae	Poales	Poaceae	*Stipa*	*S. tenacissima*	Leaf	Raw Processed
Angiospermae	Monocotyledoneae	Poales	Cyperaceae	*Scirpus*	*S. holoschoenus*	Stem	Raw
Angiospermae	Monocotyledoneae	Poales	Typhaceae	*Typha*	*Typha* sp.	Leaf	Raw
Angiospermae	Dicotyledoneae	Malpighiales	Linaceae	*Linum*	*L. usitatissimum*	Bast fibre	Processed
Angiospermae	Dicotyledoneae	Rosales	Urticaceae	*Urtica*	*U. dioica*	Bast fibre	Processed
Angiospermae	Dicotyledoneae	Malvales	Malvaceae	*Tilia*	*Tilia* sp.	Bark strip	Processed

Once the plant species were selected, they were washed to remove any residual sediment using a Bransonic® 5510EDTH ultrasonic machine at the Anthropology Unit of the Department of Animal Biology, Plant Biology and Ecology (BABVE) of the Universitat Autònoma de Barcelona (UAB). The washing procedure involved immersing the fibres in ultra-pure Milli-Q water in an ultrasonic machine for 15 minutes. This process was repeated three times, with the ultrapure water changed between each bath. The samples were then dried in a laboratory oven for approximately 48 hours or until completely dry.

Two different decalcification procedures were used in the current methodological approach, based on previous analyses of dental calculus samples. EDTA and HCl were used in two different concentrations (0.2M and 0.5M) for four different reaction times (5, 30, 90 and 170 hours). The procedure involved immersing the fibres in the different solvents for the specified times. The samples were then transferred to 1.5 ml Eppendorf tubes and washed with ultrapure Milli-Q water. The washing process consisted of manually shaking the samples, using a vortex mixer and centrifuging for 5 minutes at 3,000 rpm. This procedure was repeated three times to ensure removal of any residual solvent.

The samples were then prepared for light microscopy using Euromex PB5265 Entellan permanent mounting medium. Both transverse and epidermal sections were prepared from the raw fibres, while the processed fibres were directly mounted for longitudinal sections. The samples were examined using an Olympus BX43 light microscope with a polarised filter, coupled to an Olympus DP26 camera, linked to Olympus cellSens software. The observations were carried out in the Archaeobotany Laboratory of the Prehistory Department at the Universitat Autònoma de Barcelona (UAB).

5.2.2.1.2. The analysis of dental calculus.

5.2.2.1.2.1. Sampling.

The entire process and protocol described in the following pages was carried out at the Anthropology Unit of the Department of Animal Biology, Plant Biology and Ecology (BABVE) of the Universitat Autònoma de Barcelona (UAB).

A published protocol for the extraction of micro-remains from archaeological human dental calculus was followed for the initial steps of selection, documentation, removal, storage, weighing and decontamination (Fiorin and Cristiani 2024), although some steps were adapted to the laboratory facilities.

Dental calculus samples were selected according to their size and origin, quantity, colour and texture. The sample of control from Castell de Besora consisted on dental calculus of an adult female individual, from teeth 31, 32 and 33 (FDI System).

The teeth were photographed before and after tartar removal, with the teeth mechanically cleaned with distilled water using a new soft toothbrush prior to extraction to remove any residual debris that might interfere with the analysis.

The tartar was removed from each side of the tooth using a dental scaler and deposited separately according to the part of the tooth from which it originated (lingual, buccal, distal, medial or occlusal). The samples were weighed and transferred to 1.5 ml Eppendorf sterilised plastic tubes.

5.2.2.1.2.2. Decontamination, decalcification and microscopic observation.

Dental calculus samples were decontaminated by removing any residual soil adhering to their surface. Contaminants were extracted from the sediments using ultrapure water and the samples were manually vortexed several times at minimum speed. The sediments were then cleaned manually under a stereomicroscope using a nylon brush soaked in drops of 0.5M HCl (hydrochloric acid). After this cleaning, the samples were rinsed with ultrapure Milli-Q water and centrifuged up to three times to remove any residual sediment or HCl. The samples were then transferred to new sterile 1.5 ml Eppendorf tubes and dried until ready for calculus disaggregation.

Although there is no standardisation of the methods used to decalcify dental calculus, different approaches have been explored in the recent literature. Some researchers have opted for no chemical treatment (Power et al. 2018), while others have used different chemical solvents such as ethylenediaminetetraacetic acid (EDTA) or hydrochloric acid (HCl) (Boyadjian 2018; D'Agostino et al. 2019; Hardy et al. 2016; Tromp et al. 2017). The choice of decalcification method is crucial, as it can affect the quantity and identification of micro-remnants (Bucchi et al. 2019).

For the tartar samples from the Castell de Besora site - the case control of the thesis and used in the methodological approach - the same solvents and times were used as in the methodological approach for plant fibres: EDTA and HCl at concentrations of 0.2M and 0.5M were used for 5, 30, 90 and 170 hours. Dental calculus samples were transferred to 1.5 ml Eppendorf tubes and washed with ultrapure Milli-Q water. The washing process included manual and vortex shaking, followed by centrifugation in a microcentrifuge for 5 minutes at 5,000 rpm. The samples were then immersed in the different solvents and mixed manually and by vortexing several times during the different decalcification periods.

Based on the results obtained from the methodological approach with modern plant fibres and control tests with medieval dental calculus, 0.5M EDTA was used to disaggregate the dental calculus samples from the Cova del Pasteral site. The exposure time was until the sample was completely disaggregated, but in no case did it exceed 170 hours.

Once dental calculus is disaggregated, the samples were centrifuged at 5,000 rpm for 5 minutes and the supernatant was removed. The pellet was rinsed with ultrapure Milli-Q water and centrifuged again to remove any residual acid. In some cases, the time and speed of centrifugation was adjusted to ensure proper pellet deposition. This procedure was repeated three times for each sample to remove any residual solvent.

The tartar samples were then mounted on optical microscope slides with pure glycerine and sealed with transparent nail polish. The samples were examined using the same optical microscope as for the plant fibres, in the same laboratory facilities. Finally, the micro-remains were photographed, measured, described and compared with modern reference materials. Particular attention was paid to the micro-remains embedded in the tartar matrix and those located in the centre of the samples, which supported the absence of contamination.

5.3. Experimentation with fibre artisans: Experimental archaeology aspects of plant-fibre studies.

Experimental archaeology is a fundamental method in empirical archaeological studies, allowing the acquisition of both qualitative and quantitative data. It has been instrumental in understanding the technological parameters involved in formulating and testing hypotheses, as well as the experimental mechanisms used to validate them (Lumbreras 1987; Argelés et al. 1995; Bate 1998). Consequently, archaeological research is closely linked to these experimental protocols as a technical research approach. Although initially more commonly applied to lithic analysis (Palomo 2012; Vidal-Matutano et al. 2024), experimental archaeology has expanded to include the study of wooden materials (López-Bultó 2015; Vidal-Matutano et al. 2024) and fibre-based materials, particularly in the context of textile production - such as weaving, and dyeing fibres (Peacock 2001; Harris 2019; Beamer 2020, among others) - demonstrating its indispensable role in archaeological research.

Like other disciplines, including those outside archaeology, experimental archaeology has undergone a complex evolution that has led to the clarification and definition of its basic principles and applications (Baena 1997, 1998; Coles 1979; Ingersoll et al. 1979; Kelterborn 1987; Callahan 1981, 1999; Reynolds 1999; Mathieu 2002; Ramos 2012; Palomo et al. 2013). It is now considered a fundamental component of historical and anthropological research, involving controlled experiments to reconstruct past phenomena, ranging from simple objects to complex systems. The aim of experimental methods is to develop and evaluate hypotheses, ultimately improving the use of analogy in archaeological interpretation.

Since work on this thesis began, experimental archaeology focusing on the early use of plant fibres has expanded in Iberia in the form of seminars, workshops and exhibitions. For example, the Museu d'Arqueologia de Catalunya (MAC, Barcelona) dedicated its biennial seminar to the prehistoric and protohistoric use of plant fibres (http://arqueodebats.mac.cat/project/arqueodebat-2/#true0). The seminar focused on knowledge of the use of plant fibres for the manufacture of different types of utensils in prehistoric and protohistoric times, such as baskets and ropes, and aimed to answer questions about the emergence and evolution of these products and the techniques used to make fibre-based products, as well as possible analytical methodologies.

Figure 78. Images of the work sessions with fibre artisans.

In the present study, experimental archaeology has been used to propose different scenarios for the use of plants as raw materials for the fabrication of an array of objects, as well as the processing techniques required for their use. This research has involved collaboration with skilled fibre artisans, leading to the formation of a working group that has held regular meetings that include fieldwork gathering of plants, plant processing

(Table 14; Figure 78), fibre-based productions, and exchange of ideas and impressions. These meetings have focused on various aspects, such as the reproduction of certain archaeological objects, some of which are included in this thesis. Although the technical reproductions are not included in the current work, as they are still under development, such as the reproduction of the footwear from Cueva de los Murciélagos, it is an ongoing line of research that involves numerous contributors and will be published in the near future. The archaeological work presented in this thesis is therefore more closely related to the traditional and experimental knowledge shared by fibre artisans. They have provided valuable insights into the raw materials, including the species that may have been used for these purposes, the methods of fibre extraction and the preparation processes required before these fibres could be used to make fibre-based objects.

This methodology has been essential to the development of the current work, as knowledge gained through experimentation and years of expertise is the only way to truly understand the materials analysed here. In addition, the personal experimentation carried out in the framework of the current thesis has provided valuable first-hand insights into the artisans' perspectives. This approach has allowed new ideas and hypotheses to be proposed, rather than simply documenting what the artisans explained.

Table 14. Details about some of the artisans which have been consulted during the experimental work developed in the framework of the current thesis.

Artisan name	Localisation	Plant fibre use
Anna Homs Padrisa	Valès Occidental (Catalunya)	Cyperaceae Juncaceae *Linum usitatissimum* *Stipa tenacissima* *Tilia* sp. *Urtica dioica*
Adrià García	El Bages (Catalunya)	*Stipa tenacissima*
Alfonso Massanet	Valènica	*Stipa tenacissima*
Berta Bugallo Campo	Guadalajara	Straw *Salix* sp.
Bonifacia	Toledo	*Stipa tenacissima*
Carlos Fontales	Galícia	*Salix* sp. Straw *Stipa tenacissima*
Isidro Viejo	El Romeral	*Stipa tenacissima*
Joan Farré Oliver	Plana de Vic (Catalunya)	*Salix* sp. *Stipa tenacissima*
José Fajardo	Albacete	*Stipa tenacissima*
Lali Martínez	Murcia	*Stipa tenacissima*
Luís Moreno	Albacete	*Stipa tenacissima*
Manuel Utrilla	Almería	*Stipa tenacissima*
Mercè Bolló	El Bages (Catalunya)	*Salix* sp. *Stipa tenacissima*
Serapio	Toledo	*Stipa tenacissima*

CHAPTER VI – RESULTS (I)
- REFERENCE COLLECTION -

6. Results.

6.1. Results (I): Reference collection.

This section of Chapter VII (Results) presents the reference collection used for the identification and analysis of plant fibres in this study. The collection is alphabetically organised and includes both monocotyledonous and dicotyledonous plant families. The monocotyledonous plants include *Avena sativa*, *Carex pendula*, *Chamaerops humilis, Cladium mariscus, Cyperus fuscus, Hordeum distichum*, *Hordeum vulgare, Juncus effusus, Juncus inflexus/Juncus glaucus*, *Juncus maritimus, Lygeum spartum*, *Phragmites australis, Schoenus nigricans, Scirpus holoschoenus/Holoschoenus vulgaris/Scirpoides holoschoenus*, *Stipa gigantea*, *Stipa tenacissima/Macrochloa tenacissima*, *Triticum aestivum*, *Triticum dicoccum, Triticum durum* and *Triticum monococcum*, *Typha angustifolia* and *Typha latifolia.* Dicotyledonous plants include *Linum usitatissimum*, *Tilia cordata, Tilia platyphyllos,* and *Urtica dioica*.

For monocotyledonous plants, analysis focuses on both the adaxial and abaxial epidermal layers, as well as transverse sections of the leaves, while for stems, both the epidermis and transverse sections are examined. The plant parts included in the reference collection were selected based on their traditional use fibre production. Traditional and ethnological practices were also taken into account in the processing of these fibres. In the case of dicotyledonous plants, all were subjected to processing, including retting and, in some cases, additional physical treatments. In the case of monocotyledons, only *Stipa tenacissima* was physically processed and included in the reference collection. The anatomical descriptions were developed using plant histological atlases and relevant publications, such as Evert (2006), while the cell morphological descriptions followed the guidelines of ICPN 2.0 (ICPT 2019), as described in Chapter V (Methodology).

6.1.1. *Avena sativa.*

Class: Monocotyledoneae
Order: Poales
Family: Poaceae
Genus: *Avena*
Specie: *Avena sativa*

Common name: Oat (ENG); Civada (CAT); Avena (SP).

<u>Leaf anatomy description.</u>

Epidermis: Both adaxial and abaxial epidermis have a very similar cellular structure, characterised by elongated epidermal cells with entire cell margins, although some have crenate margins. Stomatal structures are clearly visible throughout the leaf surface and have an elongated appearance (Figures 79a-d). Cellular appendages such as trichomes with an acute bulbous shape are also present on both surfaces. On the abaxial surface they are more numerous and arranged longitudinally along the leaf (Figure 79c, d).

Transverse section: The transversal section of *Avena sativa* leaves shows a long, narrow structure with protuberances where the vascular bundles are located. The epidermis consists of a single layer of cells (Figure 79e, f). In this case the images are not very clear.

<u>Stem anatomy description.</u>

Epidermis: The epidermal cells of the stem have both entire and crenate margins, with scattered short and circular or ovate cells throughout the samples. Stomatal structures are also present, although less numerous than in the leaves. They are arranged longitudinally along the stem and in areas where stomata are present, the circular/ovate cells are less frequent (Figure 80a, b).

Transverse section: The stem of *Avena sativa* shows a hollow medulla surrounded by large parenchyma cells. Vascular bundles are distributed in alternating cavities along the circular cross section of the stem, where dense tissue structures are visible (Figure 80c, d).

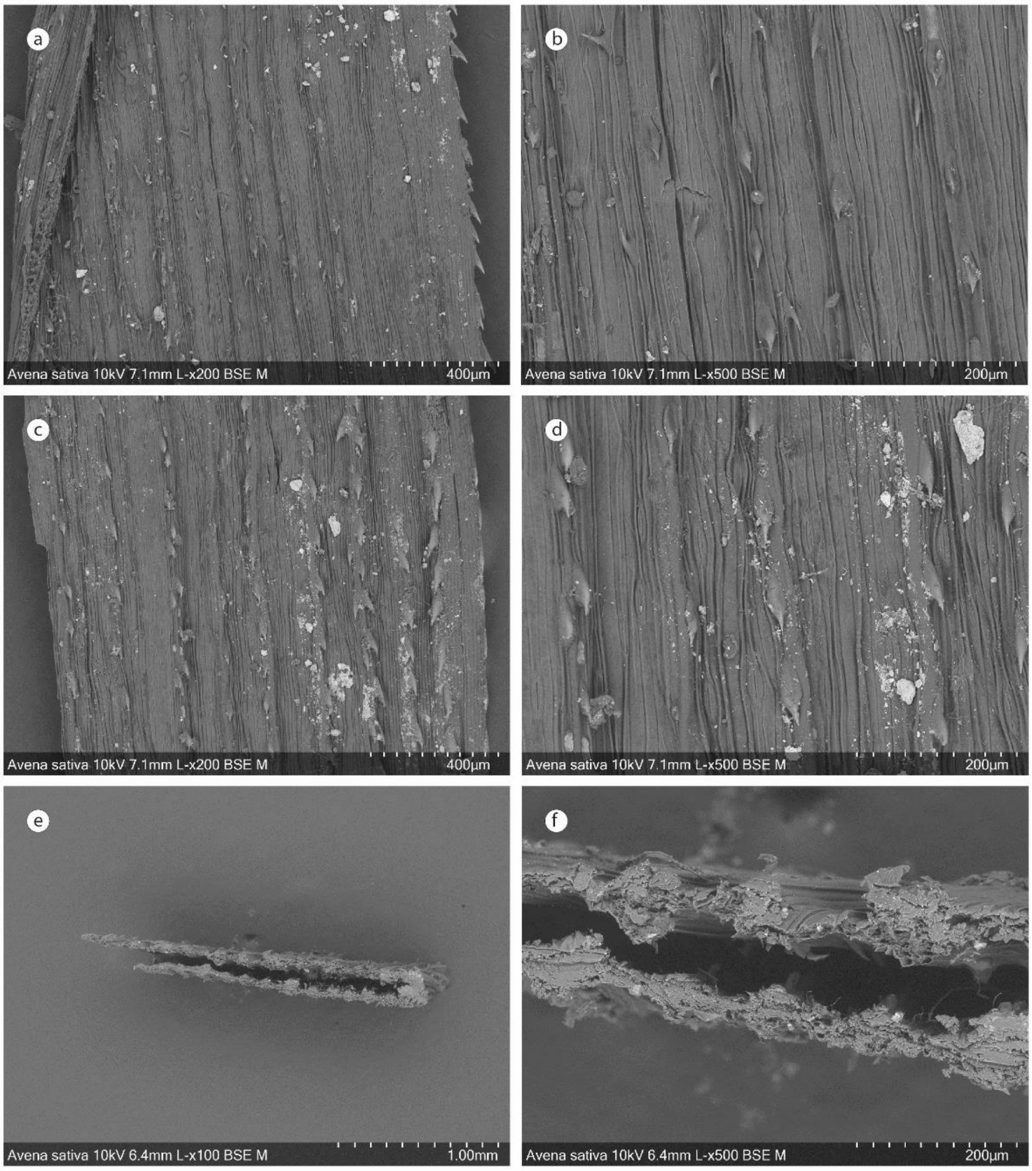

Figure 79. *Avena sativa* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

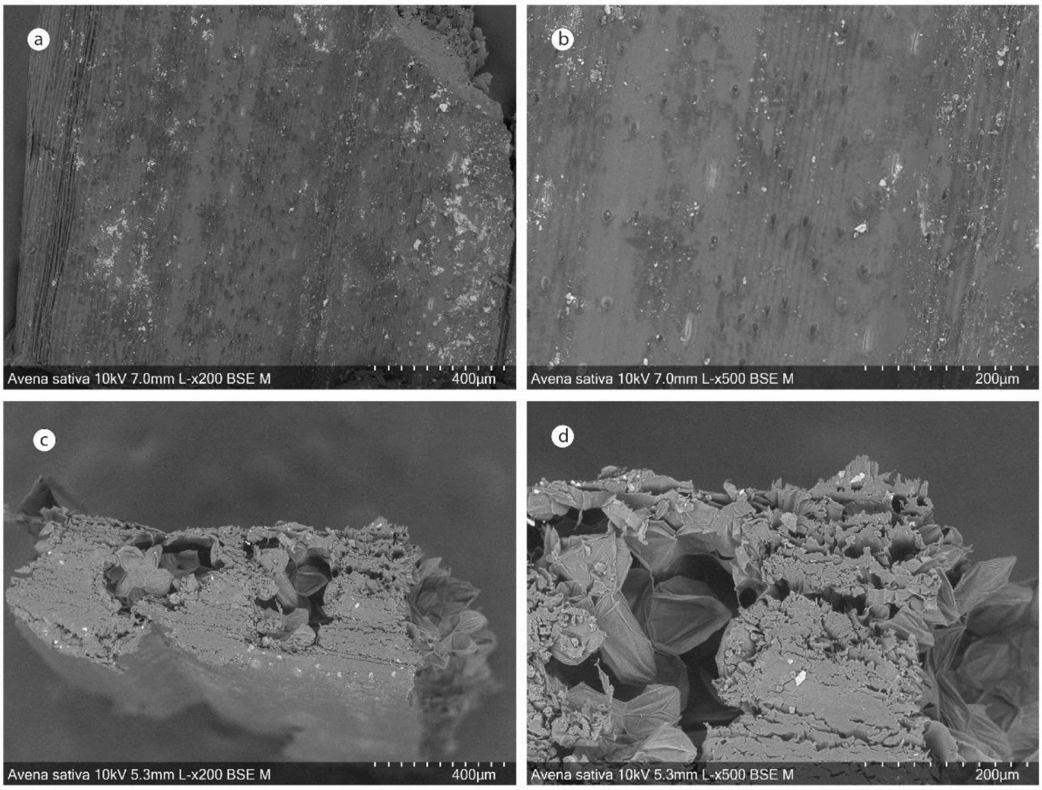

Figure 80. *Avena sativa* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.2. *Carex pendula*.

Class: Monocotyledoneae
Order: Poales
Family: Cyperaceae
Genus: *Carex*
Specie: *Carex pendula*

Common name: Pendulous sedge (ENG); Càrex pèndul (CAT); Cárice llorón (SP).

Leaf anatomy description.

Transverse section: The leaf has narrow structures with protuberances where the vascular bundles are located. Large parenchyma cells fill the spaces between these protuberances. Thick bundles of sclerenchyma tissue surround the vascular bundles and provide structural support (Figure 81a, b).

Stem anatomy description.

Transverse section: The stem is circular with a hollow pith. Similar to the leaf, it also has protuberances, although in this case they are more quadrangular. This section of the stem is quite thin (Figure 82a).

Epidermis: Elongated cells are visible, containing crystalline structures (Figure 82a). Stomata appear to be present on the undersides of the protuberances, although they are not very numerous. The stomata are round in shape (Figure 82b).

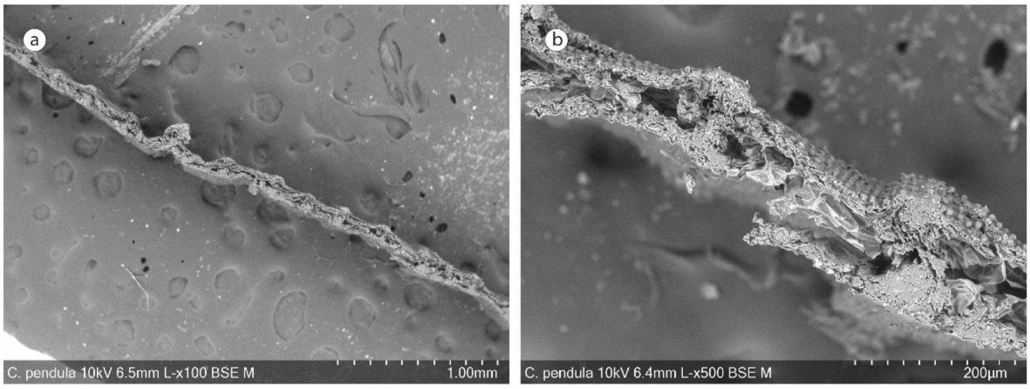

Figure 81. *Carex pendula* leaf SEM images: a, b) Transversal section.

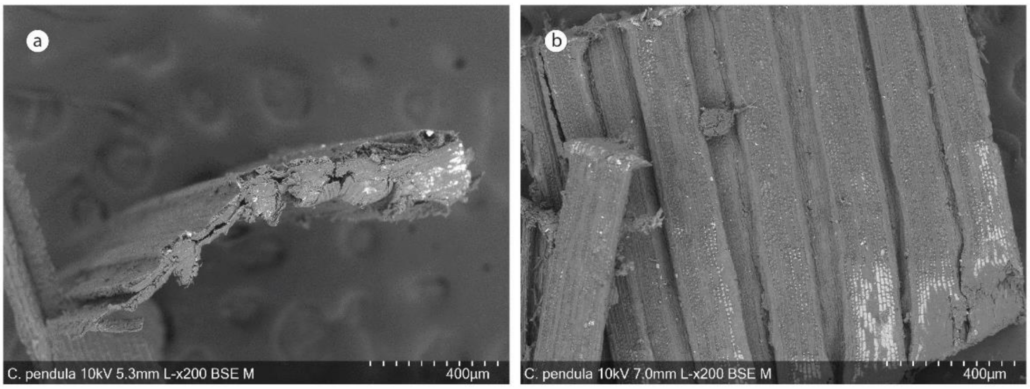

Figure 82. *Carex pendula* stem SEM images: a) Transversal section, b) Epidermis,

6.1.3. *Chamaerops humilis.*

Class: Monocotyledoneae

Order: Poales

Family: Arecaceae

Genus: *Chamaerops*

Specie: *Chamaerops humilis*

Common name: Dwarf fan palm (ENG); Margalló/Bargalló (CAT); Palmito (SP).

Leaf anatomy description.

Epidermis: The epidermis consists of elongated cells of variable length and heterogeneous morphology. The edges of these cells appear sinuate. In addition, some short cells can be observed in certain areas of the leaf epidermis. Stomatal structures, which are circular in shape, are arranged in longitudinal lines along the leaf. These lines are not perfectly straight as some stomata are arranged in a zigzag pattern (Figure 83a, b).

Transverse section: The section shows narrow elements with a wavy epidermis in which both primary and secondary vascular bundles are present. Thick sclerenchymatic tissue surrounding the vascular bundles is a characteristic feature, similar to other plants in the Arecaceae family (Figure 83c, d).

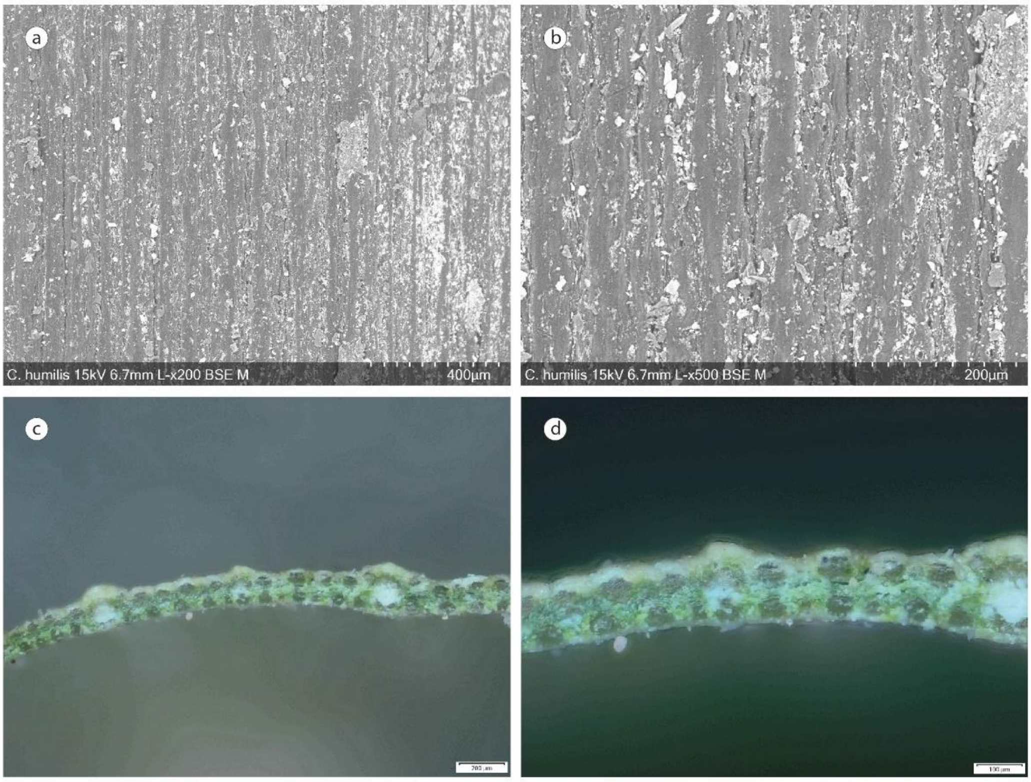

Figure 83. *Chamaerops humilis* leaf SEM and OM images: a, b) Adaxial epidermis, c, d) Transversal section.

6.1.4. *Cladium mariscus.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Cyperaceae
Genus:	*Cladium*
Specie:	*Cladium mariscus*

Common name: Swamp sawgrass (ENG); Mansega (CAT); Junco espigado (SP).

<u>Leaf anatomy description.</u>

Epidermis. The edges of the leaf have large trichomes which are sharp enough to cut on contact. The abaxial surface is densely covered with trichomes, which have an acute, bulbous shape (Figure 84a, b). Stomata are not clearly visible in the photographs.

Transverse section. The cross section shows narrow structures segmented in the middle where a small vascular bundle is located. Vascular bundles are located close to both the adaxial and abaxial epidermis, with the bundles closer to the adaxial (upper) surface being larger. The epidermis is unicellular and the parenchyma is heterogeneous with small air chambers between the dense tissues where the vascular bundles are located. Large dense masses of sclerenchyma tissue extend from the vascular bundles to the epidermis (Figure 84c, d).

<u>Stem anatomy description.</u>

Epidermis. Stomata are not clearly visible in the images. However, crystals can be seen (Figure 85a, b).

Transverse section. In transverse section, numerous vascular bundles are present near the pith. Sclerenchyma and parenchyma tissue are located between the epidermis and the first vascular bundles, all of which are relatively uniform in size. The pith of the stem is hollow, and the epidermis has a rippled appearance (Figure 85c, d).

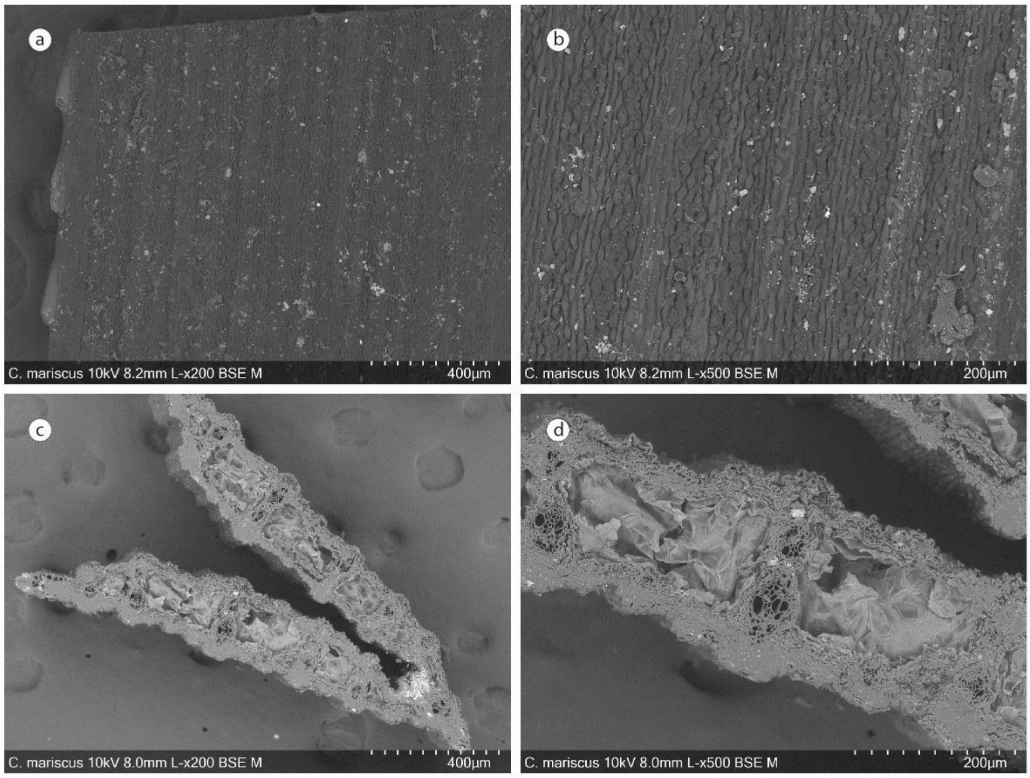

Figure 84. *Cladium mariscus* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

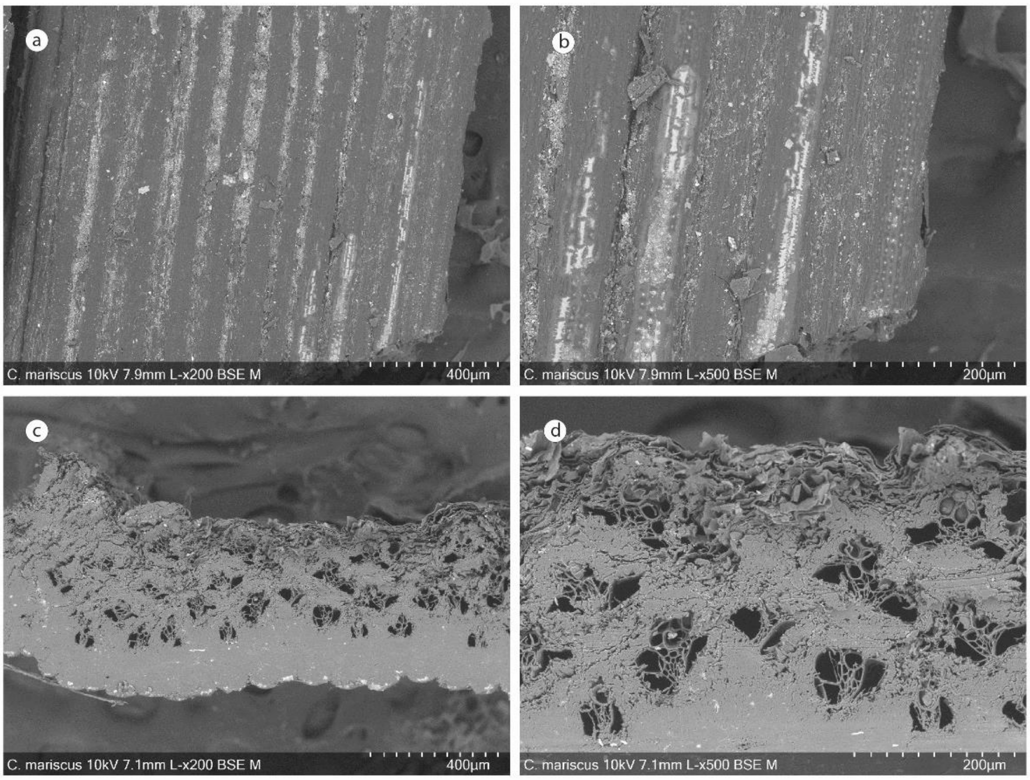

Figure 85. *Cladium mariscus* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.5. *Cyperus fuscus.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Cyperaceae
Genus:	*Cyperus*
Specie:	*Cyperus fuscus*

Common name: Brown galingale/flatsedge (ENG); Serrenca fosca (CAT); Juncia negra (SP).

<u>Leaf anatomy description.</u>

Epidermis. Both the adaxial and abaxial epidermis have a similar appearance, with elongated epidermal cells that are considerably wider than in other species and vary in length. The margins of these cells are clavate. Stomatal structures are also present and have a slightly ovate shape. A notable feature is the presence of crystal formations arranged in two distinct longitudinal lines along the leaf. This feature is also observed in other members of the Cyperaceae family. Between each pair of crystal lines there are two lines of stomatal structures (Figure 86a-d).

Cross section. The cross section shows narrow structures with protuberances where the vascular bundles are located. Each vascular bundle contains two large xylem vessels (Figure 86d, e).

<u>Stem anatomy description.</u>

Epidermis. The epidermis consists of elongated cells with clavate margins. Stomatal structures are also present and have a slightly oval shape (Figure 87b,c).

Transverse section. The transversal section of the stem shows a triangular shape, a characteristic feature of some Cyperaceae species. The outer layer or epidermis is very sinuous and contains vascular bundles with clearly visible xylem vessels. The parenchyma tissue appears heterogeneous (Figure 87c, d).

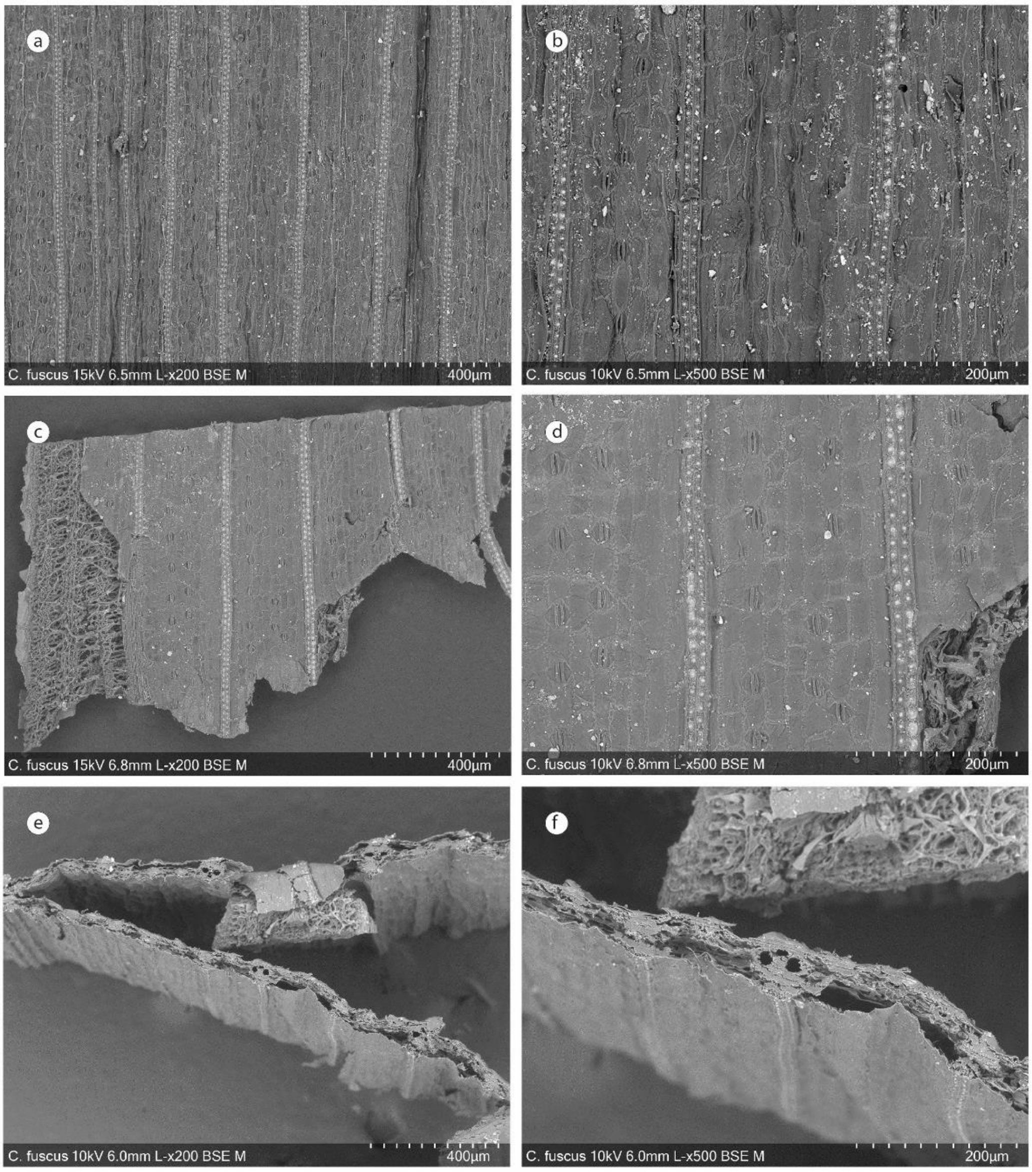

Figure 86. *Cyperus fuscus* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

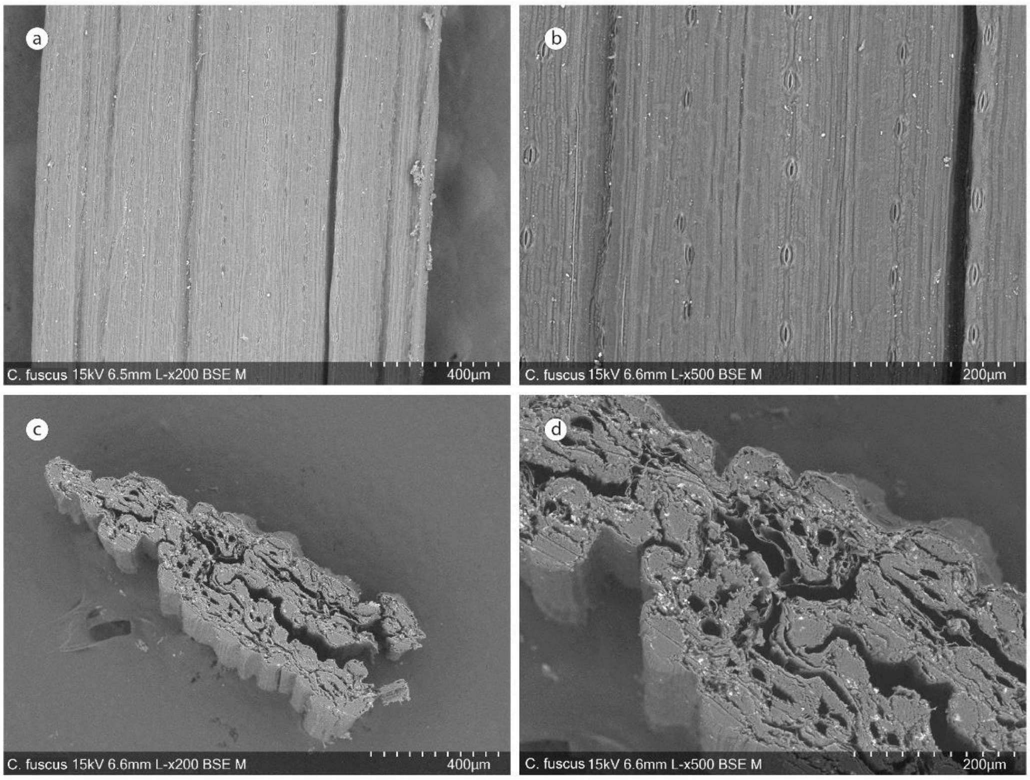

Figure 87. *Cyperus fuscus* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.6. *Hordeum distichum.*

Class: Monocotyledoneae
Order: Poales
Family: Poaceae
Genus: *Hordeum*
Specie: *Hordeum distichum*

Common name: Common barley (ENG); Ordi blanc (CAT); Cebada (SP).

<u>Leaf anatomy description.</u>

Epidermis. Both the adaxial and abaxial epidermis have similar characteristics, with long epidermal cells, mostly with entire margins, although some have crenate edges. Stomatal structures are clearly visible over the entire leaf surface and have an elongated appearance (Figure 88a-d). Cellular appendages, including large trichomes with an acute bulbous shape, are also present on both surfaces.

Transverse section. The transversal section shows a long, narrow structure with slight protuberances and an irregular epidermis. These alternate between large and small protuberances. The large protuberances contain trichomes on the surface and are where the vascular bundles are located (Figure 88e, f). The epidermis is unicellular and the cells are conspicuously large.

<u>Stem anatomy description.</u>

*Epidermis. T*here are notable differences between the outer and inner surfaces of the stems. The outer surface shows elongated cells with clavate margins, together with some shorter cells. Stomatal structures are clearly visible, large in size and oval in shape, arranged longitudinally along the stem (Figure 89a, b). In contrast, the inner surface shows elongated whole cells, many of which are quite long, along with some shorter cells. A few stomata are present on this surface, although they are significantly fewer than in the adaxial epidermis (Figure 89c, d).

Transverse section. The stem has a circular shape with a hollow pith (Figure 89e, f). The epidermis consists of a single cell layer, and only primary vascular bundles, each containing two large xylem vessels, are present. Sclerenchyma tissue is visible around the vascular bundles, while thick-walled cells near the epidermis likely correspond to collenchyma tissue. The parenchyma is heterogeneous, with varying cell sizes (Figure 89e, f).

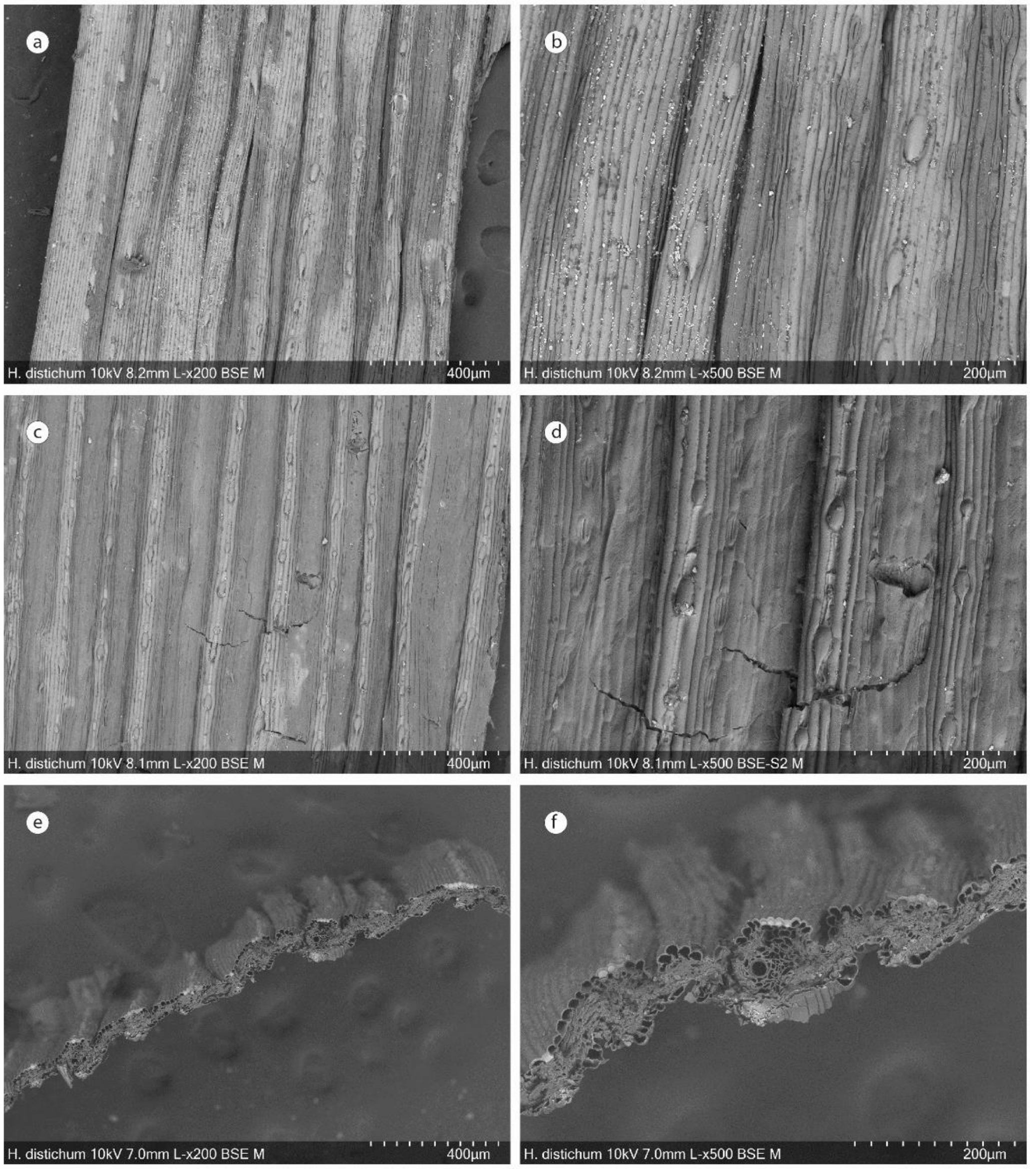

Figure 88. *Hordeum distichum* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

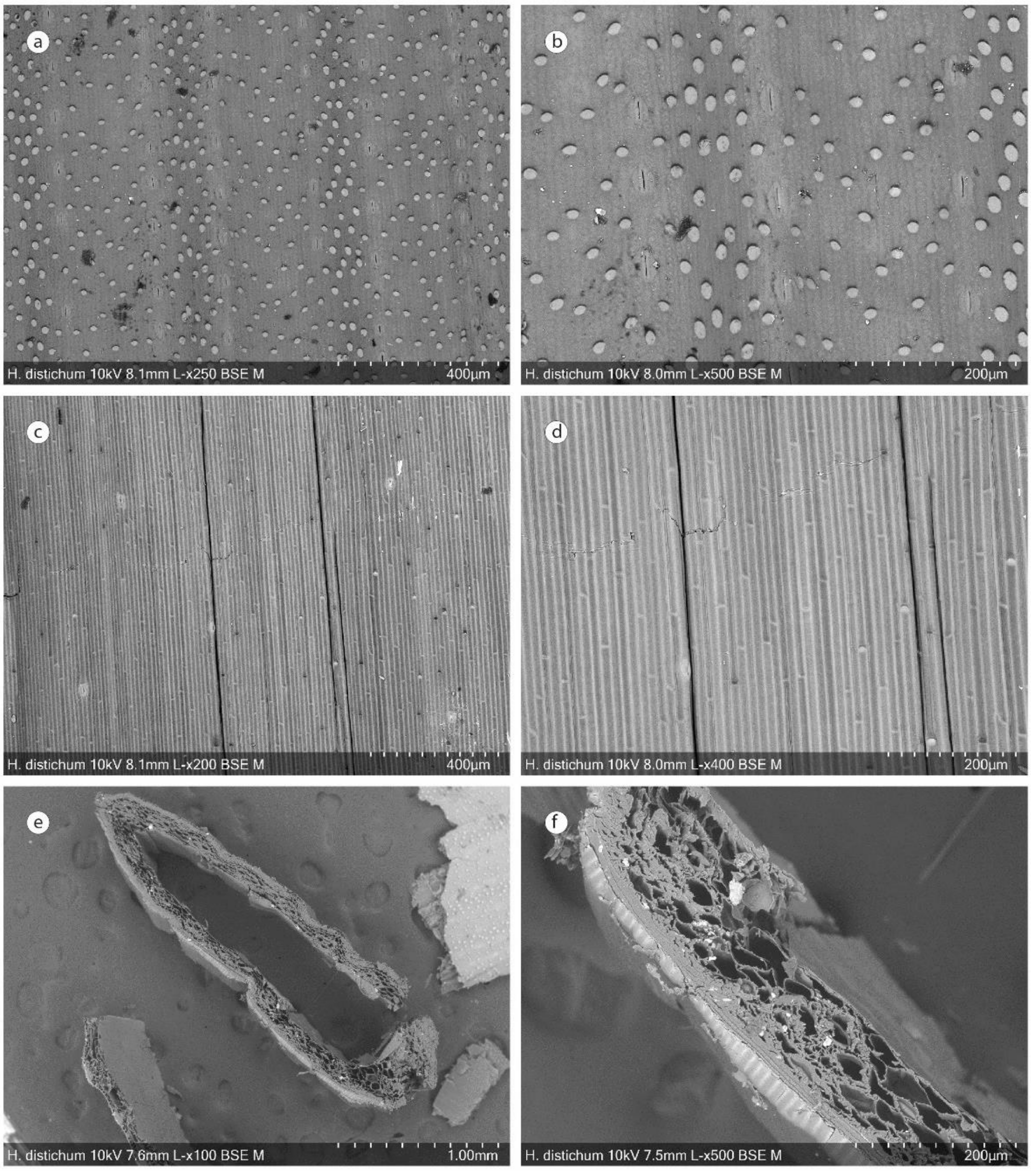

Figure 89. *Hordeum distichum* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.7. *Hordeum vulgare.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Hordeum*
Specie:	*Hordeum vulgare*

Common name: Barley (ENG); Ordi (CAT); Cebada (SP).

Leaf anatomy description.

Epidermis. Significant differences can be observed between the outer (adaxial) and inner (abaxial) surfaces of the leaves. The adaxial surface consists of long, elongated epidermal cells with clavate margins. Alternating short cells also appear in this epidermis. Stomatal structures are clearly visible over the whole surface of the leaf and have an elongated shape (Figure 90a-b). The abaxial surface is glabrous, with long, narrow, elongated cells tapering at the edges. Rectangular cells can also be observed in some areas (Figure 90c, d).

Transverse section. The transversal section shows a long, narrow structure with slight protuberances and an irregular epidermis. It alternates between larger and smaller protuberances. In areas without protuberances, the leaf is composed of only two layers of epidermis (Figure 90e, f).

Stem anatomy description.

Epidermis. The stem surface is composed of elongated cells with clavate margins, together with some shorter cells. Stomatal structures are clearly visible, large and oval. They are arranged longitudinally along the stem (Figure 91a, b).

Transverse section. The stem has a circular shape with a hollow pith (Figure 91e, f). The epidermis consists of a single layer of cells and only primary vascular bundles, each containing two large xylem vessels, are present. Sclerenchyma tissue surrounds the vascular bundles and thick-walled cells close to the epidermis probably correspond to collenchyma tissue. The parenchyma is heterogeneous with varying cell sizes (Figure 91e, f).

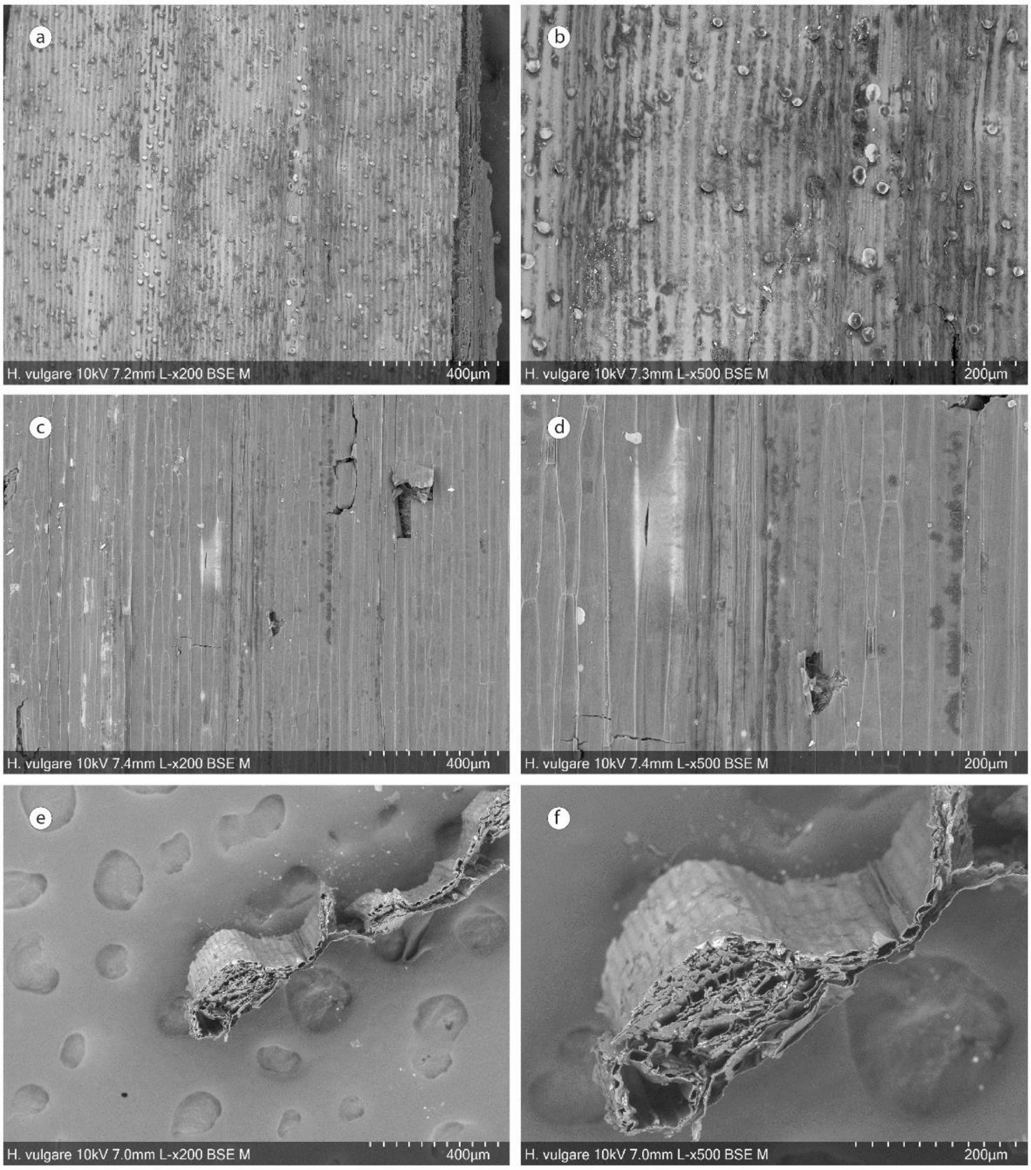

Figure 90. *Hordeum vulgare* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

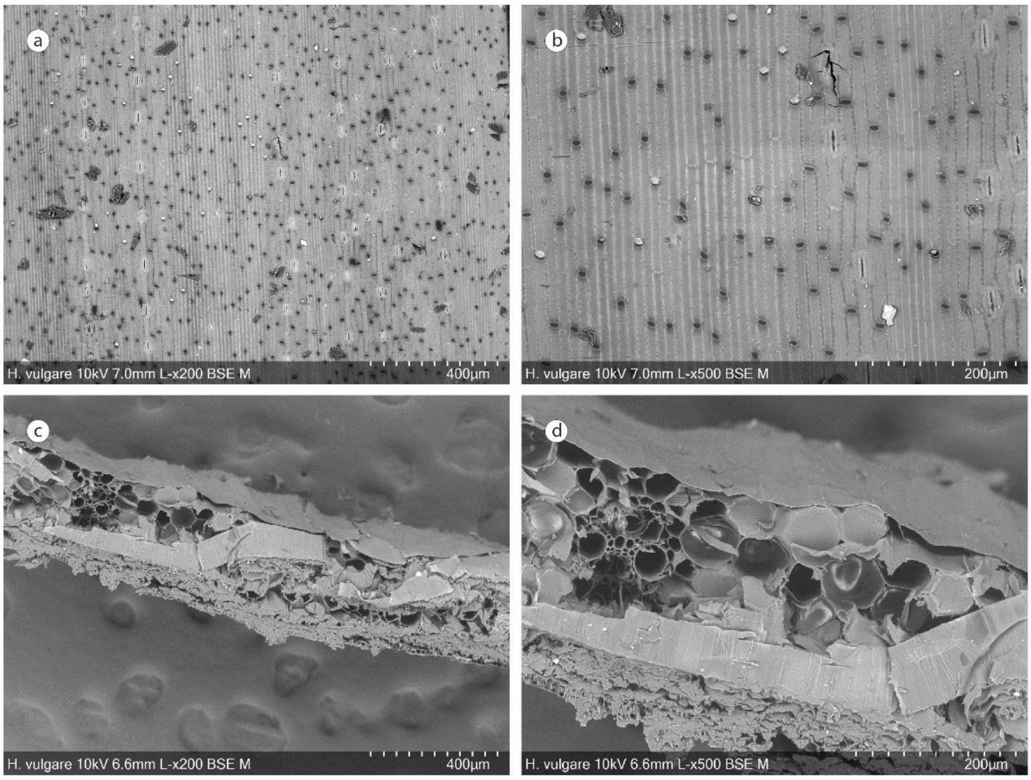

Figure 91. *Hordeum vulgare* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.8. *Juncus effusus.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Juncaceae
Genus:	*Juncus*
Specie:	*Juncus effusus*

Common name: Common/soft rush (ENG); Jonc d'estores/jonc de jardiner (CAT); Junco de esteras/junco fino (SP).

Stem anatomy description.

Epidermis. Epidermal cells are elongated with crenate margins. Stomatal structures are elliptical and arranged longitudinally along the stem (Figures 92a, b). They are more commonly found on the external protrusions of the stem, which are visible in the transverse section (Figures 92c, d).

Transverse section. A complete section of the stem is shown in Figure 92c, d. The inner part of the stem (pith) has a characteristic trabecular structure, which may contribute to support functions. The outer part of the transversal section exhibits sinuous protuberances, where the primary vascular bundles are located. Secondary vascular bundles are also present in a second line of dense tissue. Some aerial parenchyma (aerenchyma) is present between these areas of dense vegetative tissue.

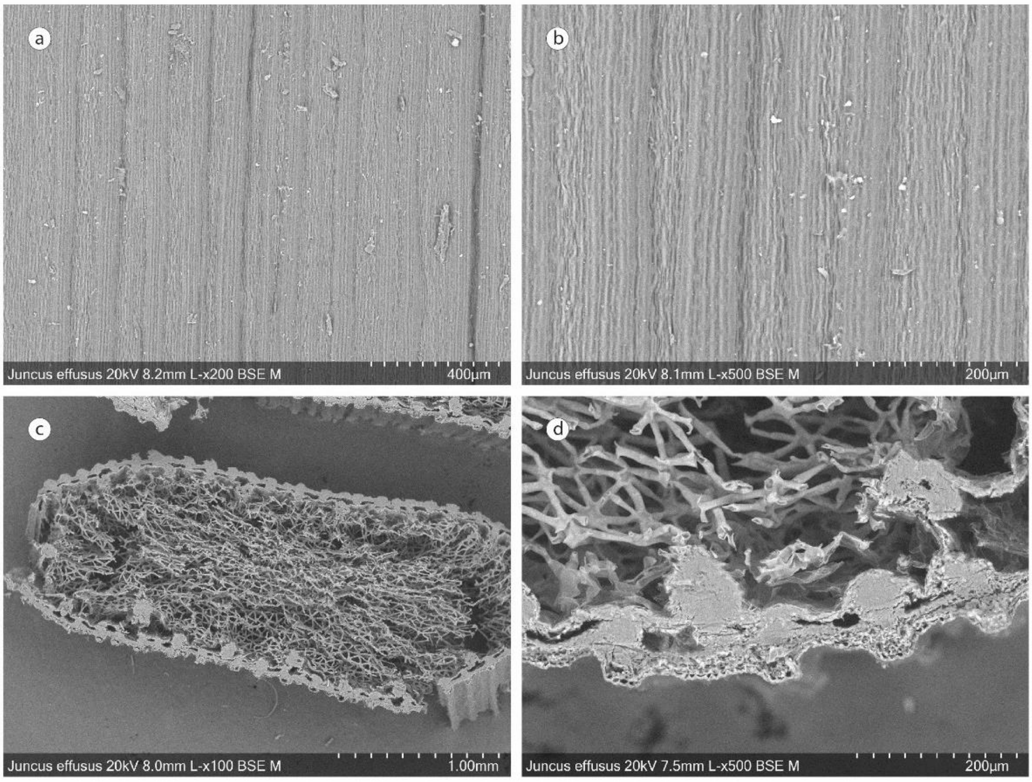

Figure 92. *Juncus effusus* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.9. *Juncus inflexus / Juncus glaucus*.

Class:	Monocotyledoneae
Order:	Poales
Family:	Juncaceae
Genus:	Juncus
Specie:	*Juncus inflexus / Juncus glaucus*

Common name: Hard rush (ENG); Jonquina (CAT); Junco glauco (SP).

Stem anatomy description.

Epidermis. Epidermal cells are elongated with crenate margins. Stomatal structures are elliptical and arranged longitudinally along the stem (Figure 93a, b). They are more frequently found on the external protrusions of the stem, which are visible in the transverse section (Figures 93e, f).

Longitudinal section. Variability in the thickness, shape and size of the parenchyma cells around the outer part and pith of the stem can be seen in Figure 93c, d.

Transverse section. A complete section of the stem is shown in Figure 93e, f. The inner part, or pith, has a dense trabecular structure. The unicellular epidermis is clearly visible in Figure 93e. The outer part of the transverse section has quadrangular protuberances where the primary vascular bundles are located. Secondary vascular bundles are located in a second layer of dense tissue. In each vascular bundle there are three to four xylem vessels, with phloem also visible (Figure 93f). Thick sclerenchyma surrounds the vascular bundles, which are separated by aerenchyma (Figure 93e, f).

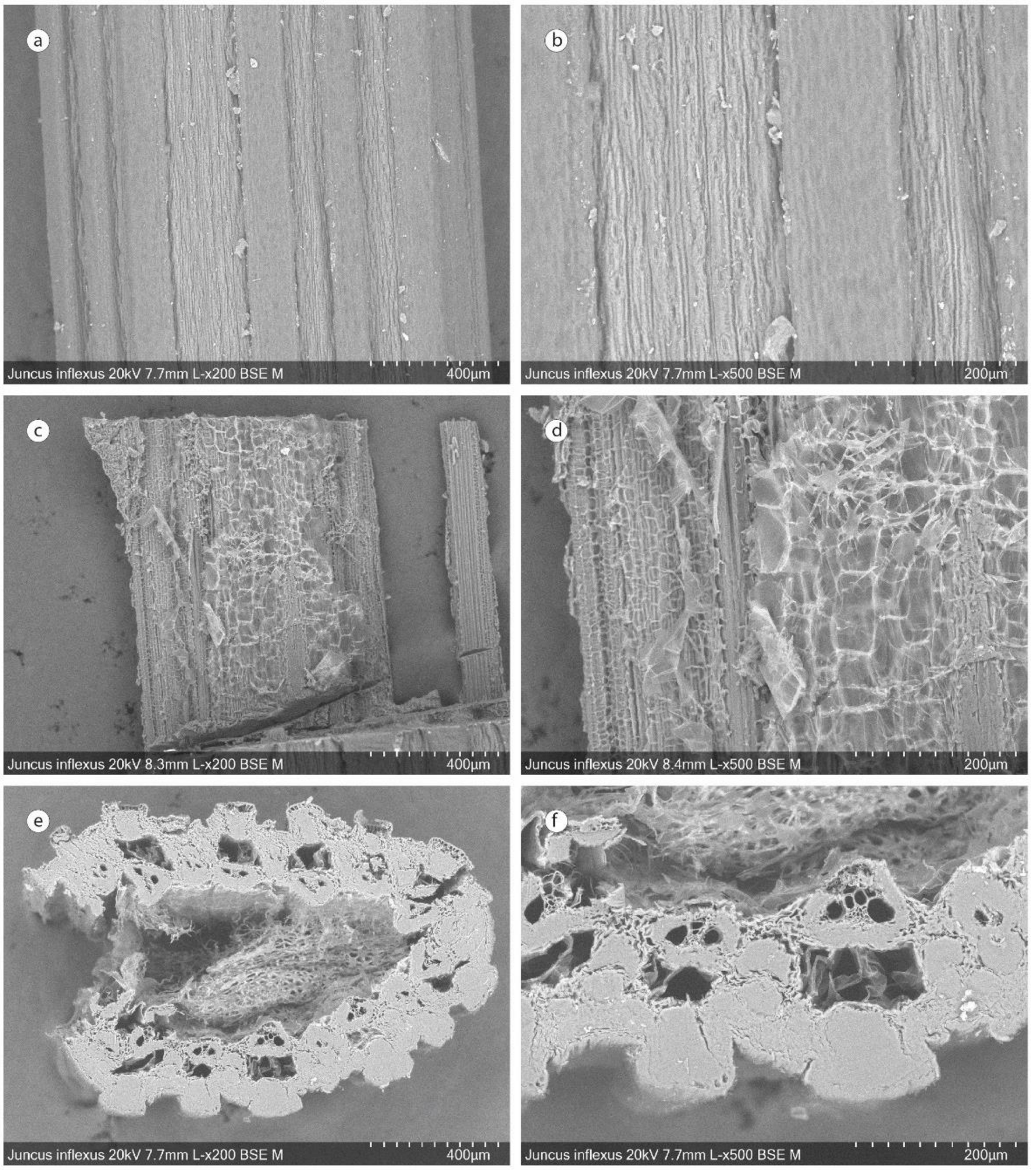

Figure 93. *Juncus inflexus* stem SEM images: a, b) Epidermis, c, d) Longitudinal view, e, f) Transversal section.

6.1.10. *Juncus maritimus.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Juncaceae
Genus:	*Juncus*
Specie:	*Juncus maritimus*

Common name: Sea rush (ENG); Jonc marí (CAT); Junco marino (SP).

Stem anatomy description.

Epidermis. The epidermal cells are elongated with crenate margins. Stomatal structures are elliptical in shape and arranged longitudinally along the stem, but appear to be less numerous than in other *Juncus* species (e.g. *Juncus effusus* or *Juncus inflexus*) (Figure 94a, b). Stomata are more commonly found on the external protuberances of the stem, visible in the transverse section (Figure 94c, d).

Transverse section. An approximate middle section of the stem is shown in Figure 94c. The inner part of the stem, or pith, shows dense tissue, unlike other Juncus species where the pith is trabecular. The outer part of the transversal section shows square-shaped protuberances, although these are less prominent than in the previous cases. Collenchyma tissue is clearly visible within these protuberances (Figure 94c). Both primary and secondary vascular bundles are present throughout the section with the inner bundles being slightly smaller. Each bundle contains two large xylem vessels, visible phloem and is surrounded by thick sclerenchyma tissue consisting of approximately three to five layers of cells (Figure 94d).

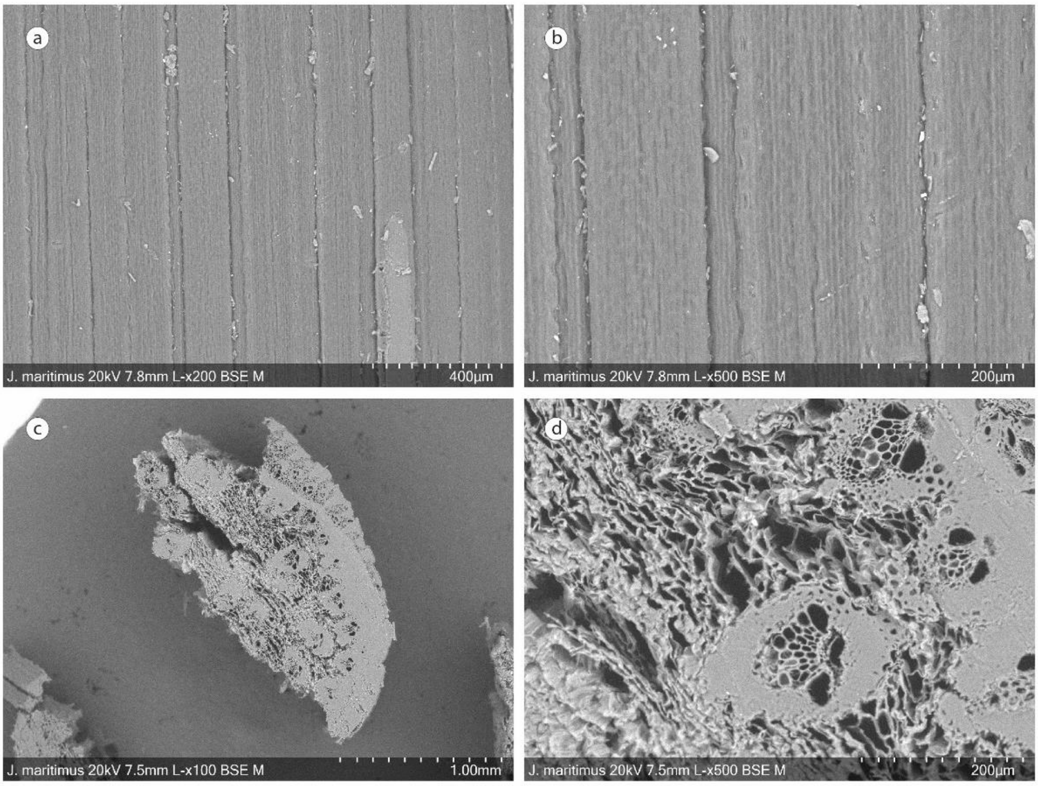

Figure 94. *Juncus maritimus* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.11. *Lygeum spartum.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Lygeum*
Specie:	*Lygeum spartum*

Common name: Albardine (ENG); Albardí/Espart bord (CAT); Albardín (SP).

<u>Leaf anatomy description.</u>

Epidermis. The adaxial epidermis is smooth, with short cells known as rondels alternating with elongated sinuate cells. Stomatal structures are absent (Figure 95a, b). In contrast, the abaxial epidermis is characterised by a dense covering of silica-rich hairs or trichomes (Figure 95c, d).

Transverse section. The leaf appears morphologically flat, but curls to reduce its surface area and minimise water loss in arid environments. This curling is evident in cross section where the abaxial surface has circular protuberances that house the primary isolated vascular bundles (Figure 95c, d). Secondary vascular bundles are distributed along the length of the leaf, each surrounded by a thick layer of sclerenchyma tissue. Parenchyma tissue is also visible in the section (Figure 95c, d).

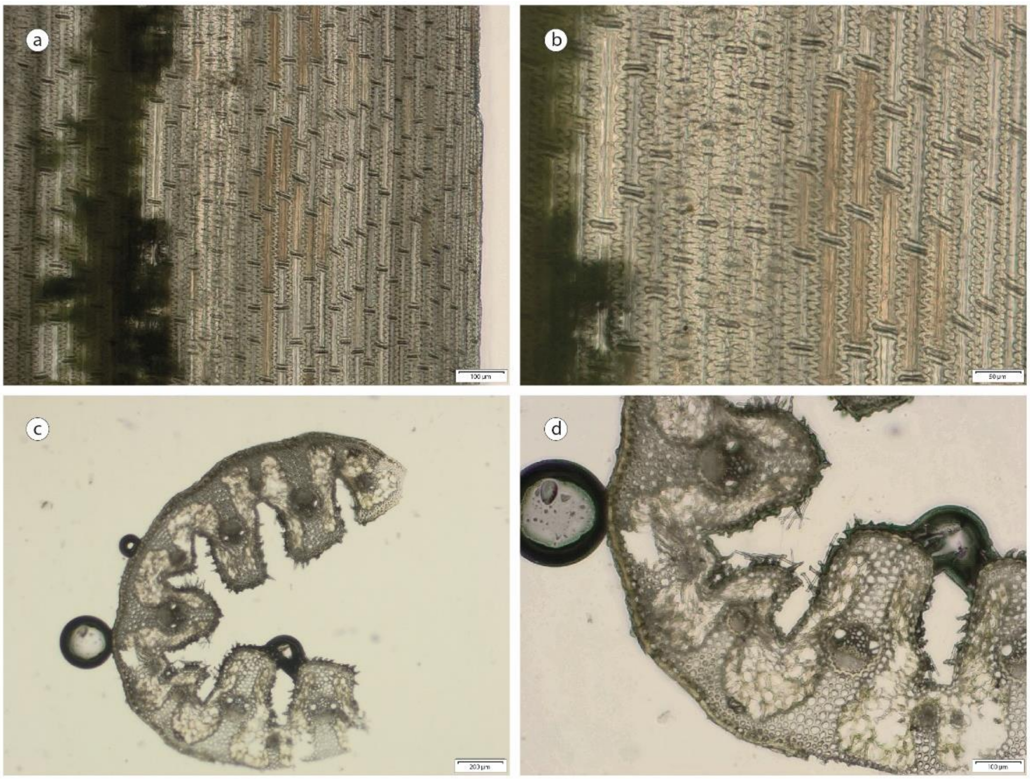

Figure 95. *Lygeum spartum* leaf OM images: a, b) Adaxial epidermis, c, d) Transversal section.

6.1.12. *Phragmites australis.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Phragmites*
Specie:	*Phragmites australis*

Common name: Common reed (ENG); Canyís/Canya borda (CAT); Carrizo (SP).

<u>Leaf anatomy description.</u>

Epidermis. The adaxial epidermis consists of alternating short and elongated cells with a high density of very small elongated stomatal structures. However, the cell borders were not clearly visible (Figure 96a, b). The abaxial surface is similar, with oval stomata arranged longitudinally along the leaf, alternating with lines of acute bulbous trichomes (Figure 96c, d).

Transverse section. The transversal section shows narrow elements with slight protuberances where the primary vascular bundles are located. The secondary vascular bundles are smaller and located in small protuberances. The xylem consists of two large vessels and the epidermis consists of a single layer of cells (Figure 96e, f).

<u>Stem anatomy description.</u>

Epidermis. The epidermis consists of alternating short and elongated cells without visible stomatal structures. The margins of the elongate cells appear sinuate or clavate (Figure 97a, b). Scattered acute, bulbous trichomes are also visible (Figures 97a, b).

Transverse section. A section of the straw is shown in Figure 97c, d. The vascular bundles are closer to the inner part near the pith, while the outer part consists of dense tissue. Each vascular bundle contains two large xylem vessels and the phloem is also clearly visible (Figure 97c, d).

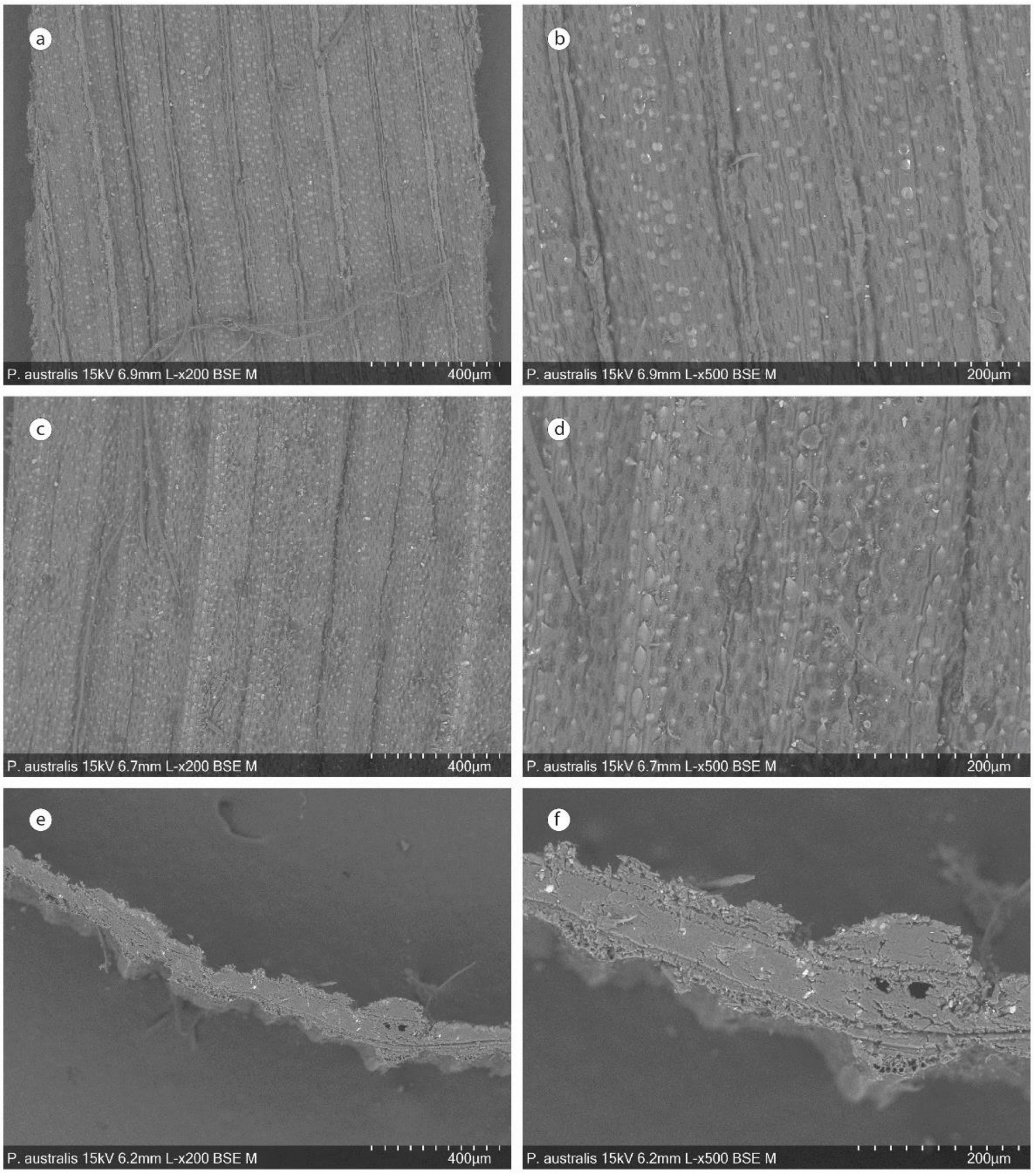

Figure 96. *Phragmites australis* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

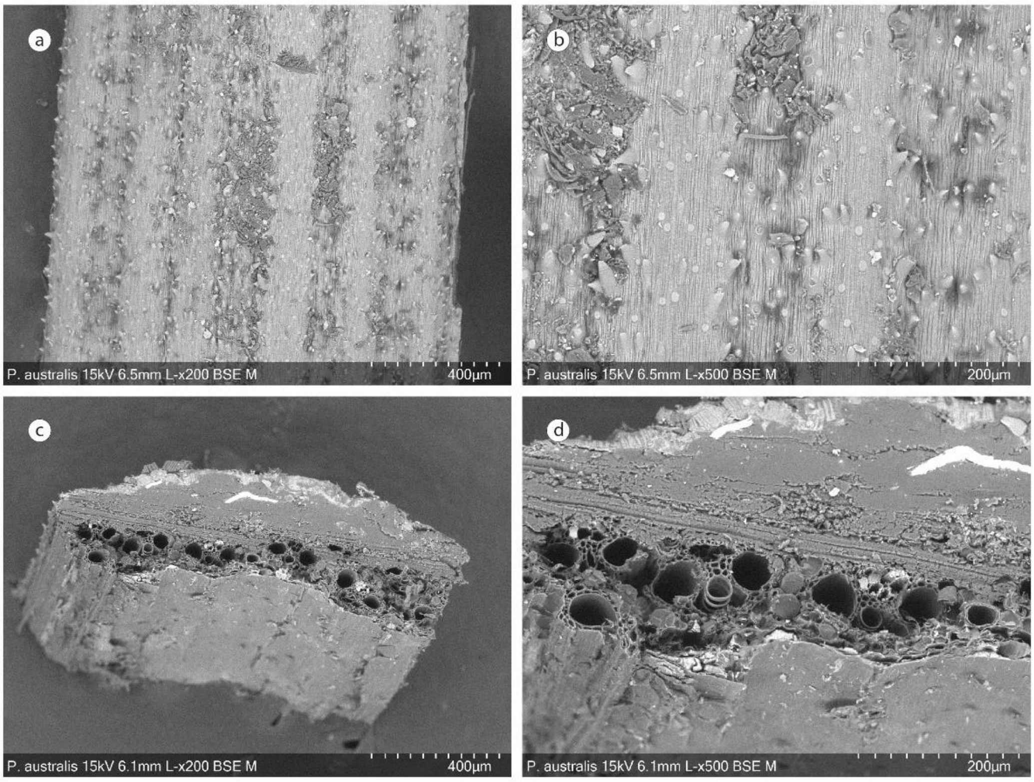

Figure 97. *Phragmites australis* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.13. *Schoenus nigricans*.

Class: Monocotyledoneae
Order: Poales
Family: Cyperaceae
Genus: *Schoenus*
Specie: *Schoenus nigricans*

Common name: Black sedge (ENG); Jonc negre (CAT); Junco negro (SP).

Stem anatomy description.

Epidermis. Epidermal cells are elongated with crenate margins. Stomatal structures are elliptical and arranged longitudinally along the stem, although their arrangement appears disordered due to the presence of protuberances visible in the images (Figure 98a, b). Stomata are quite numerous along the entire stem and are significantly larger compared to other Cyperaceae species in this reference collection.

Longitudinal section. There is remarkable variability in the thickness, shape and size of the parenchyma cells around the outer part and the pith, as shown in Figure 98c, d.

Transverse section. A complete section of the stem is shown in Figure 98e, f. The inner part of the stem, or pith, contains a tissue structure and is not hollow. The epidermis is unicellular, as shown in Figure 98f. The outer part of the Transverse section shows prominent circular protuberances. Vascular bundles are located close to the pith and appear to form a ring around the section but remain isolated from each other (Figure 98e, f). Thick sclerenchyma is also visible around the vascular bundles, particularly in the inner part.

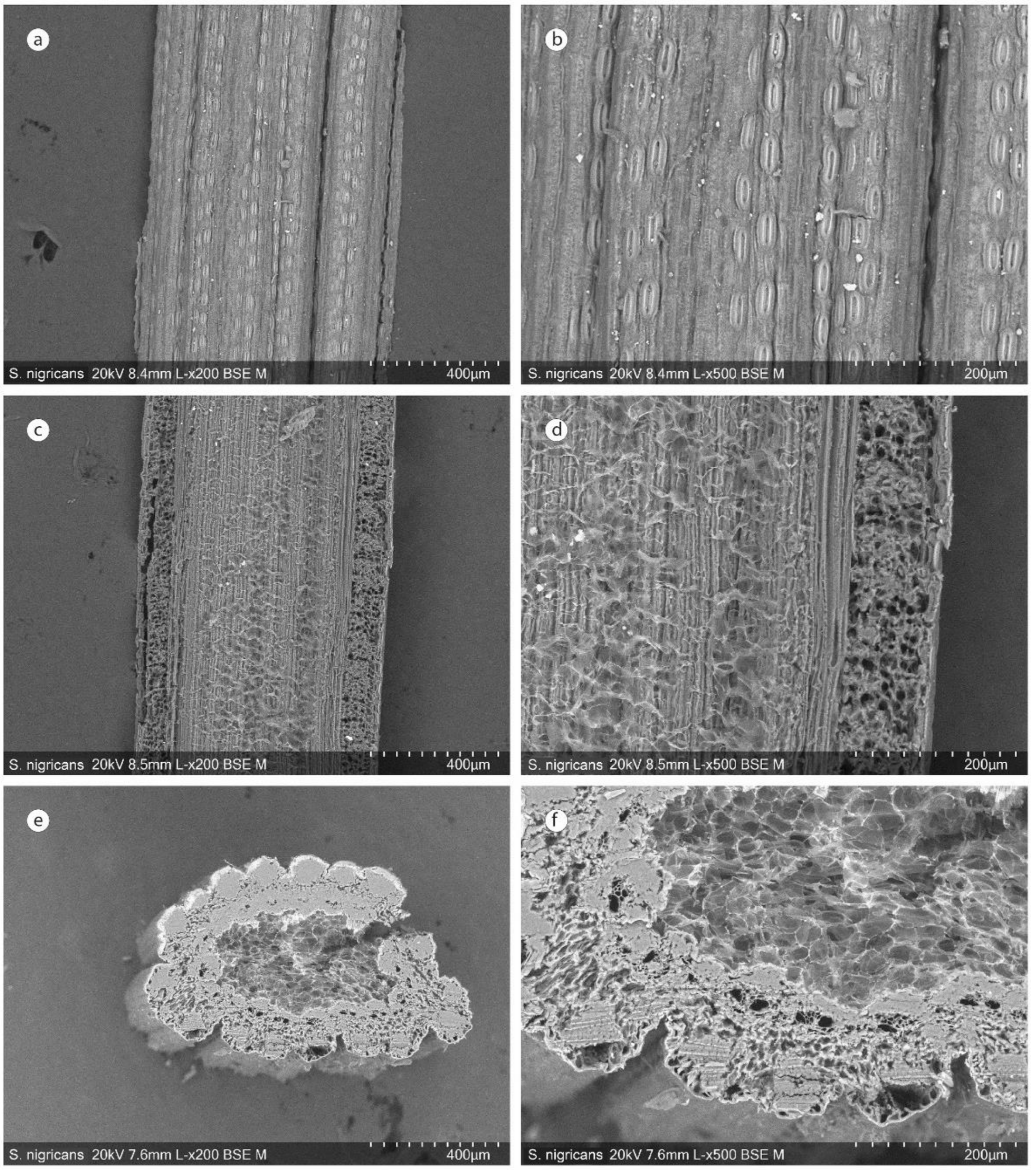

Figure 98. *Schoenus nigricans* stem SEM images: a, b) Epidermis, c, d) Longitudinal view, e, f) Transversal section.

6.1.14. *Scirpus holoschoenus / Holoschoenus vulgaris / Scirpoides holoschoenus.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Cyperaceae
Genus:	Scirpus / *Holoschoenus* / *Scirpoides*
Specie:	*Scirpus holoschoenus* / Holoschoenus vulgaris / Scirpoides holoschoenus.

Common name: Round-headed club-rush (ENG); Jonc/Jonc comú (CAT); Junco/junco común (SP).

<u>Stem anatomy description.</u>

Epidermis. The epidermal cells are elongated with crenate margins. Stomatal structures are elliptical and arranged longitudinally along the stem and are quite numerous throughout the stem (Figs 99a, b).

Longitudinal section. There is marked variability in the thickness, shape and size of the parenchyma cells around the outer part and pith, as shown in Figure 99c, d.

Transverse section. A complete section of the stem is shown in Figure 99e, f. The inner part, or pith, consists of dense tissue. A unicellular epidermis can be seen in Figure 99e. The outer part of the transversal section shows circular protuberances. Vascular bundles, both primary and secondary, are located close to the pith. Thick sclerenchyma tissue surrounds the vascular bundles, which are separated by air parenchyma (aerenchyma) (Figure 99e, f). Collenchyma tissue extends from the epidermis to the vascular bundles (Figure 99e).

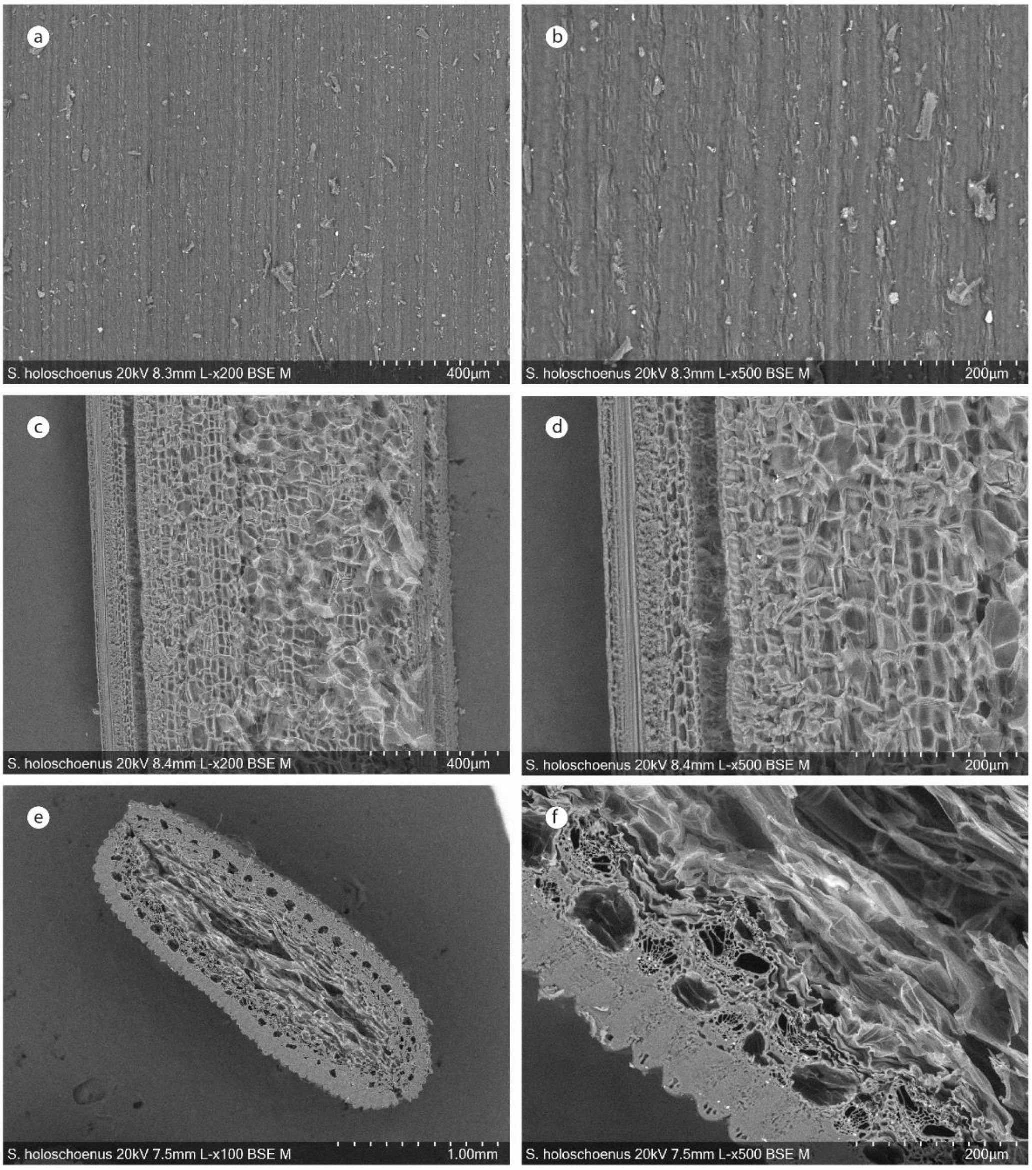

Figure 99. *Scirpus holoschoenus* stem SEM images: a, b) Epidermis, c, d) Longitudinal view, e, f) Transversal section.

6.1.15. *Stipa gigantea.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Stipa*
Specie:	*Stipa gigantea*

Common name: Giant feather grass (ENG); Espart gegant(CAT); Berceo/baraceo (SP).

Leaf anatomy description.

Epidermis. The adaxial epidermis is smooth, with short cells known as rondels alternating with elongated sinuate cells. Stomatal structures are absent (Figure 100a,b). In contrast, the abaxial epidermis is characterised by a dense covering of silica-rich hairs or trichomes (Figure 100c, d).

Transverse section. The leaf appears morphologically flat, but curls to reduce its surface area and minimise water loss in arid environments. This curling is evident in cross section where the abaxial surface has rectangular protuberances that house the primary isolated vascular bundles (Figure 100c, d). Secondary vascular bundles are distributed along the length of the leaf, each surrounded by a thick layer of sclerenchyma tissue. Parenchyma tissue is also visible in the section (Figure 100c, d).

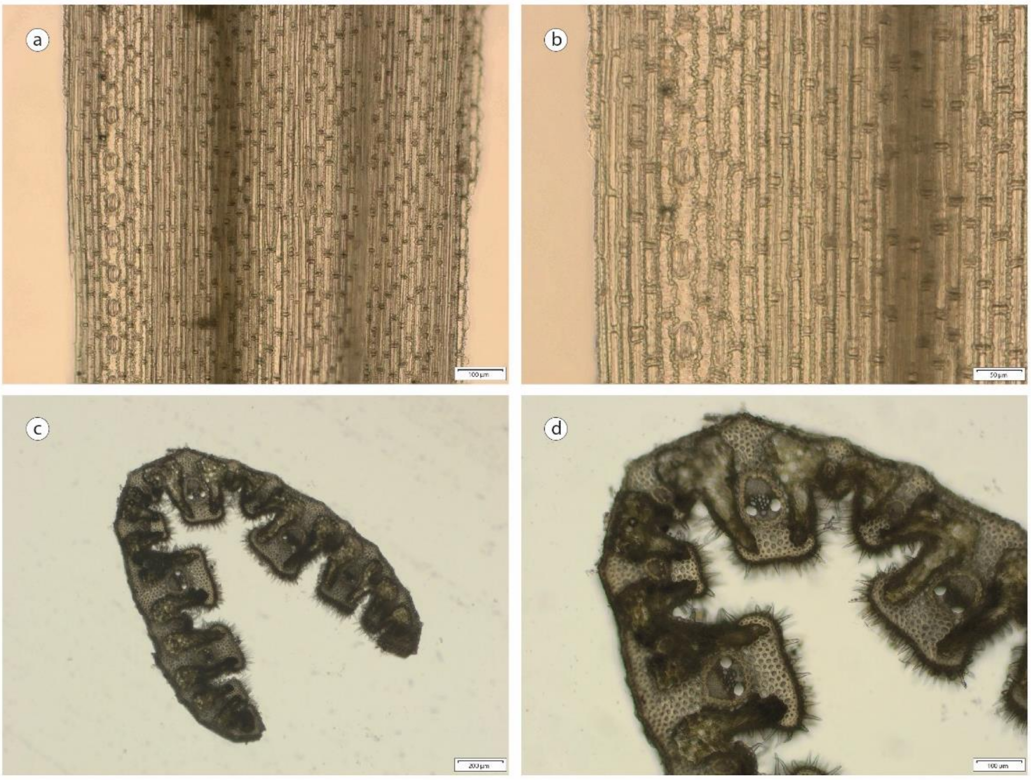

Figure 100. *Stipa gigantea* leaf OM images: a, b) Adaxial epidermis, c, d) Transversal section.

6.1.16. *Stipa tenacissima / Macrochloa tenacissima*.

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Stipa*
Specie:	*Stipa tenacissima*

Common name: Esparto grass/alfa grass/needle grass (ENG); Espart (CAT); Esparto (SP).

<u>Leaf anatomy description (raw fibres).</u>

Epidermis. The adaxial epidermis is smooth, with alternating short cells known as rondels and elongated sinuate cells, with no stomatal structures (Figure 101a,b). In contrast, the abaxial epidermis is characterised by a dense covering of silica-rich hairs or trichomes (Figure 101c, d).

Transversal section. The leaf is morphologically flat, but curls to reduce surface area and limit water loss in arid environments. This curling is evident in cross section where the abaxial surface forms protuberances that house the primary isolated vascular bundles (Figure 101e). Secondary vascular bundles are distributed along the length of the leaf, each surrounded by a thick layer of sclerenchyma tissue. Parenchyma tissue is also visible (Figure 101e, f).

<u>Leaf anatomy description (physically processed fibres).</u>

Physical processing or crushing of the fibres can cause the material to lose or alter its natural properties or appearance. In this context, Figure 102a shows lightly crushed esparto grass leaves, allowing the stomatal structures within the protuberances that characterise the leaf to be observed. Conversely, Figure 102b illustrates a high degree of processing which has caused the silica hairs on the abaxial epidermis to fall off.

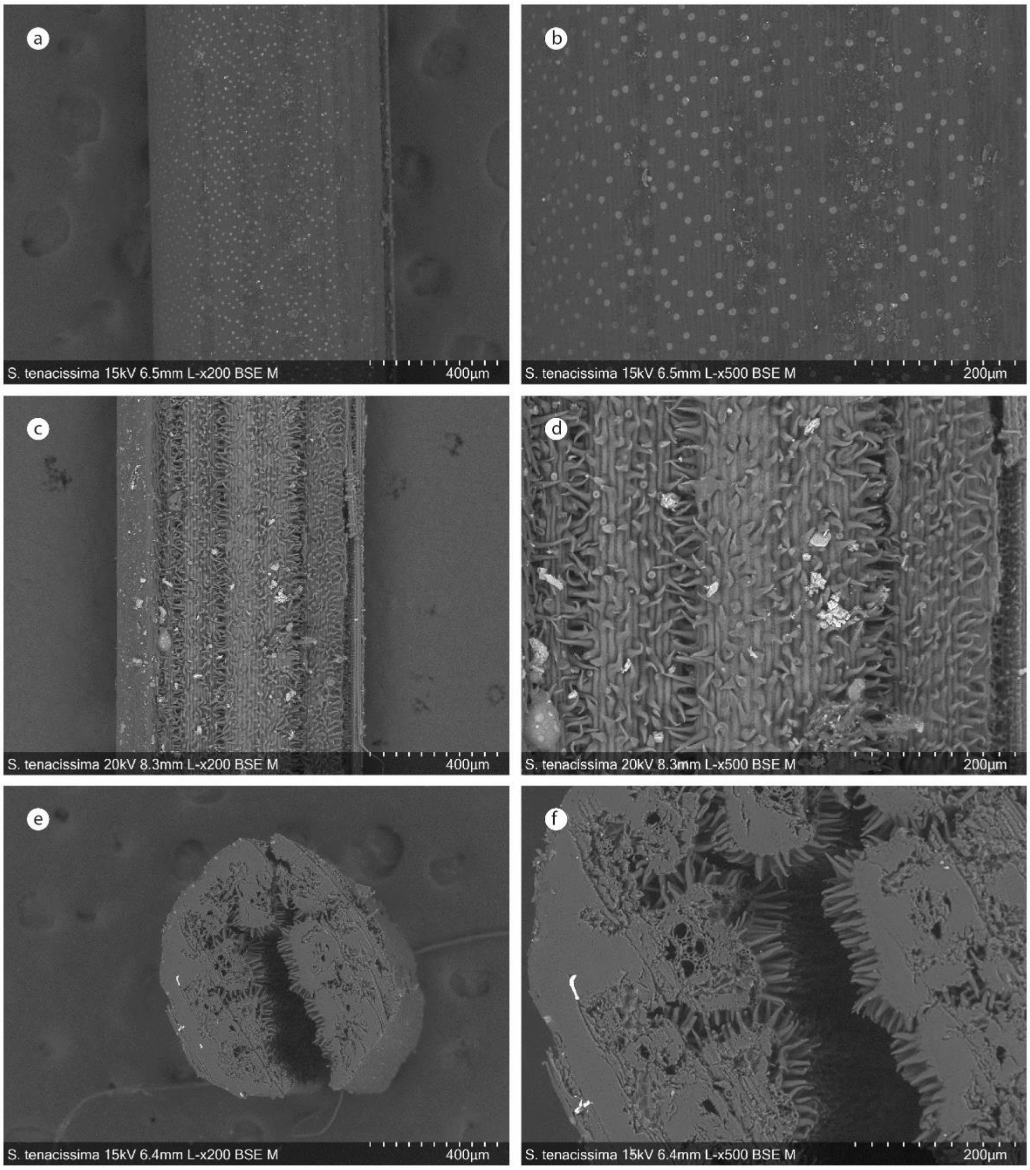

Figure 101. Raw *Stipa tenacissima* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

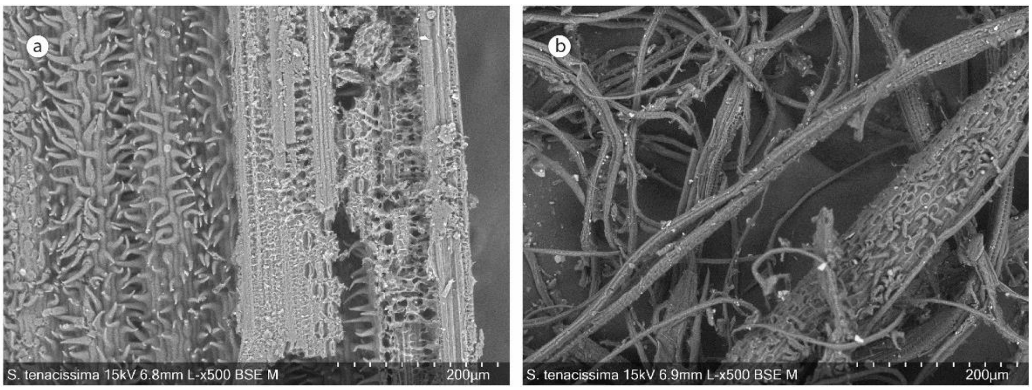

Figure 102. Processed *Stipa tenacissima* leaf SEM images: a) Abaxial epidermis with visible stomata, c) Processed esparto fibres.

6.1.17. *Triticum aestivum*.

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Triticum*
Specie:	*Triticum aestivum*

Common name: Common wheat (ENG); Blat/Blat comú (CAT); Trigo (SP).

<u>Leaf anatomy description.</u>

Epidermis. Both the adaxial and abaxial epidermis have a very similar cellular structure, the main difference being the lower number of trichomes on the abaxial surface. Both surfaces have long epidermal cells with clavate margins and short cells are also present. Stomatal structures are clearly visible on both surfaces and have an elongated appearance (Figure 103a-d). Cellular appendages, including trichomes with an acute bulbous shape, are present on both surfaces, although they are more numerous on the adaxial surface, where they are arranged longitudinally along the leaf (Figure 103c, d).

Transverse section. The transversal section of *Triticum aestivum* leaves shows a long, narrow structure with small protuberances containing the vascular bundles. The leaf also rolls on itself. The epidermis consists of a single layer of cells (Figure 103e, f).

<u>Stem anatomy description.</u>

Epidermis. The epidermal cells of the stem have crenate margins. Stomatal structures are also present, although they are fewer in number and circular in shape compared to leaf samples. They are arranged longitudinally along the stem and in areas where stomata are found, the short cells (circular or ovate) are less common (Figure 104a, b).

Transverse section. The stem of *Triticum aestivum* has an empty pith surrounded by large parenchyma. Vascular bundles are distributed in alternating cavities around the circular cross section of the stem, where dense tissue structures are visible (Figure 104c, d). Thick bundles of sclerenchyma fibres are also present, providing structural support (Figure 104d).

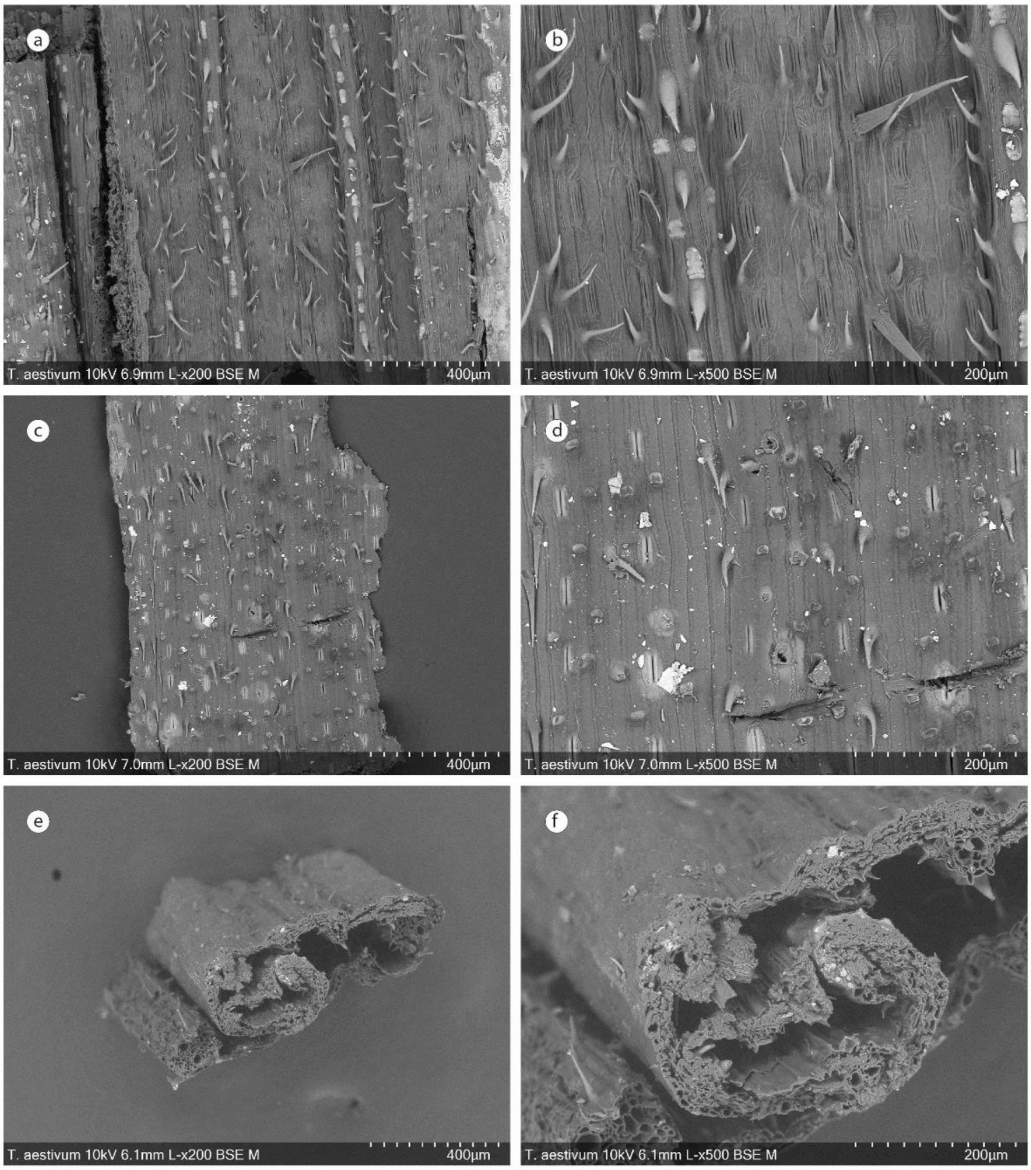

Figure 103. *Triticum aestivum* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

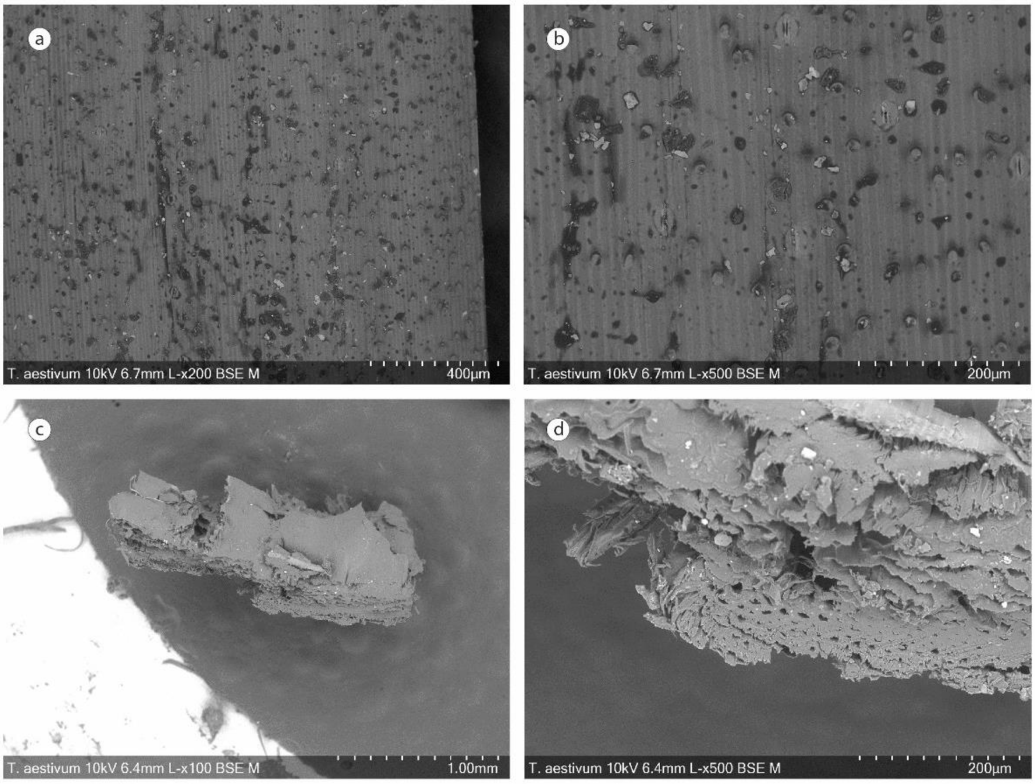

Figure 104. *Triticum aestivum* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.18. *Triticum dicoccum / Triticum dicoccon.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Triticum*
Specie:	*Triticum dicoccum* / *Triticum dicoccon.*

Common name: Emmer wheat (ENG); Pisana/espelta bessona (CAT); Trigo farro/Farro/Trico almidonero silvestre (SP).

Leaf anatomy description.

Epidermis. Both the adaxial and abaxial epidermis have a similar cellular structure, consisting of long epidermal cells with slightly sinuate margins. Stomatal structures are clearly visible on both surfaces and have an elongated shape (Figures 105a-d). Cellular appendages, including trichomes with an acute, bulbous shape, are also present on both surfaces and are located mainly on the protuberances visible in the transversal section.

Transverse section. The transversal section of *Triticum dicoccum* leaves shows a long, narrow structure with small protuberances where vascular bundles are located. The epidermis consists of a single layer of cells (Figure 105e, f).

Stem anatomy description.

Epidermis. The epidermal cells of the stem have crenate margins. Stomatal structures are present, but less numerous than in leaf samples and circular in shape. They are arranged longitudinally along the stem and where stomata are present, the short cells (circular/ovate) are less frequent (Figure 106a, b).

Transverse section. The stem of *Triticum dicoccum* has an empty pith and a large parenchyma around it. Vascular bundles are present where dense tissular structures are visible in alternating cavities around the circular cross section of the stem (Figure 106c, d).

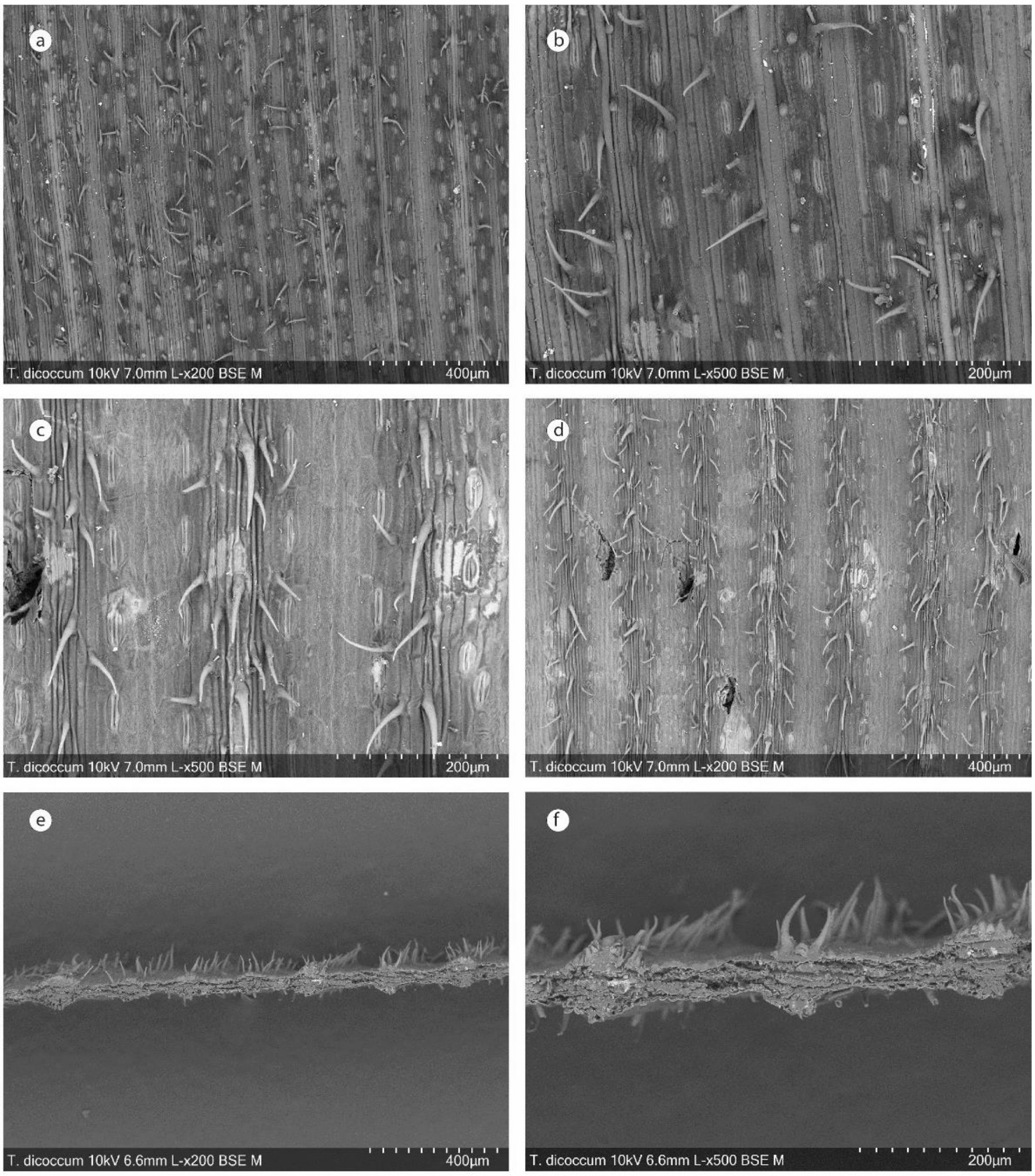

Figure 105. *Triticum dicoccum* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

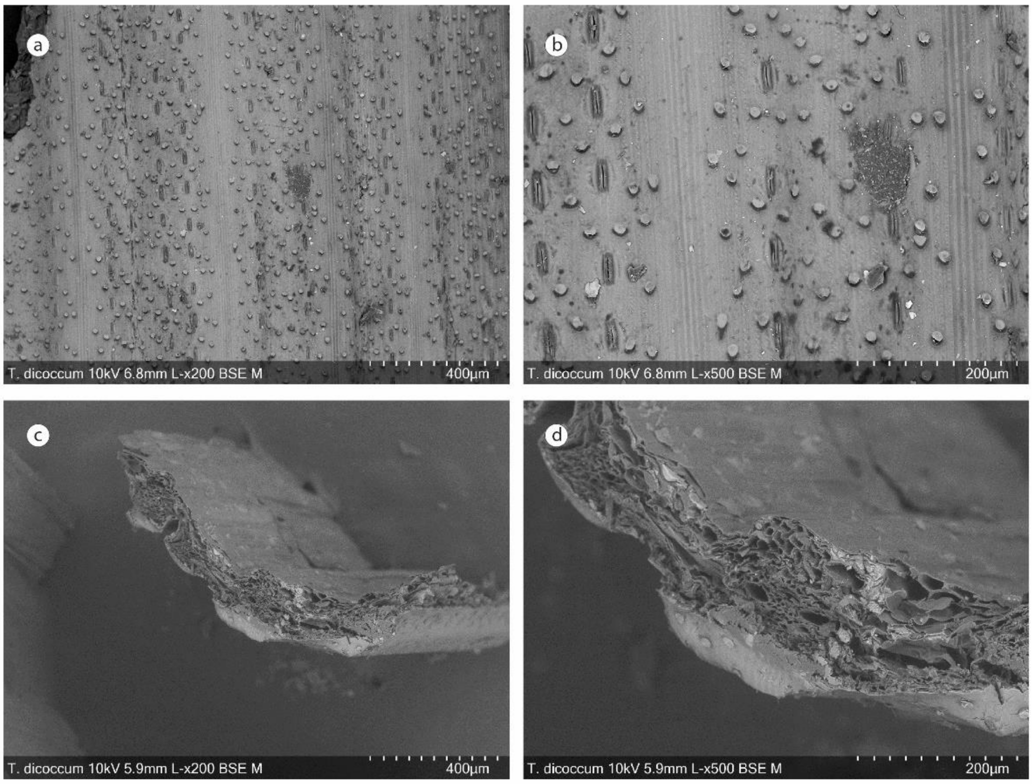

Figure 106. *Triticum dicoccum* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.19. *Triticum durum.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Triticum*
Specie:	*Triticum durum*

Common name: Durum wheat (ENG); Blat dur (CAT); Trigo duro (SP).

<u>Leaf anatomy description.</u>

Epidermis. The adaxial epidermis has a similar cellular structure, consisting of long epidermal cells with crenate margins. Stomatal structures are clearly visible on the adaxial surface and are large and elongated (Figure 107a, b). No cellular processes are observed. In contrast, the abaxial surface appears almost glabrous, with long, whole, elongated cells and some trichomes with an acute, bulbous shape (Figure 107c, d).

Transverse section. The transversal section of *Triticum durum* leaves shows a long, narrow structure with small protuberances on the adaxial surface where vascular bundles are located. The epidermis consists of a single layer of cells (Figure 107e, f) and a thick layer of sclerenchyma tissue, consisting of approximately 5-6 layers of cells, is visible.

<u>Stem anatomy description.</u>

Epidermis. The epidermal cells of the stem have crenate margins. Stomatal structures are present but few are visible. These are arranged longitudinally along the stem and are oval in shape (Figure 108a, b).

Transverse section. The stem of *Triticum durum* has a hollow pith surrounded by large parenchyma. Vascular bundles are distributed in alternating cavities around the circular cross section of the stem, where dense tissue structures are observed (Figure 108c, d). The parenchyma is heterogeneous and a thick ring of sclerenchyma tissue surrounds the stem/straw.

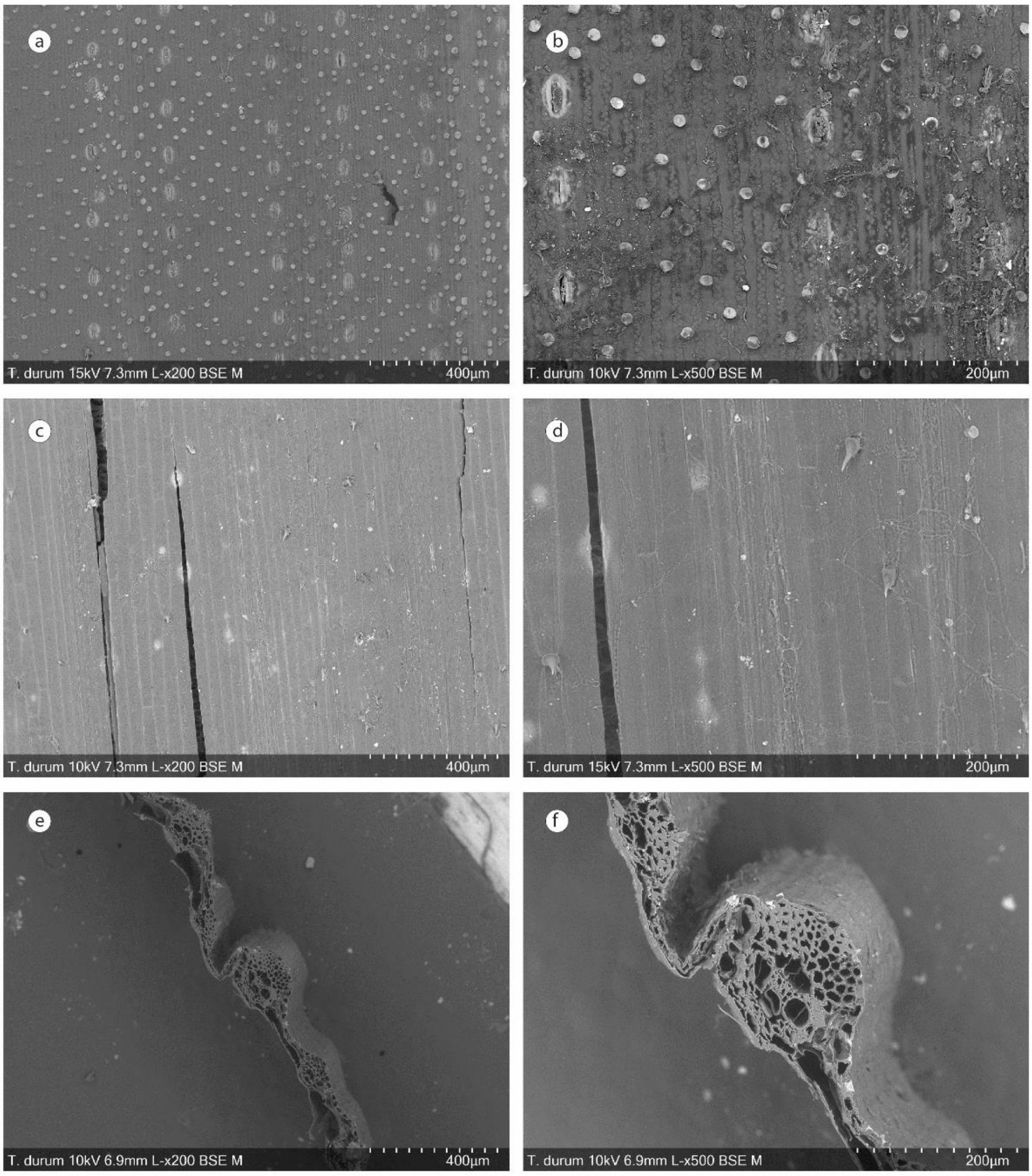

Figure 107. *Triticum durum* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

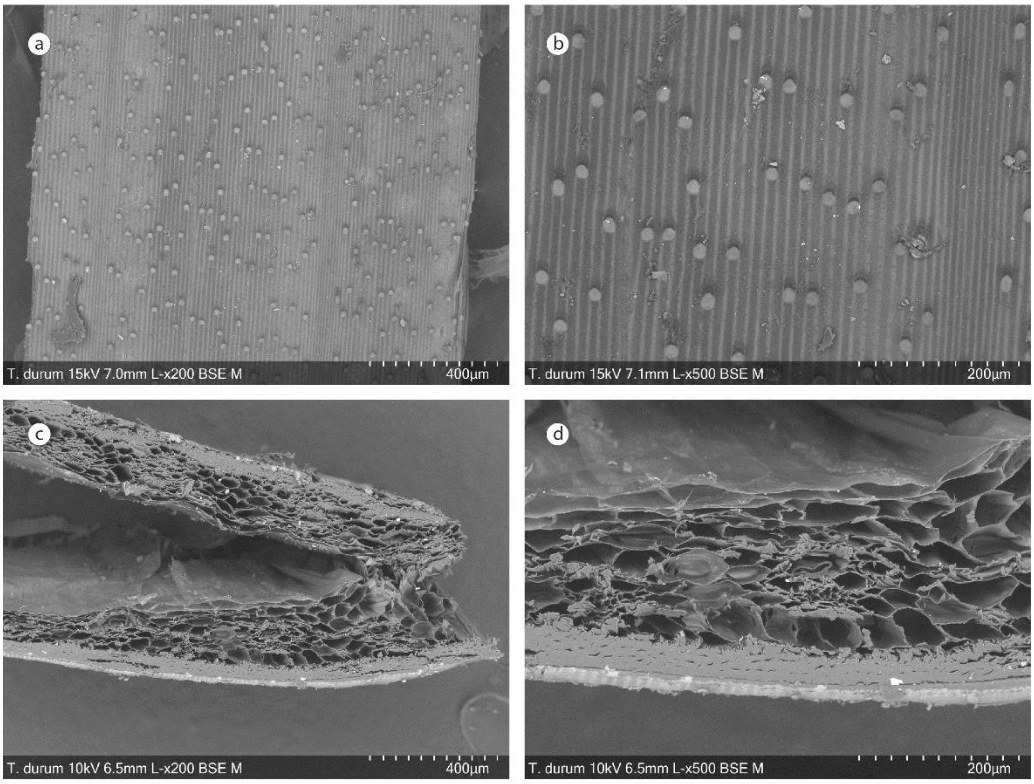

Figure 108. *Triticum durum* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.20. *Triticum monococcum.*

Class:	Monocotyledoneae
Order:	Poales
Family:	Poaceae
Genus:	*Triticum*
Specie:	*Triticum monococcum*

Common name: Einkorn wheat (ENG); Espelta petita (CAT); Escaña/escanda menor (SP).

Leaf anatomy description.

Epidermis. Both the adaxial and abaxial epidermis have a similar cellular structure consisting of long epidermal cells with slightly sinuate margins. Stomatal structures are clearly visible on both surfaces and have an elongated shape (Figures 109a-d). Cellular appendages, including trichomes with an acute, bulbous shape, are also present on both surfaces, predominantly located on the protuberances visible in the transverse section. Both trichomes and stomata are very numerous on both epidermal surfaces.

Transverse section. The transversal section of *Triticum monococcum* leaves shows a long, narrow structure with small protuberances where vascular bundles are located. The epidermis consists of a single layer of cells (Figure 109e, f).

Stem anatomy description.

Epidermis. The epidermal cells of the stem have crenate margins. Stomatal structures are present but less numerous than in leaf samples and circular in shape. They are arranged longitudinally along the stem and in areas where stomata are present, short cells (circular/ovate) are less common (Figure 110a, b).

Transverse section. The stem of *Triticum monococcum* has a hollow pith surrounded by large parenchyma. Vascular bundles are distributed in alternating cavities around the circular cross section of the stem, where dense tissue structures are visible (Figure 110c, d). The parenchyma is heterogeneous.

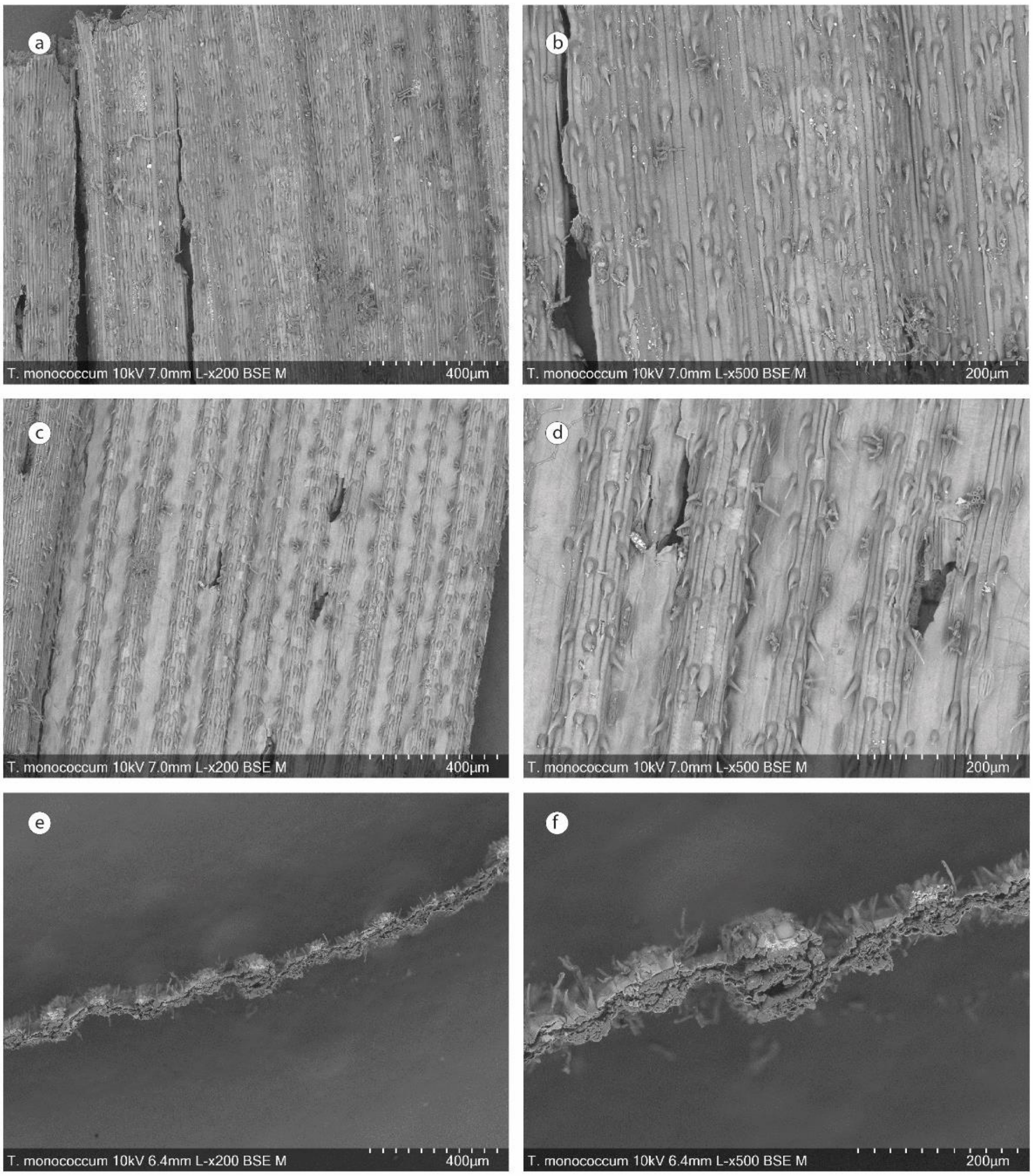

Figure 109. *Triticum monococcum* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

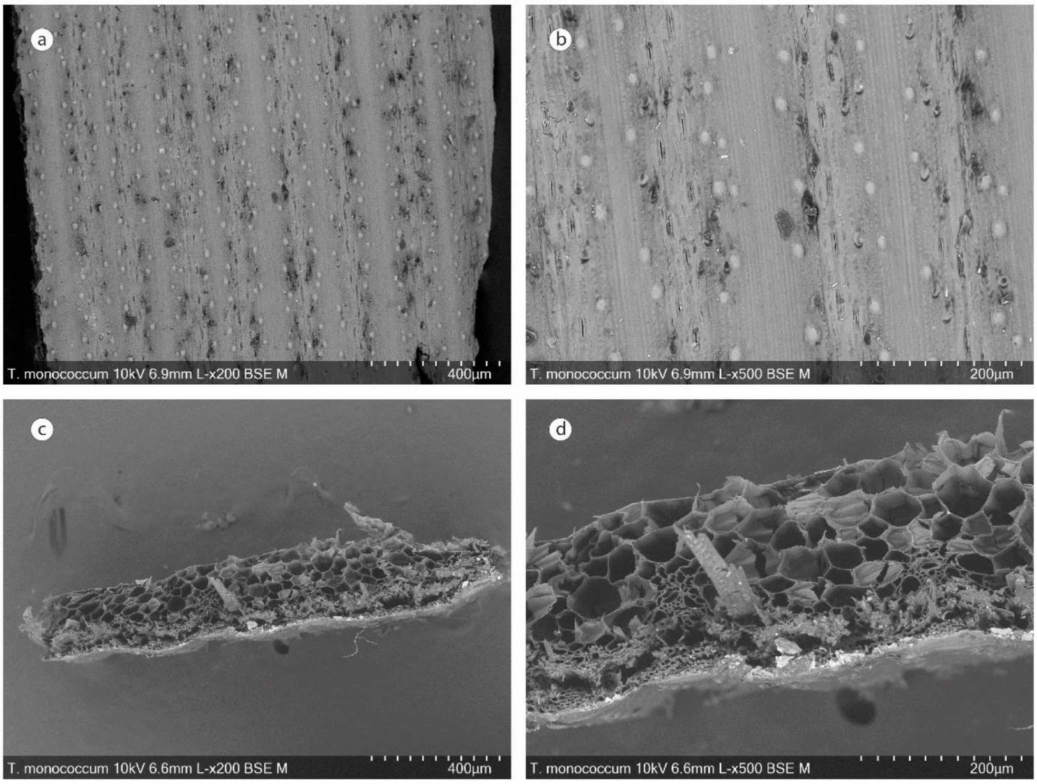

Figure 110. *Triticum monococcum* stem SEM images: a, b) Epidermis, c, d) Transversal section.

6.1.21. *Typha angustifolia*.

Class:	Monocotyledoneae
Order:	Poales
Family:	Typhaceae
Genus:	*Typha*
Specie:	*Typha angustifolia*

Common name: Lesser bulrush/narrowleaf cattail/lesser reedmace (ENG); Balca/boga de fulla estreta (CAT); Anea/enea/espadaña/tótora (SP).

Leaf anatomy description.

Epidermis. Both the adaxial and abaxial surfaces show very similar characteristics. The epidermal cells have a rectangular shape with no distinctive features at the edges, although there is some variability in cell morphology. The most notable feature is the large number of stomatal structures scattered throughout the leaf, making them the most prominent cell type in the epidermis (Figure 111a-d).

Transverse section. The epidermis is composed of a single layer (one-seriate) followed by a three-layered palisade parenchyma, which shows some heterogeneity. Both primary and secondary vascular bundles are present, with the smaller bundles located close to the epidermis and the larger ones located in parenchyma columns around the aerenchyma chambers. The xylem contains a large vessel. Sclerenchyma tissue forms a thick layer around the vascular bundles, consisting of three to four layers of cells (Figure 111e, f).

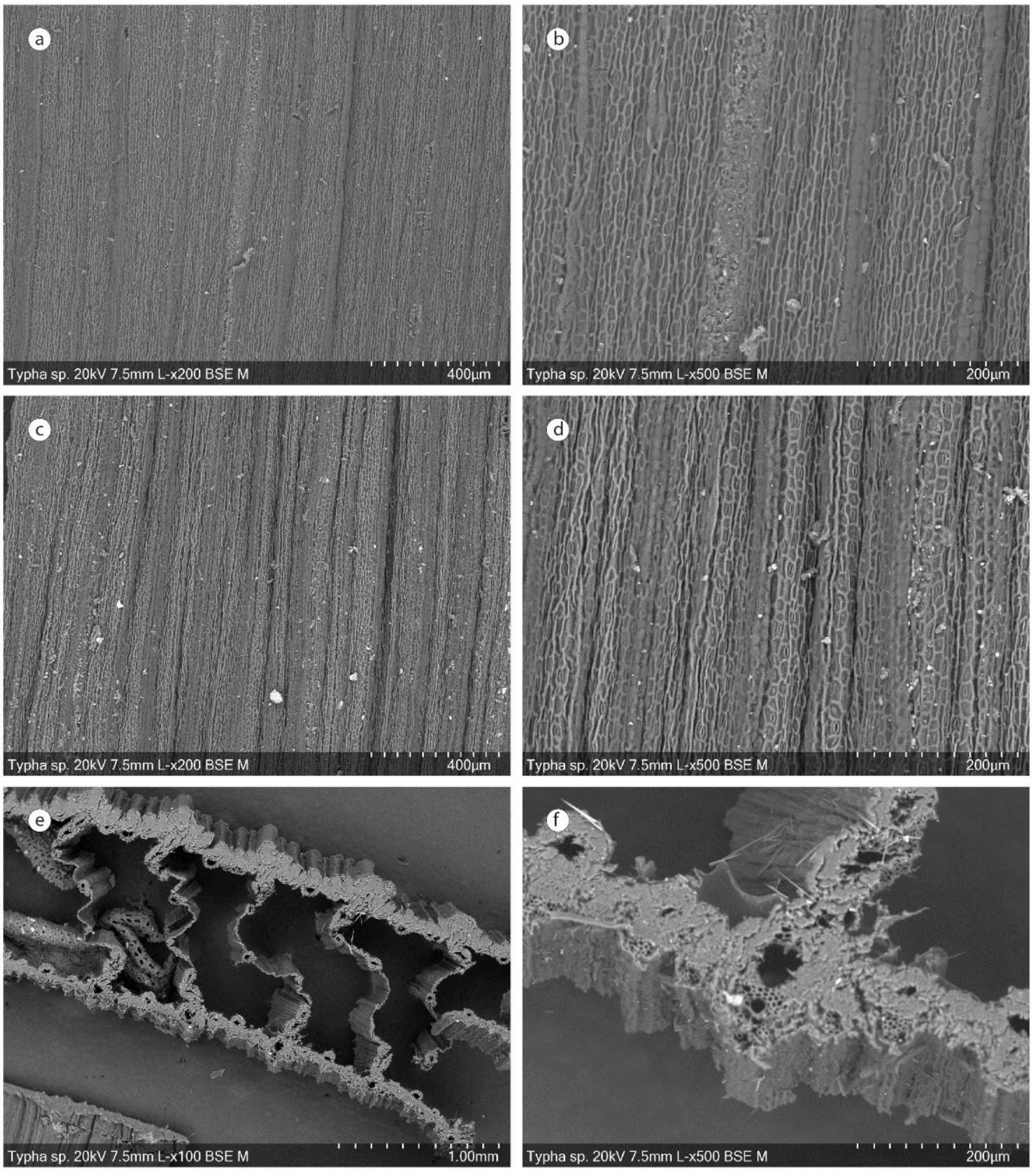

Figure 111. *Typha angustifolia* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

6.1.22. *Typha latifolia.*

Class: Monocotyledoneae
Order: Poales
Family: Typhaceae
Genus: *Typha*
Specie: *Typha latifolia*

Common name: Broadleaf cattail/common cattail (ENG); Balca/boga de fulla ample (CAT); Chuspata/cola de gato/espadaña/tótora/tule (SP).

<u>Leaf anatomy description.</u>

Epidermis. The epidermis is very similar to that of *Typha latifolia*. Both the adaxial and abaxial surfaces show very similar characteristics, with rectangular epidermal cells and no distinctive features at the margins. There is some variability in cell morphology. A high density of stomatal structures is scattered throughout the leaf, making them the most prominent feature of the epidermis (Figure 112a-d).

Transverse section. The transversal section is also similar to that of *Typha latifolia*. The epidermis is single layered (one-seriated) and is followed by heterogeneous parenchyma. Both primary and secondary vascular bundles are present, with the smaller ones close to the epidermis and the larger ones in parenchyma columns along the aerenchyma chambers. The xylem contains a large vessel. Sclerenchyma tissue surrounds the vascular bundles, forming a thick layer consisting of three to four layers of cells (Figure 112e, f).

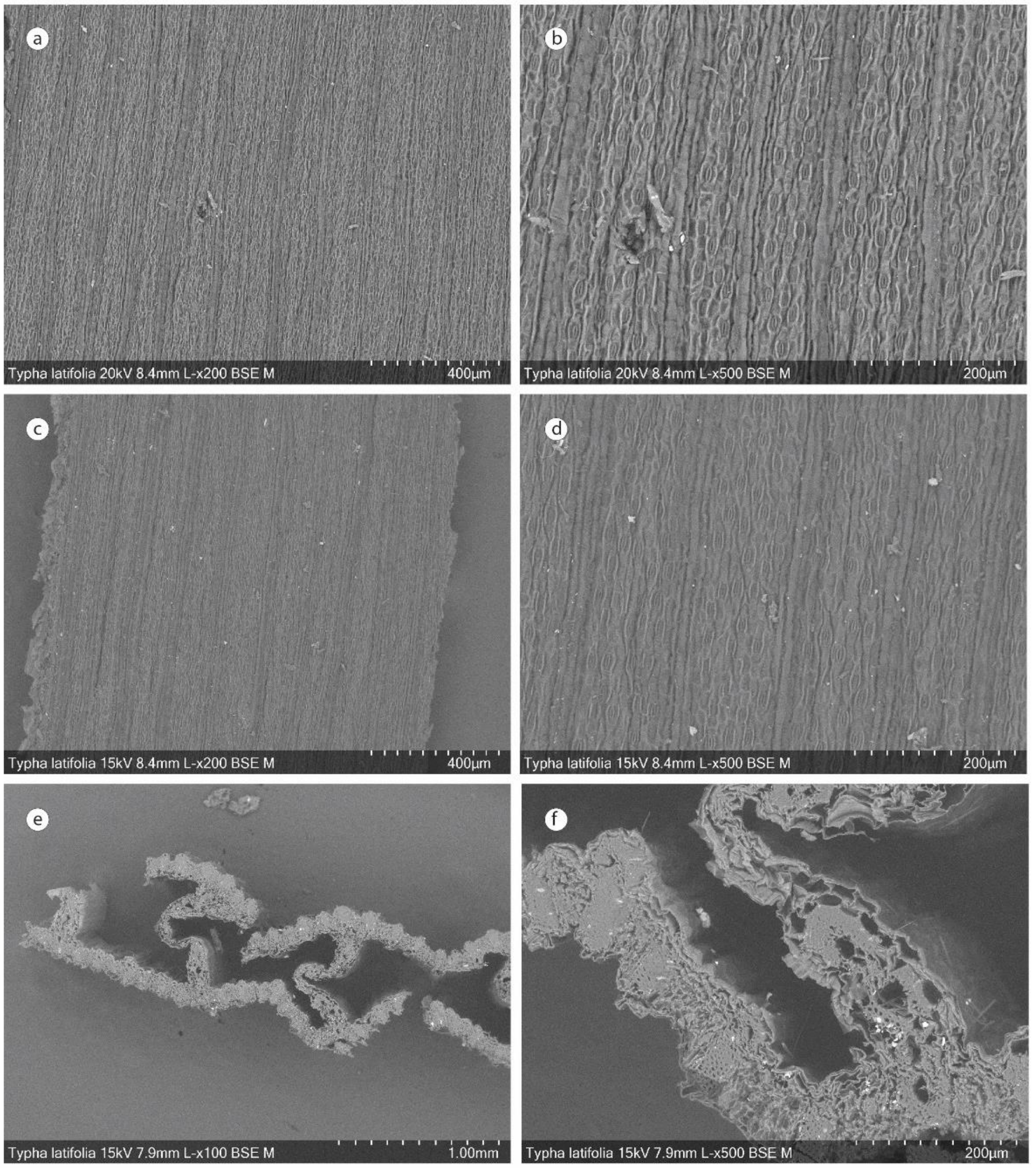

Figure 112. *Typha latifolia* leaf SEM images: a, b) Adaxial epidermis, c, d) Abaxial epidermis, e, f) Transversal section.

6.1.23. *Linum usitatissimum*.

Class: Dicotyledoneae
Order: Malpighiales
Family: Linaceae
Genus: *Linum*
Specie: *Linum usitatissimum*

Common name: Flat (ENG); Lli (CAT); Lino (SP).

<u>Stem anatomy description.</u>

Epidermis. The epidermis is covered by a cuticle (Figure 113a, b). In the surface view, the detailed morphology of the cells is not clearly visible, but stomata are present and identifiable (Figure 113b).

<u>Bast fibres anatomy description.</u>

The bast fibres are smooth, colourless and elongated with a round cross-section, with occasional knots or nodes along their structure (Figure 113c, d). When viewed under a polarised light microscope, the internal microfibrillar structure is clearly visible, with bright cross sections due to the birefringence effect (Figure 113e, f).

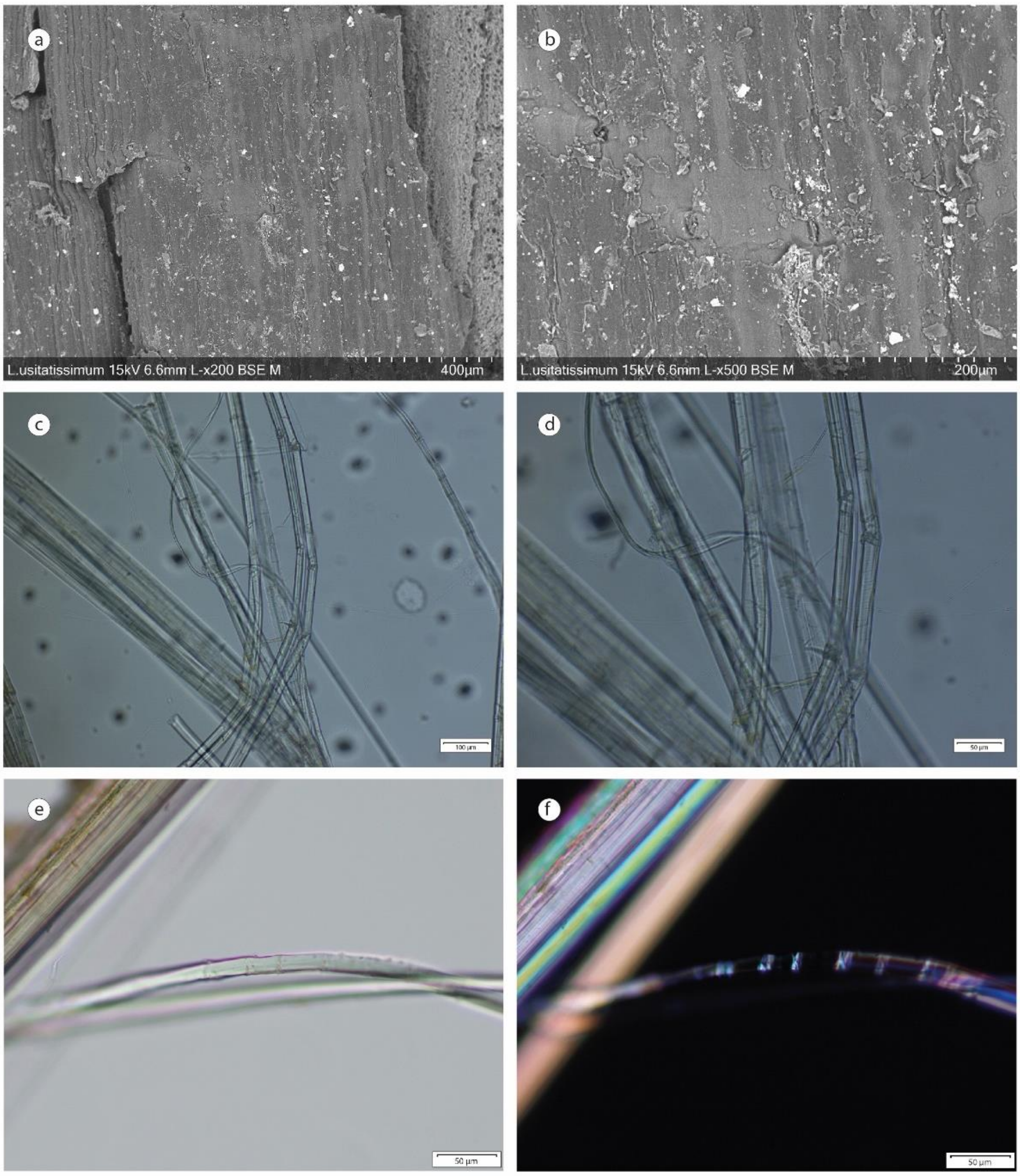

Figure 113. *Linum usitatissimum* SEM and OM stem and fibres images: a, b) Stem epidermis, c, d) Processed fibres, e, f) Processed fibres and under polarized light.

6.1.24. *Tilia cordata.*

Class:	Dicotyledoneae
Order:	Malvales
Family:	Malvaceae
Genus:	*Tilia*
Specie:	*Tilia cordata*

Common name: Small-leaved lime/linden (ENG); Til·ler/tell/tella silvestre/de fulla petita (CAT); Tilo norteño/silvestre/de hoja pequeña (SP).

Bark strips description.

Tangential section. There is a clear diversity of parenchyma cells, both in morphology and size. In addition, the lime bark strips in this case have been retted, which is evident from the empty spaces within the rays (Figure 114a-d) (Böhm et al. 2023). The authors suggest that this is related to the disruption of the connection between the axial parenchyma cells in the tree bast, as retting dissolves most of the sieve tube elements and bast rays.

Transverse section. In the transverse section of *Tilia* sp., the secondary phloem is visible, which is derived from the vascular cambium, and the outer cortex is formed by the periderm, which corresponds to dense lines formed by sclerenchyma fibres. It is not possible to distinguish between the species of *Tilia* sp.

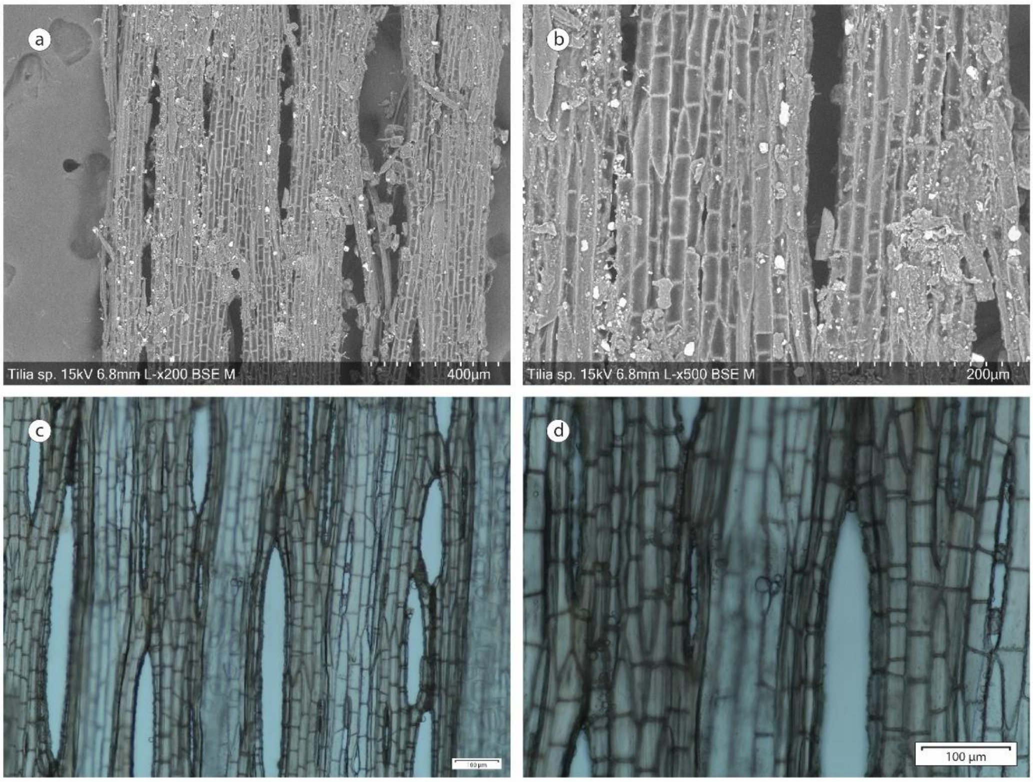

Figure 114. *Tilia cordata* SEM and OM bark strips images.

6.1.25. *Tilia platyphyllos*.

Class:	Dicotyledoneae
Order:	Malvales
Family:	Malvaceae
Genus:	*Tilia*
Specie:	*Tilia platyphyllos*

Common name: Large-leaved lime/linden (ENG); Til·ler/tell/tella silvestre/de fulla gran (CAT); Tilo común/de hoja ancha/de hoja grande (SP).

<u>Bark strips description.</u>

Tangential section. The anatomical features are very similar to those described for *Tilia cordata*. There is a marked diversity of parenchyma cells, both in morphology and size. The effects of retting are evident, as shown by the empty spaces within the rays (Figure 115a-d).

Transverse section. In the transverse section of *Tilia* sp., the secondary phloem is visible, which is derived from the vascular cambium, and the outer cortex is formed by the periderm, which corresponds to dense lines formed by sclerenchyma fibres. It is not possible to distinguish between the species of *Tilia* sp.

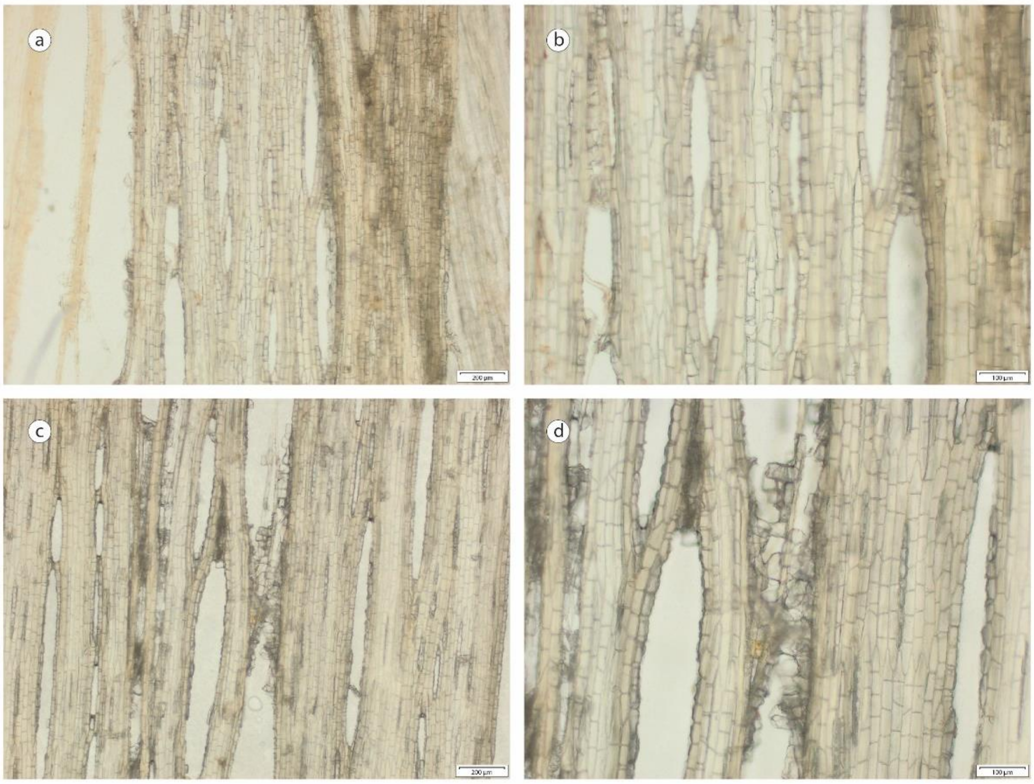

Figure 115. *Tilia platyphyllos* OM bark strips images.

6.1.26. *Urtica dioica.*

Class:	Dicotyledoneae
Order:	Rosales
Family:	Urticaceae
Genus:	*Urtica*
Specie:	*Urtica dioica*

Common name: Common/burn/stinging nettle (ENG); Ortiga major (CAT); Ortiga mayor (SP).

<u>Bast fibres anatomy description.</u>

The fibres are smooth, elongated and cylindrical in cross section, with knots or nodes along their structure. As the fibre bundles converge, clusters of oxalate crystals can be observed along the fibres (Figure 116a, b). When viewed under a polarised light microscope, the internal microfibrillar structure is clearly visible, with brightly illuminated cross sections highlighting this structure (Figure 116c, d).

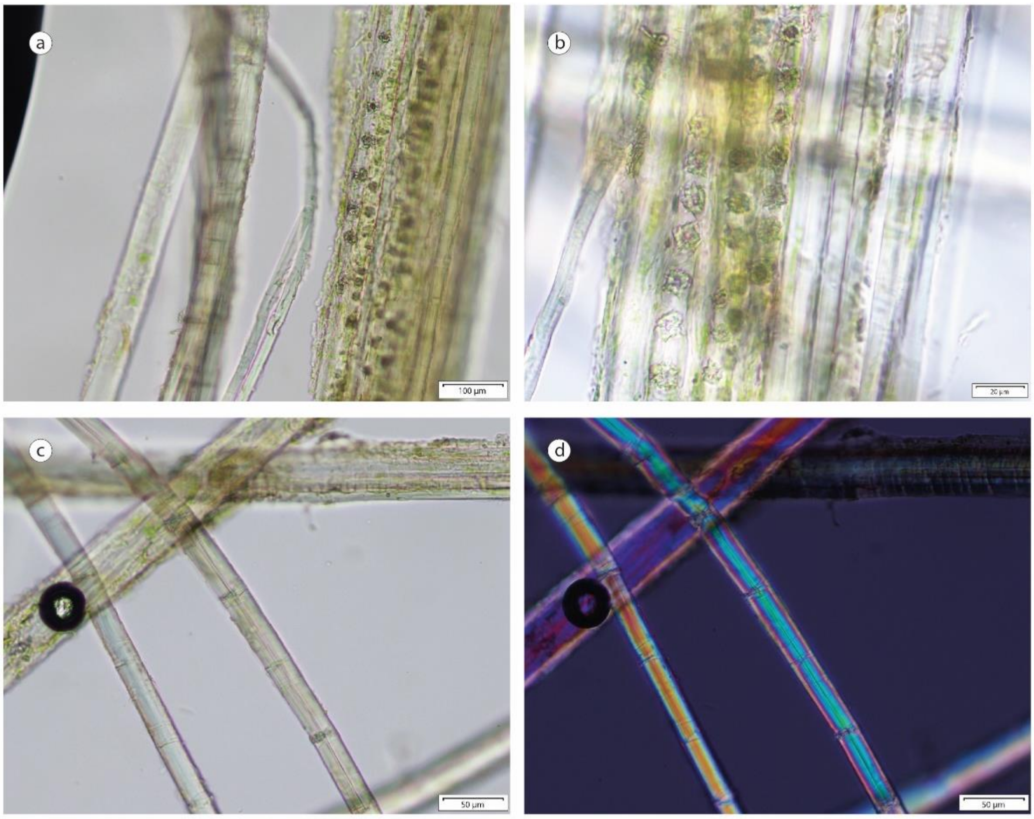

Figure 116. *Urtica dioica* OM fibres images: a, b) Processed fibres, c, d) Processed fibres and under polarized light.

CHAPTER VI – RESULTS (II)
- SCIENTIFIC PAPERS -

6.2. Results (II): Scientific papers.

The results of this thesis have been published in four different peer-reviewed journals or books, and one more is currently being revised. The results are presented in a chronological order (Mesolithic to Neolithic) and from the southeast to the northeast of the Iberian Peninsula. The methodological paper (in revision) is developed after the results of the archaeological material studies.

Martínez-Sevilla, F.*, **Herrero-Otal, M.***, Martín-Seijo, M., Santana, J., Lozano Rodríguez, J.A., Maicas Ramos, R., Cubas, M., Homs, A., Martínez Sánchez, R.M., Bertin, I., Barroso Bermejo, R., Bueno Ramírez, P., de Balbín Behrmann, R., Palomo Pérez, A., Álvarez-Valero, A.M., Peña-Chocarro, L., Murillo-Barroso, M., Fernández-Domínguez, E., Altamirano-García, M., Pardo-Martínez, R., Iriarte-Cela, M., Carrasco Rus, J.L., Alfaro Giner, C., Piqué Huerta, R. (2023) The earliest basketry in Southern Europe: hunter-gatherer and first farmers plant-based technology preserved in the Cueva de los Murciélagos (Albuñol, Spain). Science Advances, 9:eadi3055. DOI: 10.1126/sciadv.adi3055.

Romero-Brugués, S., **Herrero-Otal, M.**, Piqué, R., Rosillo, R., Terradas, X., López-Bultó, O., Berrocal-Barberà, A., Palomo, A. (2021) Los implementos elaborados con fibras vegetales del neolítico antiguo de Coves del Fem, Ulldemolins (Tarragona). MUNIBE: Antropolgia-Arkeologia, 72: 43-56. DOI: 10.21630/maa.2021.72.14.

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R., Homs, A., De Diego, M., Palomo, A. (2023) Describing neolithic cord production process: raw materials, techniques and experimental archaeology in La Draga (Girona, Spain; 5207-4862 cal BC). Journal of Archaeological Sciences: Reports, 50: 104092. DOI: 10.1016/j.jasrep.2023.104092.

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R. (2021) Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula. Vegetation History and Archaeobotany, 30: 729-742. DOI: 10.1007/s00334-021-00826-1.

Herrero-Otal, M., Canales, L., Agustí, B., Rosillo, R., Bosch, À., Barberà, A., Palomo, A., Piqué, R., Terradas, X., Malgosa-Morera, A. (Submitted) The Use of Decalcifiers in the Analysis of Dental Calculus and Plant Fibres: the Case Study of the Early Neolithic Site of Cova del Pasteral (Girona, Spain). Open Archaeology.

Science Advances

6.2.1. The earliest basketry in Southern Europe: hunter-gatherer and first farmers plant-based technology preserved in the Cueva de los Murciélagos (Albuñol, Spain).

Science Advances, 2023, 9(39): 9:eadi3055.

DOI: 10.1126/sciadv.adi3055.

View this article (and Supplementary Material) at:
https://www.science.org/doi/10.1126/sciadv.adi3055

This paper is the first scientific publication of the MUTERMUR project, in which some of the organic materials from the Cueva de los Murciélagos site (Albuñol, Granada) are described both technologically and in terms of the raw materials from which they were made. Although some preliminary studies were carried out at the end of the 20th century, this is the first time that microscopic observations, both optical and electronic, and the description of the raw material (*Stipa tenacissima*) have been carried out. In addition, 14 new radiocarbon dates are included, suggesting that the materials in the cave were deposited in two different chronological periods of the Early and Middle Holocene (ca. 7500-4200 cal BC): the Mesolithic (Phase 1) and the Neolithic (Phase 2), separated by about 2000 years. The material assemblage of this archaeological site contained the best-preserved hunter-gatherer basketry in Southern Europe, together with other unique organic artefacts associated with the first farming communities, such as sandals and a wooden hammer.

The earliest basketry in Southern Europe: hunter-gatherer and farmer plant-based technology in Cueva de los Murciélagos (Albuñol).

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Abstract

Plant material culture can offer unique insights into the ways of life of prehistoric societies; however, its perishable nature has prevented a thorough understanding of its diverse and complex uses. Sites with exceptional preservation of organic materials provide a unique opportunity for further research. The burial site of Cueva de los Murciélagos in southern Iberia, uncovered during 19th-century mining activities, contained the best-preserved hunter-gatherer basketry in Southern Europe, together with other unique organic artefacts associated with the first farming communities, such as sandals and a wooden hammer. We present 14 14C dates for the perishable artifacts (N=76), situating the assemblage between the Early and Middle Holocene (c. 7500-4200 cal BCE). Our integrated analysis includes raw material determination, and technological and chrono-cultural contextualization of this unique and important set of materials.

Teaser

Direct evidence of basketry among hunter-gatherer and farming societies in South Europe.

Introduction.

Perishable organic raw materials are widely available and versatile, and have played a crucial role in human history. Wood, plant fibers and skins have been used for the manufacture of multiple artifacts essential to the daily life of past populations. The poor preservation of such objects means that they can rarely be studied in detail, even though they are key to understanding human adaptations to environments, past technological and ecological knowledge, and provide insight into the diversity of needs for which these materials have provided a solution. For this reason, sites with well-preserved perishable materials present a unique opportunity to study past societies (1, 2). Plant-based goods and tools were among the first artifacts in history, as suggested by the use-wear of lithic tools dated to early Pleistocene (3, 4). The earliest direct evidence derives from the Middle Pleistocene (5 - 8), but examples are scarce and widely dispersed.

Most current knowledge of past societies is built from analysis of durable materials. Information relating to vegetal crafts in prehistory is limited (1) due to the lack of recovered remains but, like non-perishable objects, plant-based artifacts allow us to study ethnicity (9 - 11), frontiers of culture and identity (12 - 15), trade networking (16, 17) and human-environmental relationships including economy, adaptation, and subsistence (18 - 21). The craft of basketry is considered a particularly useful indicator for defining technological and cultural traditions (2).

The degree of preservation of perishable evidence depends on the contexts in which the materials are deposited or preserved. In Southern Europe, good preservation in archaeological contexts dated to Mesolithic and Neolithic periods is extremely rare and restricted to a few sites where waterlogging, charring or desiccation occurs. The sites of La Marmotta (c. 5840-5010 cal BCE) in west Italy (22) and La Draga (c. 5300-4700 cal BCE) in northeast Spain (21, 23) are both lakeshore settlements of Early Neolithic date, and are well-known for the exceptional preservation, due to waterlogging, of numerous organic items such as wooden artifacts, cordage, and basketry. In Iberia, plant-based materials from the Mesolithic-Neolithic are mostly preserved by charring and impression in fired clay, for example at the Coves de Santa Maira (c. 11200-8200 cal BCE) in Alicante (24) and at Coves del Fem (4941-4545 cal BCE) in Tarragona (25, 26). Material preserved by desiccation is concentrated in south-eastern Iberia which has a predominantly sub-arid climate. Most of such evidence has been recovered from Chalcolithic and Bronze Age sites, with Neolithic examples restricted to two textile fragments from Peñacalera Cave (c. 3462-3163 cal BCE) in Córdoba (27), and the outstanding examples of basketwork and wooden objects from Cueva de los Murciélagos in Granada (28, 29) that are the focus of this article.

Cueva de los Murciélagos is one of the best-known sites in Southern Europe for its exceptional preservation of organic materials by desiccation. The cave is a burial site identified in the 19th century by mining activities that uncovered partially mummified corpses accompanied by baskets, wooden tools and other goods. Numerous critiques were published regarding the authenticity of the materials and their chronology (30, 31). Questions persisted until the 1970s, when the first radiocarbon analysis was carried out on a sample of vegetal fiber and another from wood, both yielding Neolithic dates (5200-4850 cal BCE) (32). After the death of Manuel de Góngora (1884), the first investigator and owner of the remains, the archaeological materials became part of the first collections of the Museo Arqueológico Nacional of Madrid.

In this article we investigate the enduring transmission of early-middle Holocene plant-based technologies by analyzing the perishable artifacts of Cueva de los Murciélagos. We present a robust chronological assessment of the artifacts and other archaeological remains to contextualize our findings and provide a chrono-cultural sequence of the site. Our study also included the first geological characterization of the cave formation, explaining the preservation of the perishable materials. We analyzed the technological features and the raw material of plant-based artifacts, including a unique set of baskets, sandals, and wooden objects (Table S1). Our research revealed that the plant-based artifacts of Cueva de los Murciélagos were produced in both the Mesolithic and Neolithic periods, providing evidence of the ways in which these technologies evolved through time. We also present the earliest and most diverse set of plant-based footwear documented in the prehistory of Europe.

Site background and archaeological record.

Cueva de los Murciélagos [Albuñol, Granada, Spain; UTM (ETRS89) 483323.00-4073500.00] is a karstic cave, 7 km from the Mediterranean coastline of southern Spain and 2 km from the village of Albuñol (Fig. 1A). The cave was first accessed in 1831 by the owner of the surrounding lands who collected the abundant bat guano in the main chamber for fertilizer. The shelter was also used to keep goats until the identification of a vein of galena led to its exploitation by a mining company in 1857. The mining activities and the removal of blocks to access the mineral led to the discovery of a gallery that housed several partially mummified corpses accompanied by baskets, wooden tools and other archaeological remains. The activity of the miners resulted in plant-based objects being burned and scattered around the outside of the cave while other baskets and objects were distributed among the Albuñol villagers. Ten years after the discovery and subsequent looting, the cave was visited by the archaeologist Manuel de Góngora y Martínez who collected the testimonies of the miners regarding the artefacts, gathered the archaeological remains and published accounts of them (33). He describes the remains of 68 individuals distributed in different areas. Most of these human remains have yet to be re-located. Góngora's publication associates the basketry and the wooden objects with the burials but without giving an exact location for each artifact. We know only that they were recovered from the floor surface in the inner part of the cave but have no information about the association of the objects or their original positions. The non-perishable materials from the site include ceramic sherds, blades and flakes of flint, quartz, polished axe head, bone awls, as well as diverse ornaments such as perforated shells, wild boar teeth, stone and shell bracelets (34, 35), and a unique gold diadem. The pottery assemblage comprises globular vessels with impressed, incised and almagra (red painted) decorations (36). All the archaeological remains are currently deposited in the Museo Arqueológico Nacional (Madrid), Museo Nacional de Antropología (Madrid) and Museo Arqueológico y Etnográfico (Granada).

Although the archaeological organic materials from Cueva de los Murciélagos have been cited countless times as the most well-preserved set of archaeological fiber-based materials in southern Europe, just three publications focus primarily on these materials (28, 29, 37). Alfaro (28, 29) made the first systematic study of the fiber-based materials from the site regarding the technology of their production. Her publications reveal the main typologies of basketry, cordage and sandals, with a catalogue describing each object, adapting the terminology and technical variations. She specifies that the entire set of fiber-based objects was made from esparto grass (*Stipa tenacissima*) and explains the differences in the appearance of the raw material as due to the processing of the fiber through crushing the esparto – as is still traditionally done today. In a subsequent publication, Cacho and colleagues detected geometric decorations on seven of the baskets using spectrophotometry analysis (37). Two sandals, a basket fragment, a piece of wood and one undetermined object were dated by conventional radiocarbon methods, providing a chronology between 5200 and 4850 cal BCE (37), placing the site in the Early Neolithic of the region, and therefore representing an outstanding example of the earliest basketry in Europe. Although another wood sample provided an earlier chronology (6450-6030 cal BCE) (37) this was interpreted as due to the "old wood effect" and excluded from the interpretation. The possibility that this earlier date could be related to the use of the cave was previously postulated by some of the authors contributing to the present article (38). Our current study is the first to investigate these materials using an interdisciplinary approach combining geoarchaeology, radiocarbon dating and Bayesian modelling, raw material identification, and analysis of technological features.

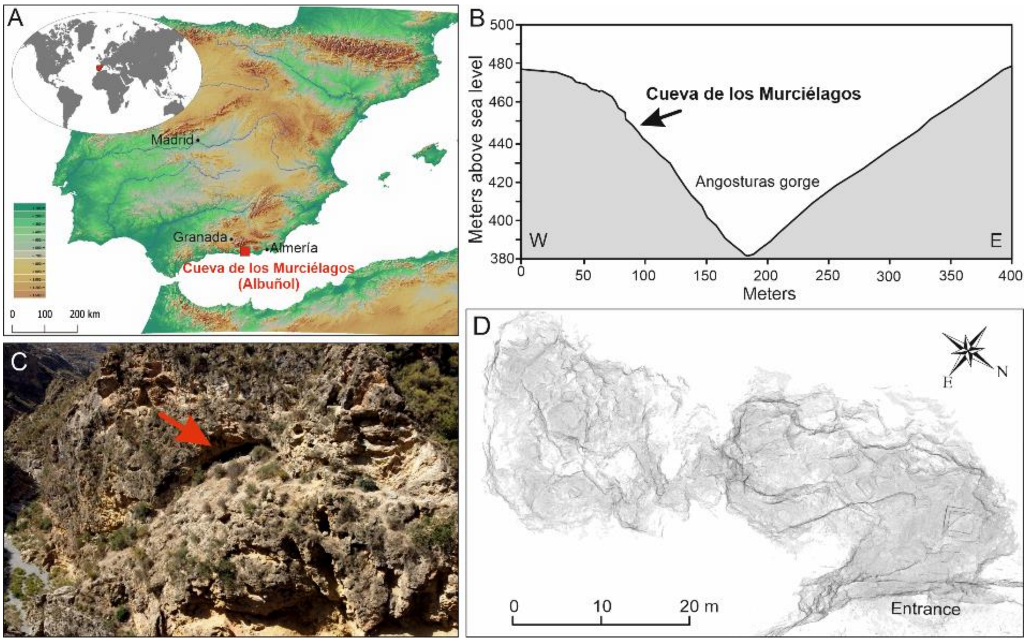

Fig. 1. The site of Cueva de los Murciélagos. (A) Location of Cueva de los Murciélagos in southeast Spain (Andalucía, Albuñol). (B) Elevation profile [east (E) –west (W)] of Angosturas gorge showing the situation of cave. (C) View from the north towards the Angosturas gorge and cave entrance. (D) Plan of the cave made with the 3D model.

Results.

Site geology and environmental conditions.

Cueva de los Murciélagos is a karstic cave (Fig. 1; Supplementary Materials). The cave has a lenticular entrance, yielding direct access to the main chamber (Fig. 1C). The entrance is 15 m wide, oriented to the east; the cave is 60 m long and 30 m wide, with a drop of about 48 m between the highest and the deepest parts (Fig. S1). It is located at the beginning of the lowest section of the Angosturas gorge, on its right bank, 450 m.a.s.l and about 70 m from the base of the gorge, on gray limestone that is highly fractured by Alpine tectonics (Fig. 1B). Impermeable rocks (chalcoschist and phyllite) are found very close to the base of the stratigraphic column, so the cave is subaerial with a few small, globular speleothems (between 0.5 and 4 cm) (Fig. S2). This limited development and growth of the speleothems is due to periods of low rainfall and/or high temperature, giving the cave practically zero humidity.

The set of plant-based tools

The perishable artifacts comprise 76 individual objects (Table S1) including ten wooden items (one of these being a composite object involving wood, reed and vegetal fibers), one made of reed, and 65 fiber-based artifacts. Radiocarbon analyses were performed on a selection of 14 objects (Table 1); raw material and technological aspects were studied in detail for each of them. Analysis revealed that a variety of plants were used to provide wood, reeds and fibers.

The wooden assemblage is heterogeneous, composed of worked wood, fragments of torches, and other wooden remains with no evidence of crafting (currently under study). The present article focuses on the two wooden items that were dated by radiocarbon analysis: a pointed object (479) and a mallet (475). The pointed object (479) was fashioned from the branch of strawberry tree (*Arbutus unedo*) (Fig. 2A-C), a shrub that produces a dense, hard wood. The mallet (475) was produced by longitudinally splitting an olive tree (*Olea europaea*) (Fig. 2D-F) trunk, selected to have a lateral branch present at the required angle (Supplementary Materials).

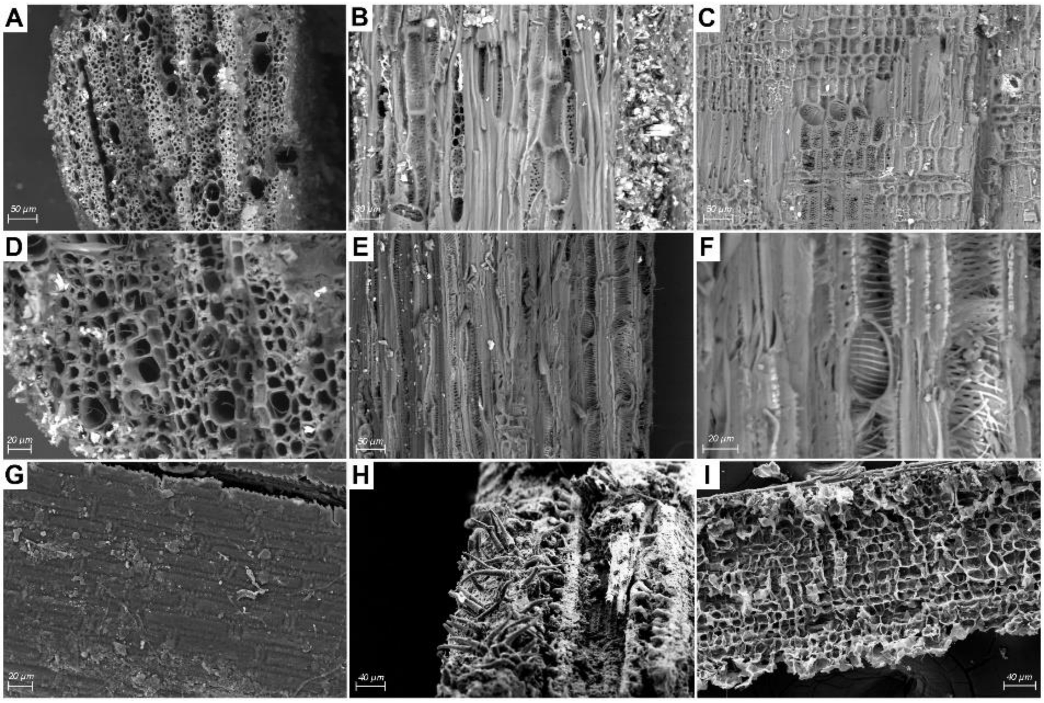

Fig. 2. Raw materials SEM images. (A, B, C) 479 *Arbutus unedo* wood (cross and radial sections); (D, E, F) 475 *Olea europaea* wood (cross, tangential and radial sections; (G) 582 *Stipa tenacissima* adaxial epidermal view; and (H, I) 580 *Stipa tenacissima* abaxial epidermal view and parenchymatic tissue.

Systematic analysis of the fibers used as raw material confirmed the use of esparto grass (*Stipa tenacissima*) for producing all types of baskets and cordage. Microscopic analysis showed microanatomical characteristics present on modern samples of esparto. These were absent on other Poaceae family, esparto-type plants (*Stipa gigantea* and *Lygeum spartum*) present near the site and used for comparison. Esparto leaves are naturally flat in shape, but in arid environments they convolute to minimize their size and limit water transpiration (39). This convolution is visible in the transverse section of the leaves as protuberances on the abaxial face that contain the main isolated vascular bundles. Secondary vascular bundles are also visible all along the leaves, and these are surrounded by a thick layer of sclerenchyma tissue. The adaxial epidermis is glabrous with alternated short cells known as rondels and long sinuate cells, and the absence of stomatal structures (Fig. 2G). The abaxial epidermis is characterized by a high concentration of silica hairs called tricomes (Fig. 2H). The parenchyma tissue is visible in Fig. 2I.

It was possible to distinguish differences in the processing of the fibers used in some objects with the naked eye, as previously indicated by Alfaro (29). While physical treatment, such as crushing, is easy to identify by observation or by histological analysis, other types of processing such as retting and fermentation are less visible. Our methodology was able to differentiate between raw, untreated esparto and crushed esparto that had been physically processed. Of the whole set of materials studied, 50.77% (33 of 65) objects indicate use of crushed esparto leaves, 41.54% (27 of 65) show raw esparto, and a further 7.69% (5 of 65) contain a combination.

The treatment of the fibers differs depending on the crafting techniques represented across the assemblage. For basketry, the esparto was either raw or crushed. Raw esparto was used for objects made from 'twined' (both simple and diagonal) and 'braided' basketry. Items fashioned using the 'pseudobraided'/'*cofín*' technique were also produced primarily with raw esparto, except for a single object (619) made with crushed esparto. Raw esparto was also used for the bundles found in 'coiled' basketry, while the stitches show opened fibers indicating that the leaves had been crushed. For the cords, both 'twisted' and 'braided', the fibers are crushed, and both types of sandals, 'simple' and 'central core', are also made with crushed esparto. Selection of leaves by size is also apparent. Analysis of the width of raw esparto leaves (it was not possible to measure crushed leaves) revealed that those used for coiled basketry (1.263-1.456 mm), and for a braided bag (1.513 mm) were wider than the leaves used in twined basketry (0.801-1.162 mm). For the pseudobraided/*cofín* technique, the width varied (0.745-1.258 mm).

Both of the wooden objects showed use-wear marks, ending their life-cycle within the cave, discarded or intentionally deposited. The pointed object preserves the diameter of the branch from which the bark and the lateral branches were removed. Only the edge of the tool is shaped to obtain a point. Smashed fibers and polished surfaces on the pointed edge are identified as use-wear, but no fractures, notches or erosion—indicative of use as a digging stick—are clearly visible to the naked eye. This object is therefore classified only as a 'pointed stick'. The head and handle of the mallet is roughly shaped, likely with cutting tools. Use-wear marks comprising smashed fibers and fractures are clearly visible on both head edges, and polished surfaces are present on the handle.

Table 1. Results of radiocarbon dating from organic-based material from Cueva de Los Murciélagos.

Lab code	Object code	Object type	Material	Species	Sample weight (mg)	Analyzed (mg)	Method	Pretreatment	Date BP	δ13C o/oo	Reference
Beta-628427	594	Pseudobraided/Cofín basket	Vegetal fibres	*Stipa tenacissima*	64.4	2.8	AMS-Standard	acid/alkali/acid: cellulose extraction: solvent extraction	6150 +/- 30 BP	-21.0	This study
Beta-628426	626	Linked rings	Vegetal fibres	*Stipa tenacissima*	22.5	3.0	AMS-Standard	acid/alkali/acid: cellulose extraction: solvent extraction	8400 +/- 30 BP	-21.4	This study
Beta-627342	617	Diagonal twined basket	Vegetal fibres	*Stipa tenacissima*	45.1	3.0	AMS-Standard	acid/alkali/acid	6210 +/- 30 BP	-21.1	This study
Beta-627341	615	Coiled basket	Vegetal fibres	*Stipa tenacissima*	16.5	3.0	AMS-Standard	acid/alkali/acid	5580 +/- 30 BP	-20.0	This study
Beta-627340	479	Pointed stick	Wood	*Arbutus unedo*	1.8	0.59	AMS-Micro-sample Analysis	acid/alkali/acid	6170 +/- 30 BP	-22.4	This study
Beta-627338	475	Mallet	Wood	*Olea europaea*	8.0	1.7	AMS-Standard	acid/alkali/acid	5660 +/- 30 BP	-21.9	This study
Beta-627337	623	Pseudobraided/Cofín basket	Vegetal fibres	*Stipa tenacissima*	19.7	2.8	AMS-Standard	acid/alkali/acid	5570 +/- 30 BP	-22.8	This study
Beta-627336	624	Pseudobraided/Cofín basket	Vegetal fibres	*Stipa tenacissima*	7.1	2.4	AMS-Standard	acid/alkali/acid	5550 +/- 30 BP	-21.2	This study
Beta-627335	625	Braided basket	Vegetal fibres	*Stipa tenacissima*	18.5	3.4	AMS-Standard	acid/alkali/acid	5550 +/- 30 BP	-20.3	This study
Beta-627334	581	Simple twined basket	Vegetal fibres	*Stipa tenacissima*	46.6	2.5	AMS-Standard	acid/alkali/acid	8300 +/- 30 BP	-21.8	This study
Beta-627333	580	Simple twined basket	Vegetal fibres	*Stipa tenacissima*	73.0	3.3	AMS-Standard	acid/alkali/acid	8320 +/- 30 BP	-19.6	This study
Beta-627332	579	Simple twined basket	Vegetal fibres	*Stipa tenacissima*	48.5	2.8	AMS-Standard	acid/alkali/acid	8350 +/- 30 BP	-20.4	This study
Beta-627331	611	Simple twined basket	Vegetal fibres	*Stipa tenacissima*	14.4	2.7	AMS-Standard	acid/alkali/acid	5640 +/- 30 BP	-23.7	This study
Beta-627330	603	Central core sandal	Vegetal fibres	*Stipa tenacissima*	66.3	3.2	AMS-Standard	acid/alkali/acid	5630 +/- 30 BP	-23.5	This study
CSIC-1132	616	Coiled basket	Vegetal fibres	*Stipa tenacissima*					5861 +/- 48 BP		38
CSIC-1134	609	Central core sandal	Vegetal fibres	*Stipa tenacissima*					5900 +/- 38 BP		38
CSIC-1133	598	Central core sandal	Vegetal fibres	*Stipa tenacissima*					6086 +/- 45 BP		38
CSIC-246	-	-	Vegetal fibres	-					5400 +/- 80 BP		33
CSIC-247	-	-	Wood	-					7440 +/- 100 BP		33

Two different basketry techniques are present: two-dimensional, flat objects like mats, and three-dimensional 'baskets' (although baskets can be made with the same variety of techniques as mats). A standardized nomenclature of basketry production is still needed, even though it has been discussed by many authors. Terminology is also affected by linguistic issues (40). Alfaro (29) identifies several basketry techniques in the Cueva de los Murciélagos assemblage: simple (N=10) or diagonal twining (N=7), coiling (N=11), pseudobraided/*cofín* basketry (N=6), and a particular type of basket constructed from knots on the base and called braided basketry (N=1). Particular techniques are associated with the production of specific basket shapes and sizes. A detailed technological description of the dated objects is available in Supplementary Materials.

Cords are also represented: a single piece (591b) of twisted cord with an S2z pattern, and a few three-strand braids (N=5). Most of the cords seem to be part of other objects such as baskets, but mainly sandals, which have been fragmented by post-depositional processes.

Sandals form an important part of the inventory. Alfaro (29) distinguished two types: 'simple' (N=2), and 'central core' (N=20). Although no evidence of 'laces' is conserved for the simple type, for the central core type, a small group of fibers emanating from the base of the sole may have been placed between the first and second toes. These fibers are also connected to a braid fixed to the middle of the sandal, which could be tied around the ankle.

A single 'ring' (626) and a non-determined object comprising knotted fibers were not included in our analysis.

Chronology and Bayesian modelling of plant-based tools.

The Kernel Density Estimation (KDE) output from 19 radiocarbon dates (14 determined as part of the current research) indicates that the human deposition of plant-based artifacts in the site began in around 7950–7360 cal BCE (95% HPD) and ended in approximately 4370–3740 cal BCE (95% HPD) (Table S2; Fig. 3). The KDE model also reveals a first phase starting around 7960–7680 cal BCE (95% HPD) and ending around 7480–7150 cal BCE (95% HPD). After a hiatus, there is a second phase of intensity in around 5380–5070 cal (95% HPD), lasting until 4390–4050 cal BCE (95% HPD). An intermediate peak is observed between these two phases that proceeds from the unidentified desiccated wood sample CSIC-247 (7440 +/- 100 BP) (Table S2; Fig. S3). This radiocarbon measurement is likely affected by inbuilt age issues and the wide-ranging standard deviation. We also carried out a model with KDE_plots of the radiocarbon dates of the two main phases. The estimates are analogous to those observed in the first KDE model (Table S2; Fig. 3A). Our results therefore suggest that the objects from Cueva de los Murciélagos were likely placed during two main chronological phases, separated by around 2000 years.

The Bayesian single model (41) included all the radiocarbon dates from the site, which yielded a good agreement (Amodel= 98.5; Aoverall= 98.4). The earliest evidence of human deposition of artifacts started in 7986–7391 cal BCE (95% HPD) and ended in 4373–3740 cal BCE (95% HPD) (Fig. S3; Table S3). The modelled chronology indicates a period of human use of around 3110–4040 years (95% HPD) (Table S3). These results are analogous to those obtained from KDE analyses. The results from the Outlier Charcoal model (see methods) were also similar to those from the Bayesian single model (Table S4; Fig. S4).

A Bayesian model of two sequential phases was created to consider the two main clusters of radiocarbon dates but excluding sample CSIC-247 (7440 ± 100 BP) (Fig. 3; Table 2). The first phase comprises the four oldest radiocarbon dates, while the second phase contains the remaining measurements. The radiocarbon dates of Phase 1 pass the test of contemporaneity (T'=6.3 [T (5 %=7.8)]) (42), which means that the artifacts were probably deposited during a short period of time. The result of the model indicates a good agreement (Amodel= 96.6; Aoverall= 97.3) (Fig. 3; Table 2). All the radiocarbon dates also show good agreement (A= >73%). Phase 1 starts in around 7680–7360 cal BCE (95% HPD) and ends around 7480–7100 (95% HPD). This phase was relatively short at 0–530 years (95% HPD) (Table 2).

The chronological gap between the end of Phase 1 and the start of Phase 2 was estimated at 2340–1780 years using OxCal's Difference command (95% HPD). Our results indicate a significant hiatus between Phase 1 and Phase 2 of around 2000 years (Table 2). Phase 2 begins in 5420–5070 cal BCE (95% HPD) and ends in 4390–4070 cal BCE (95% HPD). The analysis also indicates that the artifacts related to this phase were deposited in the cave over a long period (T'=897.189 [(5% 22.4]), estimated at 740–1260 years (95% HPD). The results of the Charcoal Outlier model were also similar to those of the Bayesian two phases model. We also tested a Bayesian model of three sequential phases including, as an additional phase, the desiccated sample CSIC-247 (7440 ± 100 BP), yielding high agreement indices (>95) in both the multi-phase and outlier model (Figs. S5-6; Tables S4-5). However, this model is not discussed here as the wide Boundaries of this phase overlap the two main phases previously analyzed.

The attribution of the directly radiocarbon dated objects to the identified phases on the site are as follows. The oldest artifacts, corresponding to Phase I of the use of the cave, are 597 (Fig. 4A), 580 (Fig. 4B), 581 (Fig. 4C), and 626 (Fig. 4D) together with the piece of wood previously dated in the seventies, the reference for which is unknown. The objects corresponding to Phase 2 are 617 (Fig. 5A), 594 (Fig. 5B), 479 (Fig. 5C), and in chronological order, 475 (Fig. 6A), 611a (Fig. 6B), 603 (Fig. 6C). The dates obtained in the nineties correspond to 616a (Fig. 7A), 598 (Fig. 7B) and 609 (Fig. 7C). Finally, 623 (Fig. 8A), 625 (Fig. 8B), 615a (Fig. 8C) and 624 (Fig. 8D). The most recent radiocarbon date obtained is that for a non-identified object dated in the seventies. A detailed description of each of the dated items is available in Supplementary Materials.

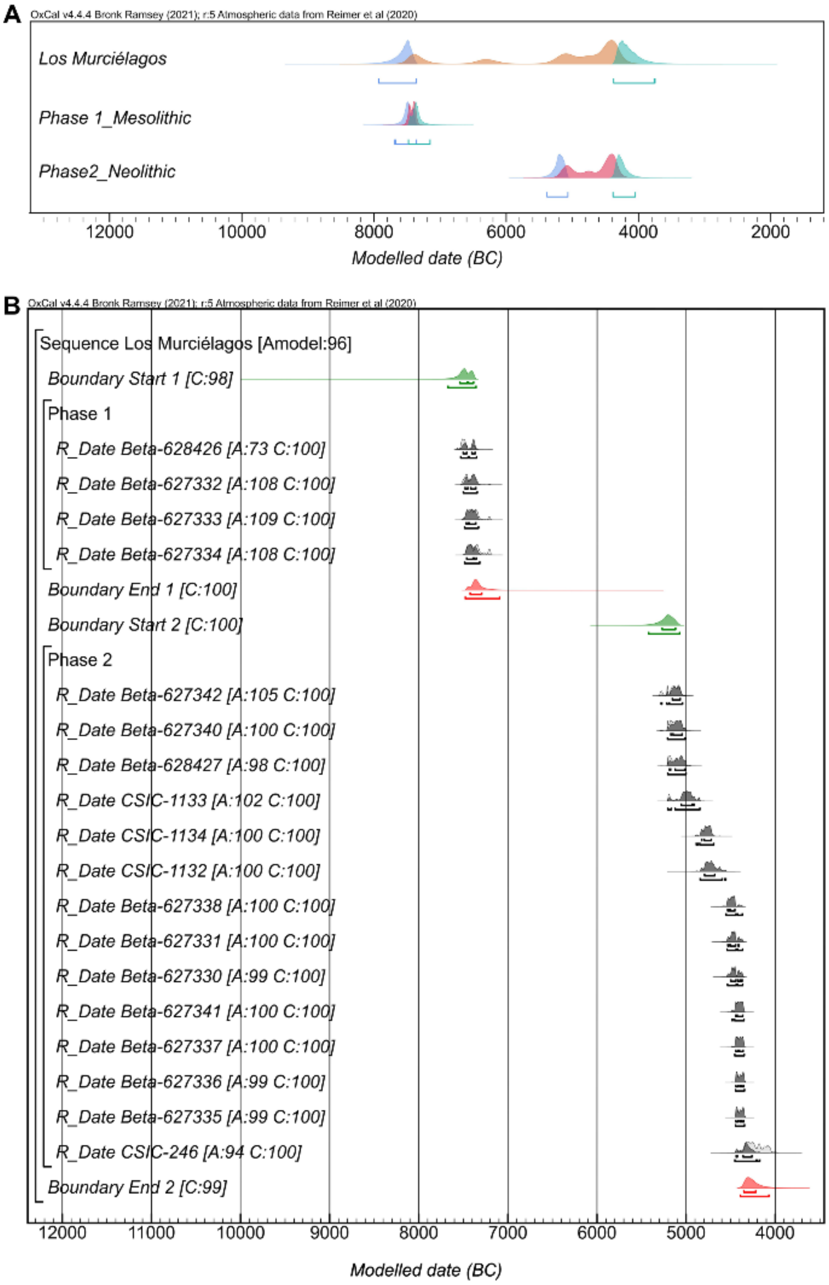

Fig. 3. Probability distribution of dates from Cueva de los Murciélagos. A) KDE plots and Bayesian chronological ranges of the overall distribution of the dated events of Cueva de los Murciélagos and within each phase (Phase 1= Mesolithic; Phase 2=Neolithic). B) Multi-phase Bayesian chronological ranges for the estimated start and end of each phase and the modeled ranges of each radiocarbon date (except outlier). OxCal v4.4.4 Bronk Ramsey (69); r:5 Atmospheric data from Reimer et al. (68).

Table 2. Modeled dates and ranges for the estimated start, interval, and end for each phase of Cueva de Los Murciélagos. The estimated difference between Phase 1 and 3 is also indicated.

Name	Unmodelled (BCE/AD)				Modelled (BCE/AD)				Indices Amodel 96.3 Aoverall 97				
	68.3%		95.4%		68.3%		95.4%						
	from	to	from	to	from	to	from	to	Acomb	A	L	P	C
Sequence Cueva de los Murciélagos													
Boundary Start 1					-7540	-7387	-7673	-7359					98
Phase 1													
R_Date Beta-628426	-7531	-7384	-7576	-7357	-7504	-7370	-7531	-7353		73.3			99.8
R_Date Beta-627332	-7491	-7358	-7516	-7336	-7481	-7361	-7501	-7346		107.5			99.8
R_Date Beta-627333	-7469	-7343	-7507	-7196	-7469	-7361	-7487	-7332		109.2			99.8
R_Date Beta-627334	-7463	-7206	-7480	-7192	-7464	-7356	-7486	-7317		108			99.8
Interval 1					0	185	0	522					99.1
Boundary End 1					-7425	-7294	-7478	-7094					99.5
Boundary Start 2					-5271	-5120	-5422	-5074					99.7
Phase 2													
R_Date Beta-627342	-5215	-5072	-5297	-5050	-5156	-5067	-5281	-5041		104.5			99.9
R_Date Beta-627340	-5208	-5054	-5214	-5015	-5173	-5046	-5210	-5013		100.1			99.9
R_Date Beta-628427	-5208	-5033	-5209	-5005	-5187	-5013	-5206	-5001		98.2			99.9
R_Date CSIC-1133	-5201	-4936	-5208	-4847	-5056	-4910	-5206	-4846		101.7			99.9
R_Date CSIC-1134	-4827	-4720	-4886	-4690	-4826	-4720	-4886	-4691		99.8			99.9
R_Date CSIC-1132	-4795	-4681	-4843	-4555	-4795	-4680	-4844	-4556		99.9			99.8
R_Date Beta-627338	-4536	-4453	-4581	-4369	-4535	-4453	-4552	-4370		99.8			99.9
R_Date Beta-627331	-4533	-4406	-4542	-4367	-4533	-4406	-4542	-4367		99.6			99.9
R_Date Beta-627330	-4498	-4371	-4537	-4365	-4499	-4371	-4537	-4366		99.2			99.9
R_Date Beta-627341	-4446	-4364	-4486	-4350	-4446	-4365	-4484	-4350		99.8			99.9
R_Date Beta-627337	-4443	-4360	-4454	-4348	-4443	-4361	-4454	-4348		99.8			99.9
R_Date Beta-627336	-4443	-4350	-4447	-4346	-4443	-4351	-4447	-4346		99.4			99.9
R_Date Beta-627335	-4443	-4350	-4447	-4346	-4443	-4351	-4447	-4346		99.3			99.9
R_Date CSIC-246	-4342	-4068	-4440	-3996	-4438	-4262	-4453	-4173		93.6			99.8
Interval 2					817	1046	744	1258					99.6
Boundary End 2					-4352	-4219	-4391	-4071					99.3
Difference Phase 1 to Phase 2					-2257	-2034	-2340	-1783					99.4

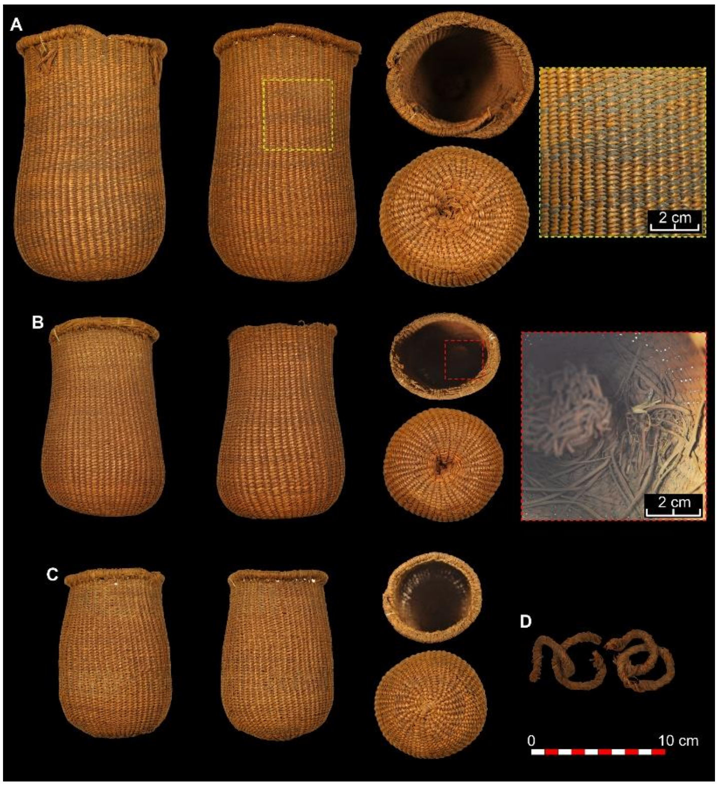

Fig. 4. Mesolithic organic-based artifacts. (A) Basket 579 (Beta-627332: 8350 ± 30 BP); (B) Basket 580 (Beta-627333: 8320 ± 30 BP); (C) Basket 581(Beta-627334: 8300 ± 30 BP); (D) 626 Linked rings (Beta-628426: 8400 ± 30 BP).

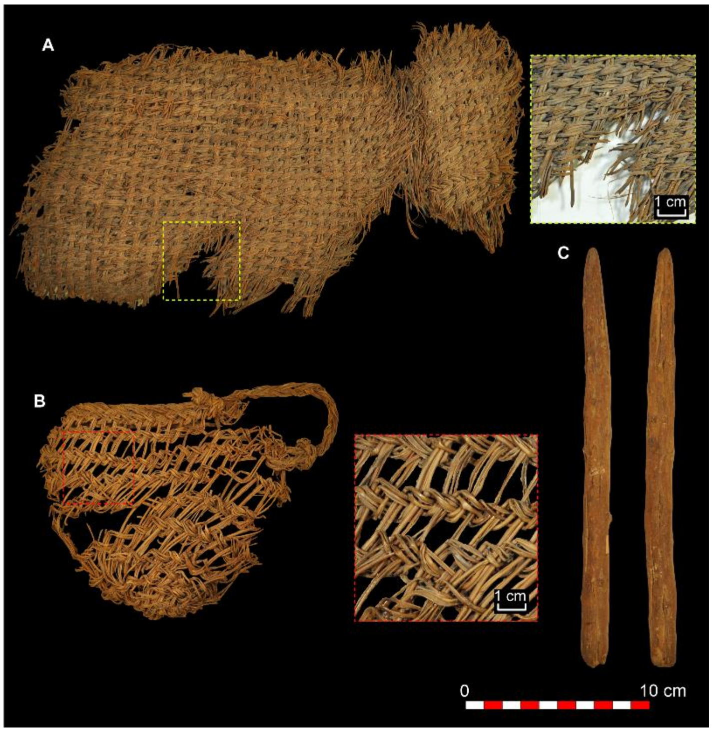

Fig. 5. Neolithic organic-based artifacts. (A) Basket fragment 617 (Beta-627342: 6210 ± 30 BP); (B) Basket 594 (Beta-628427: 6150 ± 30 BP); (C) Digging stick 479 (Beta-627340: 6170 ± 30 BP).

Fig. 6. Neolithic organic-based artifacts. (A) Mallet 475 (Beta-627338: 5660 ± 30 BP); (B) Sandal 603 (Beta-627330: 5630 ± 30 BP); (C) Sandal 611 (Beta-627331: 5640 ± 30 BP).

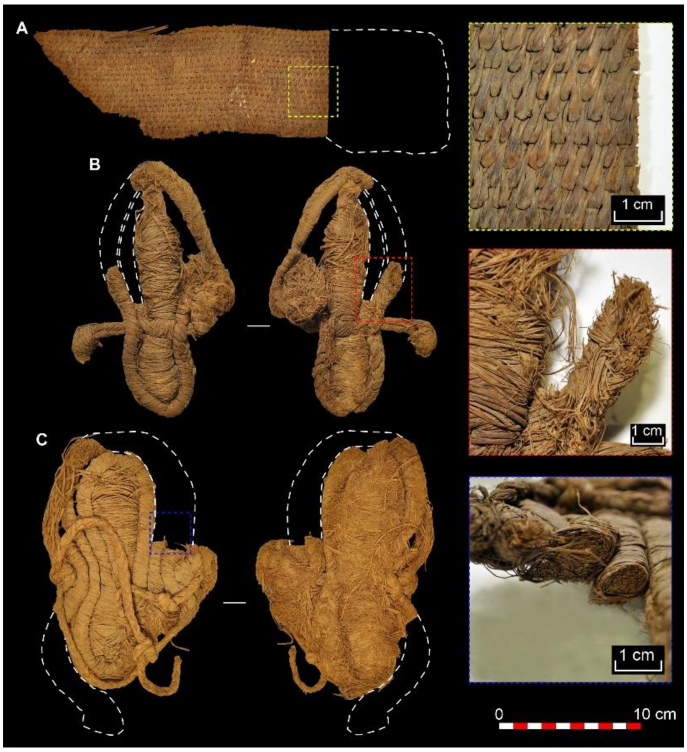

Fig. 7. Neolithic organic-based artifacts dated in previous work with detail of damage (32, 38). The white dashed line shows the portion of the object now lost. (A) Basket fragment 616a (CSIC-1132: 5861 ± 48 BP); (B) Sandal 598 (CSIC-1133: 6086 ± 45 BP); (C) Sandal 609 (CSIC-1134: 5900 ± 38 BP).

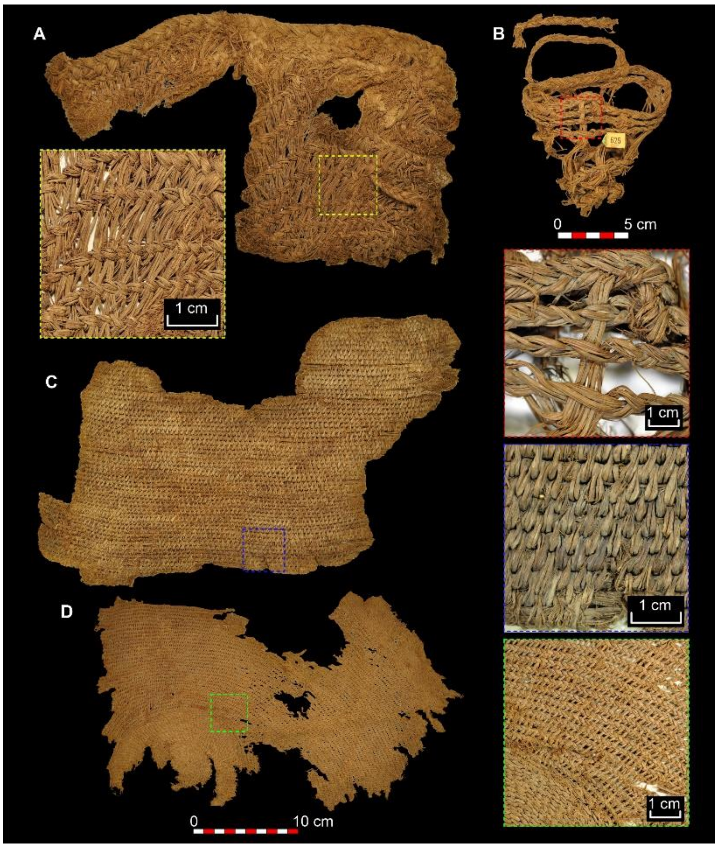

Fig. 8. Neolithic organic-based artifacts. (A) Basket/mat fragment 623 (Beta-627337: 5570 ± 30 BP); (B) Basket 625 (Beta-627335: 5550 ± 30 BP); (C) Basket fragment 615 (Beta-627341: 5580 ± 30 BP); (D) Basket/mat fragment 624 (Beta-627336: 5550 ± 30 BP).

Discussion.

The unique conditions for the preservation of organic material in the cave are related to the null humidity resulting from the geological character of the cave. Moreover, a dry wind current is generated by the prevailing climate in the area, and the N-S direction and narrow and deep morphology of the Angosturas gorge channel the wind towards the cave, through the narrow upper entrance. The wind cools as it travels through the cave, increasing in speed; it is cold as it exits through another narrow entrance located in the lower part of the shelter. The lack of prevailing humidity in the area and the circulation of wind in the cave as it cools and dries, prevents the proliferation of bacteria, increasing the amount and diversity of preserved perishable material at the site. Unfortunately, the original contexts of the artefacts are unknown, so establishing associations is difficult. Even so, the characteristics of the fragments, in terms of the techniques used to make them, their measurements, and the raw materials and fiber processing used, suggest a refitting hypothesis for some of the pieces (Table S1). According to Góngora (33) the materials suffered substantial fragmentation or charring when the lead workers burned them to keep their boiler working.

In summary, despite the mining activity, this assemblage represents one of the oldest and best-preserved collections of hunter-gatherer basketry in Southern Europe. The sandals, baskets and wooden artefacts with Neolithic chronologies constitute a unique sample of organic artefacts absent in other archaeological sites of early farmer communities. Previous studies assumed that all organic materials from the cave were Neolithic, based on three conventional radiocarbon dates (37). Our study, however, offers a fine-grained chronological framework based on AMS radiocarbon dating and Bayesian modeling that clearly indicates two distinct main phases of deposition of plant-based objects, both occurring between the early and middle Holocene (c. 7500 to 4200 cal BCE) but each linked to periods having very different economic and social systems: a first phase of deposition is related to early Holocene hunter-gatherer populations and a second phase is associated with middle Holocene farmers. Other non-perishable materials from the site, like bone tools, lithics and pottery sherds, confirm that the cave was used regularly by Early and Middle Neolithic populations but beyond the organic-based objects, no other durable material can currently be related to the Mesolithic use (Phase 1) of the site. Our results also highlight that direct radiocarbon dates from plant-based objects are essential for understanding the depositional sequence of perishable materials in non-stratified archaeological contexts such as caves (43). This information also provides a chronological framework within which to integrate these objects allowing more general archaeological discussions on the significance of plant-based technologies in human evolution. Furthermore, this contribution indicates differences between raw materials, techniques, and object typologies for each depositional phase in Cueva de los Murciélagos.

<u>The Mesolithic fiber-based objects.</u>

The three dated objects (579, 580 and 581) corresponding to the earlier occupation phase of the cave (Phase 1) are three-dimensional twined baskets made with raw esparto. They are well preserved compared with the other fiber-based materials, being almost complete and decorated with geometric motifs made with dyed fibers (Fig. 2A); some incorporate human hairs or pigments (Fig. 2B). Other baskets recovered at the cave (582, 583, 585, 586, 586a, 586b, 592 and 593) share similar morphologies, techniques and raw material suggesting they are also related to Phase 1.

Simple twining is the only basketry technique clearly represented in the Mesolithic phase. It is not present in later periods and may thus be the oldest method represented in Cueva de los Murciélagos. The same technique has also been identified in basketry imprints on clay fragments from the Coves de Santa Maira site (Alacant, Spain, 12,900-10,200 cal BCE). Here, however, the imprints show space between the weft elements (open twining). In the dated baskets from Cueva de los Murciélagos there is no space (closed twining), although, there is one example of open twining that has not been dated (593). Our study therefore offers direct evidence of the oldest fiber-based objects made by hunter-gatherer populations in Iberia, and in Europe. Elsewhere, fiber artifacts are associated with hunter-gatherer societies at various archaeological sites in the Great Basin (US), where a notable number of objects made using a wide range of basketry techniques have been recorded, including plaited, twined and coiled basketry (13, 14, 44).

Baskets 584 and 593 present variations of the twining technique, specifically regarding the warp, which gives a twill weave (584) and a diagonal twining (593) appearance to the baskets. The attribution of these examples to the Mesolithic phase is, however, unclear but some of their characteristics, such as raw material measurements and preparation are similar to those of the Mesolithic baskets. Only radiocarbon dating will confirm this hypothesis.

Four linked rings (626), whose function is unknown, also have hunter-gatherer chronologies. Góngora (33) suggested the rings were part of an ornamental necklace, although no further information is available. Five rings were preserved in the 19th century but only four now survive. No other objects or techniques are represented in Phase 1. Only raw esparto was used for the twined Mesolithic baskets and the linked rings. No evidence of physical processing of the fibers was identified in the earlier chronologies of the cave. Although the twining technique and its variations can be achieved with crushed esparto, processing was not used during this phase.

<u>The Neolithic perishable objects.</u>

Phase 2 of Cueva de los Murciélagos encompasses a wider diversity of objects, techniques and raw material processing. The plant-based artifacts include cords, two and three-dimensional baskets, and sandals made with several techniques. The modeled dates of three pieces (594, 623 and 624) place the pseudobraided or *cofín* technique in this phase. These items were selected for radiocarbon analysis because of differences in their morphology and the treatment of raw material, but this technique is also present in three other objects (618, 619 and 621). Object 594 is an almost complete bag. It shows space between the pseudobraids, as is also observed in the second object, 623, a formless fragment. Fragment 623 is the only *cofín* object which is made of crushed esparto. The third item, 624, is a two-dimensional object that exhibits both closed and open pseudobraiding in different areas. Object 617 is the only example of diagonal twining documented in this phase. Other undated objects (622, 627, 627a and 627b) present similar techniques and raw material, which suggest they may also be attributed to this phase. These are all fragmented, and no specific object shape can be identified. The esparto used in these pieces is raw, as used for the simple twining baskets in Phase 1. This group of plant-based objects provides the only evidence of diagonal twining, pseudobraided/ *cofín* and braided baskets in the prehistory of the Iberian Peninsula and, indeed, that of Europe. No earlier parallels are documented, indicating that these techniques may originate exclusively from South Iberia.

The unique braided basket or bag (625) also corresponds to the Neolithic phase. In this object the esparto leaves are, again, used in their raw state. The coiled basketry technique is represented in this phase by two artifacts: one (616a) dated in the 20th century (37), and one (615) dated within the present study. With regard to the processing of the esparto, it is important to differentiate between the active and passive elements of the coiled baskets. The stitches (active) are always made using crushed (except for object 620), while bundles (passive) can comprise either raw or crushed esparto, although the degree of crushing differs across the objects. This technique is represented in nine further pieces (587, 588, 589, 590, 616b, 620, 627c, 627d and 627e). Contemporaneous examples have been documented in Western Mediterranean sites including La Marmotta (Lazio, Roma, c. 5840-5010 BCE) (22), La Draga (Girona, 5207-4862 cal BCE), and Coves del Fem (Tarragona; 6065-4545 cal BCE) (25, 26). In La Draga, eight coiled baskets were identified, made of fibers from various monocot families (Poaceae, Cyperaceae and Typhaceae) and lime tree (*Tilia* sp.). A coiled basket made of a Cyperaceae fibres, found covering a pit and related to storage purposes, was found at Coves del Fem (Tarragona; 6065-4545 cal BCE) (25, 26). The coiling technique therefore seems to be the most widely used in southern Europe during the Neolithic.

Twenty-two artifacts corresponding to two typologies of fiber-based sandals were found in the cave. Our radiocarbon analysis of a simple sandal (611) and a central core sandal (603) agrees with the previous analysis of two central core shoes (598 and 609) (37), confirming that they date to the Neolithic period. No chronological differences are visible between the two forms, although the central core type is most common. Other examples of shoes have been recovered in Europe, including one from a pit in the Areni-1 Cave (Armenia, 3627-3377 cal BCE). This was made of leather and a large number of grasses (45). Sandals made with lime bast (*Tilia* sp.) and ramie (*Boehmeria nivea*) were recovered at the Allensbach site (Germany, c. 3000 cal BCE), being very similar to examples found in Sipplingen (Germany; 2900 cal BCE) (46). The footwear associated with the Ötzi (Italy, 3350 cal BCE) present a sock-like structure made of lime/linden bast and covered with leather (47, 48), and similar to a shoe found at the Sutz-Rütte site (Switzerland; 2750 cal BCE (49).

The various sandals mentioned above are completely different in technological terms from those found at Cueva de los Murciélagos in that, although they used grasses in their structure, other materials including leather, lime and ramie bast were also used. Further studies should be undertaken regarding this aspect of the fiber-based collection, which potentially contains both direct and indirect information about the population that wore the sandals. This would be of interest given the loss of the human remains extracted from the cave in the 19th century. The esparto used in sandals is always crushed, and this may be directly related to their function as they needed to be flexible and comfortable to wear. This sandal set therefore represents the earliest and widest-ranging assemblage of prehistoric footwear, both in the Iberian Peninsula and in Europe, unparalleled at other latitudes.

Cord elements are also recorded in the cave, and these are either twisted or braided. Most seem to be detached fragments from baskets handles or cords used to tie sandals to the feet. The Neolithic site of La Draga has yielded examples with an extended S and Z-twist, and braided cords made of lime tree and nettle (Urtica sp.) (21), and a small, twisted strand made of an undetermined monocot family was also recovered from Coves del Fem (26). One twisted cord example from Cueva de los Murciélagos (591b) is especially striking. The vegetal material used to produce this cord is heavily crushed. No specific association can be made with braids, although these are also made with crushed esparto. The twist (S2z), measurements, and processing of the fibers are similar to those of the bowstring associated with Ötzi (50) and with a possible bowstring roll from La Draga (21). The similarity of the twisted cord to these examples suggests that it could also be a bowstring; several arrow shafts recovered from the same context in the cave confirms that archery was practiced.

Technological features.

The esparto grass shows evidence of several processing methods which each produce distinctive working characteristics and which influence the typology and the aesthetics of the final object. Esparto artisans traditionally collect the leaves in the summer months. They are then dried for 20-30 days (51,52) to produce 'raw' esparto or en rama, which can be used for crafting after rehydrating by water submersion for approximately 24 hours. The nomenclature en rama refers to the fact that the leaves are complete and have not suffered physical damage. The dried, raw esparto can be further processed for specific applications, by retting in stagnant water for 20-40 days to produce an anaerobic fermentation resulting in the decay of organic materials such as lignin. The organic degradation is halted by drying the material. The timing of this process is dependent on environmental conditions such as temperature and humidity. There are no standardized parameters because it is a traditional process that varies depending on the artisan and their experience. The material resulting from this processing is known as 'cooked' or 'retted' esparto, and traditionally acknowledged to be more resistant and flexible than raw esparto. The retted esparto can be rehydrated in the same way as the raw esparto (to produce 'cooked' en rama esparto) or can be crushed physically using a wooden mallet to break the leaves and extract the fibers, creating 'crushed' esparto. In later periods -and linked to industrial processes- the thinnest fibers are extracted by combing with a comb to produce 'combed' esparto.

Given the possible variations in esparto processing, it is important to note that, although the appearance of the leaves in Phase 1 (Mesolithic) indicates they are not crushed, this does not mean that they did not undergo preparation. Although no microscopic differences are detectable to indicate whether the esparto is retted/cooked, rehydration of the fibers would be needed to make them malleable and useful for crafting. None of the objects in the cave could have been produced using dried fibers, so raw material would have been prepared by hydration before the items were fashioned. Further, the esparto leaves used in the Mesolithic objects present a smaller diameter (0.801-1.162 mm) than those used in the Neolithic phase (1.263-1.513 mm), except for the material used in some specific pseudobraided artifacts. This could indicate the selection of younger esparto leaves for Mesolithic crafting. It is important to highlight that the physical treatment of crushing the leaves is evidenced only in Neolithic materials, suggesting that this practice was not used in earlier periods. A degree of humidity is still needed when using crushed esparto, but to a lesser extent. Histological differences in the cross-section of the leaves are visible in some of the samples. These may be related to the part of the leaf where the sample originated (apical-basal) -which is difficult to determine during sampling from archaeological objects- or to its growth stage. Our results therefore indicate an extended knowledge of the plant resources within the local environment and a high level of understanding and expertise amongst the last hunter-gathered populations and, most likely, their continuity towards the first farming societies.

The wooden remains studied are also unusual within the archaeological record in southern Europe. The raw material, size, and morphology of the pointed object (479) are similar to those of Neolithic digging sticks, such as the set from La Draga (53), however some technical features are absent, including the fire treatment of the point. In the case of the wooden mallet (475), a parallel with the same morphology but different size has been identified in a Neolithic context at Meare Heath (Somerset, UK) (54). The same approach, using wood from the trunk and a branch as a handle, has been identified at several other Neolithic sites, where it has been used for crafting adze or axe handles and spoons (55, 56). It has been suggested that the mallet could have been involved in the processing of vegetal fibers. It is notable that this artifact is contemporaneous with the evidence for the use of crushed esparto for crafting purposes in the Neolithic phase of Cueva de los Murciélagos.

Typologies and function of the plant-based artifacts.

This assemblage presents an unprecedented diversity of basket typologies and techniques compared to other Mesolithic and Neolithic sites in the Mediterranean region. This high variability may be related to the unusual environmental conditions of the cave and its impact on the conservation of the plant-based artifacts. Other Mediterranean Early Neolithic sites preserve these artifacts under waterlogged conditions, as at La Marmotta (22) and La Draga (57), or by carbonization as at the Coves del Fem (26). The desiccating conditions of Cueva de los Murciélagos likely favored greater preservation of organic materials, yielding a wider variability of preserved artifacts. The nature of the human activities in the cave during both Mesolithic and Neolithic periods may also explain this distinctive assemblage. In contrast to the preserved organic objects from La Marmotta, La Draga and Coves del Fem, which were recovered from domestic contexts (so basket fragments probably correspond to discarded elements), we know from 19th century accounts that the objects found in Cueva de los Murciélagos were associated with burials (33). Unfortunately, only a few of these human remains have been preserved in the museum and they have not yet been dated. We cannot, therefore, determine whether all the plant-based objects were related to burial practices as there is no contextual information for the finds; they may have been the result of single or multiple events of deposition over time.

The most prevalent functional category of the plant-based objects is the ‘container’. Our results highlight the diversity of items in this category in terms of shape, size, raw material, and preservation. They include objects made of carved wood and three-dimensional basketry, both rigid and flexible. Bayesian modelling of the radiocarbon dates indicates that the oldest basket elements are the semi-rigid, simple twined baskets, with a very closed weft, and others with similar shapes but different sizes. Some contain rare materials such as hair and mineral pigment and this, together with their extraordinary state of preservation—mainly complete—suggests they were introduced to the cave for a unique purpose, which is consistent with their use in funerary practices during the Mesolithic (Phase 1).

Our results suggest differences in the functions of Mesolithic and Neolithic plant-based objects. The Neolithic containers are more diverse than those from the Mesolithic in terms of shape, size, raw material preparation and state of preservation. The Neolithic basketry objects are largely fragmented, preventing their identification as either two- or three-dimensional artifacts. The flexibility and diversity in shape and size, also suggest a greater range of functions compared with the Mesolithic basketry. Flexibility is a valuable attribute for transport, and the more open or closed the weft and warp, and the presence of active and passive elements (depending on the technique) can be related to the type of material to be contained (2). Two-dimensional basketry often corresponds to mats. The description of the finds provided by Góngora (33) indicates that the individuals buried in this cave wore textiles made of esparto grass, as well as hats and sandals. The only remains in both museum collections that can be identified as clothing are the sandals, all the dated examples having Neolithic chronologies. Some sandals had clear use marks, while others were apparently never used, suggesting that whilst some individuals were buried with their daily clothing, others had specific clothing prepared.

In summary, the technology and finishing of these baskets and tools from Cueva de los Murciélagos open up ground-breaking perspectives on the complexity of early-middle Holocene populations in Europe. They provide insights into the perishable material technologies used on plants and into the knowledge involved in the acquisition and processing of these plants. Only a small sample of basketry from the cave has been dated and although these objects are representative of the typology of organic objects recovered, not all the organic remains can be ascribed to these periods. Further radiocarbon analyses are needed to corroborate these initial hypotheses.

Plant material culture offers unique insights into the life of prehistoric societies. Lack of preservation has meant that perishable materials have not previously been extensively considered during archaeological research. It is vital that, where they do survive, these materials are the focus of detailed study, in order to further examine the role of such technologies during prehistory.

Materials and Methods.

Cave geomorphology and 3D documentation.

In order to study the geomorphology of the cave, in situ data on the various speleothems present was recorded. The morphological characteristics and the dimensions of these formations, which are created by chemical precipitation (dripstone, existence or not of flowstone, complex shapes, etc.) were described. A complete topographical model of the entire cave was constructed using two different laser scanners: a portable NavVis VLX manual and a fixed portable FARO Laser Scanner Focus3D. A virtual 3D visit to the cave is available at: Cueva_Murciélagos - FARO WebShare (websharecloud.com)

Raw material identification and technological analysis.

An inventory of the whole set of perishable objects was produced, many of which were also included in previous studies (28, 29). The objects were described during observation in the museum and the documentation was enhanced with an extensive photographic record, created using a Nikon D5000 camera with a NIKKOR AF-S DX 18-55 mm VR lens. More detailed images were captured using a portable digital microscope (Dino-Lite Edge Digital Microscope AM7915MZT) with a magnification of x20-220. The volume of the baskets studied in this work has been calculated with the free software Blender 3.5.1. using the revolution 3D model of the baskets.

Wooden objects were taxonomically identified following standard methods, by observing the three anatomical sections of wood: cross, tangential, and radial (58). Each object was observed under the portable digital microscope. Where possible, a tiny wood sample was obtained from cracks or broken areas for further analysis. These samples were observed under a Scanning Electron Microscope (ZEISS EVO LS 15, RIAIDT-USC). Diagnostic features were compared with atlases of wood anatomy (59, 63).

In tandem with taxonomic identification, dendrological features from the wooden objects, such as plant part (trunk, twig, root) and tree-ring curvature, were also registered using qualitative categories (strong, moderate, weak) (64). Other features related to taphonomic aspects were also documented, such as evidence of biodeterioration (xylophagous galleries, fungal hyphae) (65, 66). In addition to aspects related directly to their raw material, objects were described in morphological terms, and technical aspects of their crafting were recorded, along with other features related to their life cycle (use, repair, re-use) (67). Finally, they were classified according to their function, or their morphology when function was unclear.

Fiber-based objects were sampled using tweezers and a blade cleaned with ethanol 96% between each different object to avoid cross-contamination for further studies. Although sampling is a destructive process, very small fragments are needed for identification analysis. Due to the fragility of these objects, small parts break off during restoration and storage processes and, in most cases, it was these fragments that were sampled to avoid further damage to the objects. In just one case, 592, sampling was not possible because the object was completely consolidated, and sampling could have been damaging.

Identifications were performed under x50-500 magnification using a transmitted light bright-dark field (BF-DF) Olympus BX51 microscope coupled with an Olympus DP26 camera and linked to Olympus cell Sens software. Some samples were placed on stubs using double-sided carbon tape, and were coated with a 15 nm layer of gold using an Emitech K550 Sputter Coater Unit to be observed under a Zeiss Merlin® FE-SEM electronic microscope. Fiber taxonomic identification was based on the anatomical and histological description of the archaeological samples, and by comparison with modern species collected in the immediate area of the site. Alfaro (29) identified the raw material as 'esparto grass' but provided no other details. Due to the variety of Gramineae known as 'esparto', the archaeological samples were compared with a reference collection of similar plants also used in fiber crafting activities, and which also grow naturally close to the site. These included species of different genera such as Stipa (*Stipa tenacissima*, *Stipa gigantea*) and *Lygeum* (*Lygeum spartum*).

Other characteristics of the raw material were also recorded, including the size of the leaves and their integrity, to identify the criteria used to select the fibers. The diameter of the leaves was measured to check for differences in the raw material selection in relation to the technique used and processing method applied, and to the chronology of the materials.

A standardized nomenclature for basketry production is still needed. Terminology has been much discussed and used differently by many authors throughout history; it is also affected by linguistic issues (40). The vocabulary used by Adovasio (2) is applied in this article to describe the functional relationship between passive (warp) and active (weft) elements of fiber-based materials, but some techniques are not covered, so the work of other authors was also considered (28, 52). The basketry techniques were therefore classified as simple or diagonal twining, coiling (2), *cofín* (52) or pseudobraided (29), and a specific type of basket with knots on the base called 'braided' by Alfaro (29). Descriptions of the techniques are presented below using this nomenclature. Each object exhibited individual characteristics not detailed here. Detailed accounts of the dated objects can be found in Supplementary Materials.

In our study, we refer to weft twining which consists of vertical, passive warps linked by an active weft which forms a twisted cord around them. In closed twining, no space is visible between the weft strands. The newly added fibers of the weft are visible on the inner surface. Simple twining presents a single warp around the whole basket, while in diagonal twining (also called rhomboidal twining by Alfaro (29), a pair of warps alternate in each round of the basket production, creating a diagonal pattern on the finished object. The coiling technique involves a passive, wrapped bundle or foundation wrapped by active stitches or a winder, forming a spiral. There are variations in the typology of the sewing element. The *cofín* (52) or pseudobraided (29) basketry technique involves braiding three bundles of fibers, one of which is changed in each round, forming the warp of the basket. The technique may be 'closed' or 'open', depending on the distance between the braided rows. This method has been documented only in Iberia (various chronologies) and does not appear in basketry atlases. The final basketry technique documented in the Cueva de los Murciélagos is braided (28). This rare type is not described in basketry handbooks. Five knotted fiber bundles on the base of the basket form the warp. They pass several times towards a braid (weft) started from one of these five knotted bundles, which increases in the number of braids and makes the basket larger at the top. It is finished with a wider braid, wrapping the leaves from the warp and the weft, and has a braided handle.

Cords are also represented within the materials from Cueva de los Murciélagos. Braids are most common form, with only a single example of the twisted form, this having a S2z pattern. Most of the cords seem to be components of other objects such as baskets and sandals, which have been fragmented by post depositional processes.

Sandals represent an important part on the inventory of the fiber-based materials from the cave. Alfaro (28, 29) distinguished two types: simple and central core. Simple sandals consist of a braid wrapped around itself which shapes the sandal sole and makes it wider. Central core sandals are based on a bunch of wrapped fibers that forms a central core which is surrounded by fiber bundles, increasing the width of the sole. The front of the sole is always wider than the back because it includes one extra bundle. Although no evidence of tying elements was conserved for the simple sandals, in the central core type, a small group of fibers originating from the bottom of the sole may have been placed between the first and second toes. This element is connected to a braid in the middle of the sandal, which could have been fixed to the instep and tied around the ankle. Other objects (e.g., 626) are not described here because they are singular elements, the typologies of which have not been determined.

Artifact selection and sampling.

Selection of objects for radiocarbon dating was based on criteria including sample availability, raw material, technology, and typology. A set of 14 artifacts representing the complete typology of the assemblage was selected for dating. Of the wooden artifacts, the hammer (475) and the digging stick (479) were chosen due to their unique presence in the set, but were also prioritized as they were partially broken with areas available for sampling. Obtaining samples from other wooden materials was not possible due to preservation issues (472, 473, 474, 1140, 1141, 1165, 1138/532 and 1139/532). For the vegetal fiber-based materials, the dating selection covered the basketry techniques of twining (579, 580, 581, & 617), coiling (615), cofin basketry (594, 623, and 624), the special basketry technique with knots on the base (625), and the four linked rings (626). Finally, the two types of sandals were chosen: the simple circular string (611); and the central core type (603). Only one piece (592) in the fiber-based set could not be sampled due to complete consolidation.

Radiocarbon dating

Our analysis considered 18 radiocarbon dates: 14 made in the framework of this research and 4 from published results (32, 38). Radiocarbon dates for the present study were obtained from Beta Analytic Laboratory (Miami, US). Sampling was carefully undertaken to preserve the total integrity of the objects, taking small fibers or fragments from areas of breakage. The weight of each sample was around 0.5 mg (Table 2). At the level of taxon, the material was found to belong to short-lived terrestrial species: 12 were plant material (*Stipa tenacissima*) and two samples were wood (Arbutus unedo and Olea europaea). Thirteen samples were dated by AMS-Standard and one was dated by AMS-Micro-sample (Beta-627340) due the small size of the wood sample. The samples were pretreated with acid/alkali/acid: the sample was gently crushed then dispersed in deionized water; it was then washed with hot HCl acid to eliminate carbonates, then treated with an alkali wash (NaOH) to remove secondary organic acids. This was followed by a final acid rinse to neutralize the solution before drying. For two of the samples (Beta-628427 and Beta-628426), it was necessary to carry out a complementary cellulose extraction pretreatment to remove solvents resulting from restoration. This followed the full acid/alkali/acid pretreatment and involved bathing the samples in sodium chlorite (NaClO2) under controlled conditions (pH 3 and temperature at 70°C) to eliminate all components except wood cellulose.

Our analysis also considered five radiocarbon measurements obtained using standard radiometric dating at Consejo Superior de Investigaciones Científicas (Madrid, Spain) (37). Four samples correspond to short-lived terrestrial species, and one to an unidentified desiccated wood artifact (Table 2). All the radiocarbon measurements were calibrated with the internationally agreed IntCal20 atmospheric calibration curve (68).

Bayesian chronology

The radiocarbon measurements were subjected to Bayesian analyses to obtain reliable estimations of the start, end, and duration of deposition of the artifacts in Cueva de los Murciélagos. Our analyses were performed using the OxCal online software version 4.4

(69). The two-sigma probability interval (95.4%) was used when discussing the 14C measurements, and the one-sigma probability interval (68.2%) was added in the tables and figures, as recommended by Millard (70). The degree of contemporaneity between the different radiocarbon measurements was tested through the Chi-Square test (42), which assesses the degree of overlap between the probability ranges of each of the dates.

We firstly applied non-parametric statistical methods based on Kernel Density Estimation (KDE) (71) as an exploratory mode to characterize the potential phases of the human deposition activities in the cave through time. KDE methods allow the identification of discontinuities in the probability distribution that may relate to several chronological phases (71). These methods are widely implemented when there is no formal prior data, reducing the noise from the calibration procedure (71). We used this method as the analyzed samples originate from historical excavations and there is a lack of information regarding the stratigraphic relationships between them (71). We used the KDE_Plot Oxcal tool (71, 72).

The uncalibrated radiocarbon dates were also modeled using Single Uniform Phase and Multi-Phase Models (72). This approach combines the radiocarbon dates in a uniform distribution model based on the hypothesis that all the dated events have the same likelihood of occurring at any time at the start and end of the phase. The model then calibrates the radiocarbon dates based on prior information from other early measurements of the chronological phase. The model was developed using OxCal tools (Sequence, Phase, Boundary, Interval, and Difference commands).

We also modeled the radiocarbon dates with the Charcoal Outlier Model (41, 73). This model is designed to lessen the impact of potential inbuilt age issues, as three measurements correspond to undetermined and long-lived desiccated wood samples (Table 2). The Charcoal Outlier Method provides younger age estimates, as the correct age of the modeled events is more recent than the non-modeled calibrated radiocarbon dates (73). A prior 5% probability of being outliers was assigned to these three samples. In the text, he modeled dates are rounded to the nearest half-decade since the modeled results vary from run to run.

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Data and materials availability: All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials. All necessary permits were obtained from the Museo Arqueológico Nacional (Madrid) and Museo Arqueológico y Etnográfico (Granada) for the artifacts sampling and the described study. The fieldwork in Cueva de los Murciélagos had all the required permits from the Delegación Territorial de Cultura (Granada), local authorities and landowners; the work was directed by FMS. The identification numbers (IDs) of the artifacts analyzed in this paper are provided in Table 1.

The materials are housed at the Museo Arqueológico Nacional (Madrid) and Museo Arqueologico y Etnográfico (Granada). The objects are available to any researcher to be inspected with the permission of both institutions.

References.

1. L. Hurcombe, Perishable Material Culture in Prehistory: Investigating the Missing Majority (Routledge, London, 2014).

2. J. M. Adovasio, Basketry Technology: A guide to identification and analysis (Routledge, New York, 2016).

3. L. Keeley, N. Toth, Microwear polishes on early stone tools from Koobi Fora, Kenya. Nature 293, 464–465 (1981).

4. P. Bello-Alonso, J. Rios-Garaizar, J. Panera, S. Rubio-Jara, A. Pérez-González, R. Rojas, E. Baquedano, A. Mabulla, M. Domínguez-Rodrigo, M. Santonja, The first comprehensive micro use-wear analysis of an early Acheulean assemblage (Thiongo Korongo, Olduvai Gorge, Tanzania), Quat. Sci. Rev. 263,106980 (2021).

5. N. J. Conard, J. Serangeli, G. Bigga, G., V. Rots, A 300,000-year-old throwing stick from Schöningen, northern Germany, documents the evolution of human hunting. Nat. Ecol. Evol. 4(5), 690-693 (2020).

6. B. L. Hardy, M. H. Moncel, C. Kerfant, M. Lebon, L. Bellot-Gurlet, N. Mélard, Direct evidence of Neanderthal fiber technology and its cognitive and behavioral implications. Sci. Rep. 10, 4889 (2020).

7. B. Aranguren, A. Revedin, N. Amico, F. Cavulli, G. Giachi, S. Grimaldi, N. Macchioni, F. Santaniello, Wooden tools and fire technology in the early Neanderthal site of Poggetti Vecchi (Italy). Proc. Natl. Acad. Sci. 115(9), 2054-2059 (2018).

8. J. Rios-Garaizar, O. López-Bultó, E. Iriarte, C. Pérez-Garrido, R. Piqué, A. Aranburu, M. J. Iriarte-Chiapusso, I. Ortega-Cordellat, L. Bourguignon, D. Garate, I. Libano, A middle Paleolithic wooden digging stick from Aranbaltza III, Spain. PLoS ONE 13(3), e0195044 (2018).

9. J. M. Adovasio, "Artifacts and ethnicity: basketry as an indicator of territoriality and population movements in the prehistoric great basin" in Anthropology of the Desert West: Essays in Honor of Jesse D. Jennings, C. Condie, D. D. Fowler, Eds. (Utah Anthropological Press, 1986), pp. 44–84.

10. D. R. Croes, Prehistoric ethnicity on the northwest coast of North America: an evaluation of style in basketry and lithics. J. Anthropol. Archaeol. 8 (2), 101–130 (1989).

11. E. A. Goldberg, Recent analyses of fibre perishables from the promontory caves, Utah. COMPASS 2 (1), 36–53 (2018).

12. P. Barker, "Woven sandals as boundary markers between the great basin and southwest culture areas" in Past, Present, and Future Issues in Great Basin Archaeology: papers in honor of Don D. Fowler, B. Hockett, Ed. (Bureau of Land Management Cultural Resource Series, No. 20, Nevada, 2009), pp. 125–145.

13. A. Camp, Catlow Twine basketry in the western Great Basin: use and Reuse in the Archaeological Record. Quat. Int. 466, 318–323 (2018).

14. T. J. Connolly, J. P. Barker, "Basketry chronology of the early Holocene in the Northern Great Basin" in: Early and Middle Holocene Archaeology of the Northern Great Basin, D. L. Jenkins, T. J. Connolly, C. M. Aikens, Eds. (University

of Oregon Anthropological Papers 62, Eugene, Oregon, 2004), pp. 241–250.

15. T. J. Connolly, E. A. Kallenbach, P. Barker, S. J. McCabe, Netting in the Northern and Western Great Basin. J. California Great Basin Anthropol. 37 (2), 143–167 (2017).

16. C. S. Fowler, E. M. Hattori, "Exploring prehistoric trade in western great basin textiles" in Perspectives on Prehistoric Trade and Exchange in California and the Great Basin, R. E. Hughes, Ed. (University of Utah Press, Salt Lake City, 2011), pp. 201–220.

17. C. S. Fowler, E. M. Hattori, "Prehistoric textile trade and exchange in the western great basin: outland coiling and catlow twining" in Meeting at the Margins: Prehistoric Cultural Interactions in the Intermountain West, D. Rhode, Ed. (University of Utah Press, Salt Lake City, 2012), pp. 92–102.

18. J. M. Adovasio, R. L. Andrews, J. S. Illingworth, "Netting, net hunting, and human adaptation in the eastern great basin" in Past, Present, and Future Issues in Great Basin Archaeology: papers in honor of Don D. Fowler, B. Hockett, Ed. (Bureau of Land Management Cultural Resource Series, No. 20, Nevada, 2009), pp. 84-102.

19. P. R. Geib, E. A. Jolie, The role of basketry in early Holocene small seed exploitation: implications of a ca. 9,000-year-old basket from Cowboy Cave, Utah. Am. Antiq. 73 (1), 83–102 (2008).

20. S. Noshiro, Y. Sasaki, K. Kobayashi, M. Suzuki, I. Nishida, Material selection and weaving techniques for the oldest basketry in Japan found at the Higashimyou Site, Saga Prefecture. J. Archaeol. Sci. 23, 12–24. (2019).

21. R. Piqué, S. Romero, A. Palomo, J. Tarrús, X. Terradas, I. Bogdanovic, The production and use of cordage at the early Neolithic site of La Draga (Banyoles, Spain). Quat. Int. 468, 262–270 (2018).

22. M. Mineo, N. Mazzuco, M. Rottoli, G. Remolins, L. Caruso-Fermé, J. F. Gibaja, Textiles, basketry, and cordage from the Early Neolithic settlement of La Marmotta, Lazio. Antiquity 97(392), 314-330 (2023).

23. A. Bosch, J. Chinchilla, J. Tarrús, Els objectes de fusta del poblat neolític de La Draga. Excavacions de 1995-2005 (Centre Arqueologia Subaquàtica de Catalunya-Museu d'Arqueologia de Catalunya, Girona, 2006).

24. J.E. Aura Tortosa, G. Pérez-Jordà, G., Y. Carrión Micó, J. R. Seguí Seguí, J. F. Jordá Pardo, C. Miret i Estruch, C. C. Verdasco Cebrián, Cordage, basketry and containers at the Pleistocene–Holocene boundary in southwest Europe. Evidence from Coves de Santa Maira (Valencian region, Spain). Veg. Hist. Archaeobot. 29, 581-594 (2020).

25. M. Herrero-Otal, S. Romero-Brugués, R. Piqué Huerta, Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula. Veg. Hist. Archaeobot. 30(316), 729-742 (2021).

26. S. Romero-Brugués, M. Herrero-Otal, R. Piqué, R. Rosillo, X. Terradas, O. López-Bultó, A. Berrocal-Barberà, A. Palomo, Los implementos elaborados con fibras vegetales del neolítico antiguo de Coves del Fem, Ulldemolins (Tarragona). Munibe Antropologia-Arkeologia 72, 43-56 (2021).

27. M. Gleba, M. D. Bretones-García, C. Cimarelli, J. C. Vera-Rodríguez, R. M. Martínez-Sánchez, Multidisciplinary investigation reveals the earliest textiles and cinnabar-coloured cloth in Iberian Peninsula. Sci. Rep. 11, 21918 (2021).

28. C. Alfaro, Estudio de los materiales de cestería procedentes de la Cueva de los Murciélagos (Albuñol, Granada). Trabajos de Prehistoria 37, 109-139 (1980).

29. C. Alfaro, Tejido y cestería en la Península Ibérica. Historia de su técnica e industrias desde la prehistoria hasta la romanización (Bibliotheca Praehistorica

Hispana 21. CSIC Instituto Español de Prehistoria, Madrid, 1984).

30. M. Gómez Moreno Martínez “La cerámica primitiva ibérica” in Homenagem a Martins Sarmento no centenario do seu Nascimento (Ediçao da Sociedade Martins Sarmento, Guimaraes,1933), pp. 125-136.

31. M. Gómez Moreno Martínez, “La cerámica primitiva ibérica” in Misceláneas. Historia del Arte y Arqueología. Primera Serie. La antigüedad (Consejo Superior de Investigaciones Científicas, Madrid, 1949), pp. 104.

32. P. López, “La problemática cronológica del Neolítico Peninsular” in C-14 y Prehistoria de la Península Ibérica, M. Almagro-Gorbea, M. Fernández-Miranda, Eds. (Fundación Juan March - Serie Universitaria, Madrid, 1978), pp. 45-56.

33. M. de Góngora, Antigüedades Prehistóricas de Andalucía (Imprenta a cargo de C. Moro, Madrid, 1868).

34. P. López, Estudio de la cerámica, industria ósea y lítica de la Cueva de los Murciélagos de Albuñol (Granada). Trabajos de Prehistoria 37:164-180 (1980).

35. F. Martínez-Sevilla, Brazaletes de piedra neolíticos en la península ibérica (VI-V milenio a. C.): tecnología, funcionalidad y circulación (British Archaeological Reports. International Series 2913, Oxford, 2018).

36. J. Carrasco Rus, J. A. Pachón Romero, Algunas cuestiones sobre el registro arqueológico de la Cueva de los murciélagos de Albuñol (Granada) en el contexto Neolítico andaluz y Lsus posibles relaciones con las representaciones esquemáticas. Cuadernos de Prehistoria y Arqueología de la Universidad de Granada 19: 227-287 (2009).

37. C. Cacho, C. Papi, A. Sánchez-Barriga, F. Alonso, F. La cestería decorada de la Cueva de los Murciélagos (Albuñol, Granada). Complutum Extra 6(1), 105-122 (1996).

38. J. Carrasco Rus, F. Martínez-Sevilla, Las cronologías absolutas del Neolítico Antiguo en el sur de la península ibérica. Nuevas dataciones. Archivo de Prehistoria Levantina 30, 57–80 (2014).

39. S. S. Aliscioni, Anatomía ecológica de algunas especies del género Paspalum (Poaceae, Panicoideae, Paniceae). Darwiniana 38(3-4), 187-207 (2000).

40. W. Wendrich, The World According to Basketry. An Ethnoarcheological Interpretation of Basketry Production in Egypt (UCLA – Cotsen Digital Archaeology series, Leiden University, 1999).

41. C. Bronk Ramsey, Dealing with Outliers and Offsets in Radiocarbon Dating. Radiocarbon 51, 1023-1045 (2009).

42. G. K. Ward, S. R. Wilson, Procedures for comparing and combining radiocarbon age determinations: a critique. Archaeometry 20, 19-31 (1978).

43. C. Earwood, Radiocarbon dating of late prehistoric wooden vessels. The Journal of Irish Archaeology 5, 27-44 (1989-90).

44. M. M. Coe, 2021. Basketry, cordage, and perishable artifact manufacture at Bonneville Estates Rockshelter: Diachronic technological variation. J. Anthropol. Archaeol. 64, 101325 (2021).

45. R. Pinhasi, B. Gasparian, G. Areshian, D. Zardaryan, A. Smith, G. Bar-Oz, T. Highman First Direct Evidence of Chalcolithic Footwear from the Near Eastern Highlands. PLoS ONE (5)6: e10984 (2010).

46. J. Banck-Burgess, “Mehra als nur Leder. Regionen und Kulturen – die Pfahlbauten der Jungsteinzeit” in 4000

Jahre Pfahlbauten. Archäologischen Landesmuseum Baden-Württemberg und dem Ladesamt für Denkmalpflege im Regierungspräsidium Stuttgart. (Thorbecke, Ostfildern, 2016).

47. R. Goedecker-Ciolek, "Zur Herstellungstechnik von Kleidung und Aüstrustungsgegensta¨nden" in: Die Gletschermumie vom Ende der Steinzeit aus den Ötztaler Alpen, M. Egg, R. Goedecker-Ciolek, W. Groenman-van Waateringe, K. Spindler, Eds. (Jahrbuch des Römisch-Germanisches Zentralmuseums, Mainz, 1993), pp. 100–113.

48. A. Hafner, K. Glauser, P. Curdy, D. von Rütte, C. Rérolle, M. Bader, M. "Schnidejoch und Lötschenpass: Naturraum, Entdeckung und Feldarbeiten" in: Hafner, A. Schnidejoch und Lötschenpass, A. Hafner (Bern, Archäologische Forschungen in den Berner Alpen 1, 2015), pp. 69-129.

49. A. Hafner, R. Stapfer, J. Francuz, J. (2016) Die Bucht von Sutz-Lattrigen. In: 4000 Jahre Pfahlbauten. Archäologischen Landesmuseum Baden-Württemberg und dem Ladesamt für Denkmalpflege im Regierungspräsidium Stuttgart (Thorbecke, Ostfildern, 2016).

50. J. Junkmanns, J. Klügl, W. Schoch, G. Di Pietro, A. Hafner, A. (2019) Neolithic and Bronze Age archery equipment from Alpine Ice-Patches: a review on components, construction techniques and functionality. Journal of Neolithic Archaeology 21: 283-314 (2019).

51. B. Kuoni, Cestería tradicional ibérica (Ediciones del Serbal, Barcelona, 1981)

52. J. Fajardo, A. Verde, D. Rivera, C. Obón, S. Leopold, Traditional craft techniques of Esparto Grass (*Stipa tenacissima* L.) in Spain. Economic Botany 69: 370–376 (2015).

53. O. López-Bultó, R. Piqué, F. Antolín, J. A. Barceló, A. Palomo, I. Clemente, Digging sticks and agriculture development at the ancient Neolithic site of la Draga (Banyoles, Spain). J. Archaeol. Sci. Rep. 30, 102193 (2020).

54. J. M. Coles, F. A. Hibbert, A Neolithic wooden mallet from the Somerset Levels. Antiquity 46(181), 52-54 (1972).

55. X. Terradas, R. Piqué, A. Palomo, F. Antolín, O. López, J. Revelles, R. Buxó, "Farming practices in the Early Neolithic according to agricultural tools: evidence from La Draga site (Northeastern Iberia)" in Times of Neolithic transition along the Western Mediterranean, O. García-Puchol, D. C. Salazar-García, Eds. (Berlin, Springer International Publishing, 2017), pp. 199-220.

56. A. Bocquet, M. Noël, The Neolithic or Wood Age. Endeavour 9(1), 34-41 (1985).

57. S. Romero-Brugués, R. Piqué Huerta, M. Herrero-Otal, The basketry at the early neolithic site of La Draga (Banyoles). J. Archaeol. Sci. Rep. 35, 102692 (2021)

58. C. R. Cartwright, The principles, procedures and pitfalls in identifying archaeological and historical wood samples. Annals of Botany 116 (1): 1-13 (2015).

59. F. H. Schweingruber, Anatomy of European Woods. An atlas for the identification of European trees, shrubs and dwarf shrubs (Stuttgart, Paul Haupt, 1990).

60. Ü. Akkemik, B. Yaman, Wood anatomy of Eastern Mediterranean species (Kessel Publishing House, 2012).

61. R. Gale, D. Cutler, Plants in Archaeology. Identification manual of vegetative plant materials used in Europe and the southern Mediterranean to c. 1500 (Kew: Westbury and Royal Botanic Gardens, 2000).

62. J.G. Hather, The Identification of the Northern European Woods. A guide for archaeologists and conservators (London, Archetype Publications, 2000).

63. A. Crivellaro, F. H. Schweingruber, Atlas of wood, bark and pith anatomy of Eastern Mediterranean trees and shrubs: with a special focus on Cyprus (Springer Science & Business Media, 2013).

64. D. Marguerie, J. Y. Hunot, Charcoal analysis and dendrology: data from archaeological sites in north-western France. J. Archaeol. Sci. 34(9), 1417-1433 (2007).

65. R. A. Blanchette, A review of microbial deterioration found in archaeological wood from different environments. International Biodeterioration & Biodegradation 46(3), 189-204 (2000).

66. M. Toriti, A. Durand, F. Fohrer, Traces of Common Xylophagous Insects in Wood (Berlin, Springer International Publishing, 2021).

67. R. Sands, Life beyond life: Repair, reuse, and recycle—the many lives of wooden objects and the mutability of trees. Archaeometry 64, 168-186 (2022).

68. P. J. Reimer, E. Bard, A. Bayliss, J. W. Beck, P. G. Blackwell, C. Bronk Ramsey, C. E. Buck, H. Cheng, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, H. Haflidason, I. Hajdas, C. Hatté, T. J. Heaton, D. L. Hoffmann, A. G. Hogg, K. A. Hughen, K. F.Kaiser, B. Kromer, S. W. Manning, M. Niu, R. W. Reimer, D. A. Richards, E. M. Scott, J. R. Southon, R. A. Staff, C. S. M. Turney, J. van der Plicht, The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon 62(4), 725-757 (2020).

69. C. Bronk Ramsey. OxCal v.4.4.4. Available at: https://c14.arch.ox.ac.uk/oxcal.html (accessed February 2023) (2021).

70. A. R. Millard, Conventions for Reporting Radiocarbon Determinations. Radiocarbon 56, 555-559 (2014).

71. C. Bronk Ramsey, Methods for Summarizing Radiocarbon Datasets. Radiocarbon 59, 1809-1833 (2017).

72. C. Bronk Ramsey, Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51, 337-360 (2009).

73. M. W. Dee, C. Bronk Ramsey, High-Precision Bayesian Modeling of Samples Susceptible to Inbuilt Age. Radiocarbon 56, 83-94 (2014).

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6.2.2. Los implementos elaborados con fibras vegetales del neolítico antiguo de Coves del Fem, Ulldemolins (Tarragona).

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The following paper deals with the technological and raw material analysis of the fibre-based materials found at the Coves del Fem site (6065-4545 cal BC; Ulldemolins, Tarragona) in the Late Early Neolithic (Epicardial level). The remains correspond to various carbonised and dehydrated fragments of a coiled basketry found inside a pit, which was considered to be the lining of this structure identified during the fieldwork. Furthermore, after flotation and water sieving of the sediment from the structure, a small fragment of twisted cord was also found and is also examined in this publication. The results showed that the basket fragments were made using the coiling technique and that they all belonged to a single object. In the case of the cord fragment, it was made by twisting fibres that had previously been mechanically processed. The identification of raw materials revealed at least the use of sedges (Cyperaceae or Juncaceae) for basketry and unidentified monocots for cordage.

Los objetos elaborados con fibras vegetales del Neolítico Antiguo de Coves del Fem, Ulldemolins (Tarragona)

The fibre-based objects from the Early Neolithic site of Coves del Fem, Ulldemolins (Tarragona)

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Resumen

Los objetos manufacturados con materias orgánicas raramente se conservan excepto bajo condiciones ambientales específicas, ya sea en medios de sequedad constante, en contextos anaeróbicos sumergidos, bajo congelación o por carbonización. Por ello, las técnicas de cestería y cordelería, así como las materias primas utilizadas están escasamente documentadas en el registro arqueológico del Neolítico peninsular. Se aporta aquí nueva información acerca de las técnicas cesteras y de cordelería, así como de las materias primas utilizadas en Coves del Fem (Ulldemolins, Tarragona). Estos restos fueron recuperados en una fosa adscribible al Neolítico antiguo. La cestería estudiada se encuentra manufacturada a través de la técnica de espiral cosida, mientras que en el caso de la cordelería se trata de un único fragmento torsionado. Se discute su funcionalidad en un contexto de hábitat en cueva, así como su tecnología y materias primas usadas, contextualizándolos con otros ejemplos de cestería de espiral cosida de la península ibérica.

Palabras clave: Fibras vegetales, cestería cosida, cordelería, Neolítico Antiguo.

Laburpena

Materia organikoekin egindako objektuek ingurumen-baldintza espezifikoetan bakarrik irauten dute: lehortasun iraunkorretan, murgildutako testuinguru anaerobikoetan, izoztuta edo ikaztuta, adibidez. Horregatik, gutxi dira penintsulako Neolitoko erregistro arkeologikoan dokumentatutako erabilitako lehengaiak eta saskigintzako eta sokagintzako teknikak. Saskigintzako eta sokagintzako teknikei buruzko informazio berria gehitu dugu hemen. Gainera, Coves del Fem-en (Ulldemolins, Tarragona) erabilitako lehengaiei buruzko informazioa ere eskaini dugu. Antzinako Neolitoan koka dezakegun hobi batean berreskuratu zituzten aztarna horiek. Aztertutako saskigintza jositako espiralaren teknika bidez fabrikatuta dago; aldiz, sokagintzaren kasuan, bihurtutako pusketa bakarra da. Iberiar penintsulako jositako espiraleko saskigintzako beste adibide batzuekin alderatuta, erabilitako lehengaien eta teknologiaren funtzionalitatea jorratu ditugu kobazuloko habitataren testuingurua kontuan hartuta.

Gako-hitzak: Zuntz begetalak, jositako saskigintza, sokagintza, Antzinako Neolitoa.

Abstract

Plant-based artefacts are considered one of the first technologies used by human populations playing an important role in the daily life of all societies. Even though, they are made of perishable material which usually disappears in archaeological contexts except for some specific environmental conditions that permit their conservation as arid, anaerobic, waterlogged atmospheres or carbonization. Some examples of the first implements produced by organic materials are baskets and cords which are documented since the very beginning of human populations. Nevertheless, these fibre-based materials have been excluded from archaeological studies. The lack of knowledge in this vegetal technology is a consequence of the difficulty of organic material preservation and the non-suitable analysis and identification methodologies. Even they represent a living material culture as history and ethnography demonstrate, vegetal fibres were probably used for producing indispensable everyday objects and artefacts in the past. The aim of this paper is to provide new information about vegetal technology as basketry and cordage techniques, as well as the raw materials used in Neolithic chronologies in the North-East of the Iberian Peninsula.

The materials analyzed in this study were recovered at the site of Coves del Fem (Ulldemolins, Tarragona) which is a rock shelter preserved thanks to the fallen rock blocks.

Basketry and cordage fragments came from the archaeological fieldwork of 2019 and were recovered inside a pit in levels of the final Early Neolithic. They were preserved thanks to the carbonization and dehydration they were submitted to. Both basketry and cordage examples from Coves del Fem, were deeply described considering their morphology and technology, as well as the raw materials they were made of. The methodology consisted of describing the technique used and taking measures of the different fragments aiming to obtain information about the way the basket and the cord were made. The identification of raw materials was performed by observing cross, peridermal and longitudinal sections of samples using a transmitted optical microscope. Descriptions were based on microanatomical observation by comparing with reference modern material and specialized technical literature.

The results showed the basketry assemblage was produced using the coiling technique and all the fragments belong to a single object. In the case of the cordage fragment, it was made by twisting the fibres which had been previously mechanically processed. The identification of raw materials revealed at least the use of sedges for basketry and non-identified herbaceous plants for making cordage. The functionality of the objects is discussed, and they are also contextualized with other Neolithic fibre productions examples from the Iberian Peninsula and the Middle East, both technologically and the chosen raw materials. In summary, fibre-based productions from Coves del Fem, along with the assemblage from the lake dwelling site of La Draga, fill the gap of this archaeological record from the Iberian Peninsula to Europe, demonstrating the long history of the technical skills related to plant exploitation.

Key words: Vegetal fibres, coiled basketry, cordage, early Neolithic.

Introducción.

Los restos de cestería y cordelería, en tanto que objetos manufacturados con materias orgánicas, son poco frecuentes en el registro arqueológico y su conservación se materializa en condiciones muy excepcionales. Por ello, nuestro conocimiento sobre las producciones elaboradas con fibras vegetales es parcial, sesgada y restringida a ciertas áreas geográficas y periodos. Estas circunstancias limitan nuestro conocimiento sobre la llamado cultura material perecedera y de su importancia para las sociedades prehistóricas. Sin embargo, se ha apuntado que probablemente su presencia fue mayoritaria (Hurcombe 2014) y su importancia mucho mayor de lo que permiten suponer los escasos restos recuperados. La proximidad y abundancia de material vegetal, así como la facilidad de su manejo, hacen de la cestería una tecnología sencilla en cuanto a adquisición de la materia prima, su manejo y su posterior transformación en objetos funcionales, al no requerir de abundantes herramientas para el procesado vegetal, siendo muchas veces posible con las propias manos. Este hecho nos permite pensar que su uso fue habitual para las sociedades agrícolas, pero también para las sociedades cazadoras-recolectoras.

La cestería en espiral cosida ha estado presente en sociedades pasadas y su uso ha permitido solucionar diversas necesidades cotidianas, tales como el transporte, almacenamiento o conservación de alimentos.

En Europa, y más concretamente en la península ibérica, se conocen ejemplos cesteros desde finales del Paleolítico Superior a través del conocimiento indirecto, procurado por improntas arcillosas de cestería. Este es el caso de la Cova de Santa Maira (Castell de Castells, Alacant), donde se encontraron restos de improntas arcillosas de cestería tejida y fibras de esparto trenzadas con una cronología entre 12900 – 10200 cal BC (Aura-Tortosa et al., 2019). Estos restos permiten revelar que las técnicas cesteras eran conocidas en la península ibérica mucho antes de la llegada de las primeras comunidades agrícolas y ganaderas, si bien en este caso no se documenta la técnica de cestería en espiral cosida.

Ya de cronología neolítica también contamos con datos indirectos como son las improntas que se conservan en la arcilla de la fosa número 13 de la Cova de les Cendres (Moraira, Alacant) (Bernabeu-Aubán y Fumanal-García, 2009) o las marcas de una estera del yacimiento de la Cova 120 (Sales de Llierca, Girona) (Agustí et al., 1987).

Para el conocimiento de evidencias directas cesteras en Europa nos hemos de remontar al neolítico. A modo de ejemplo, podemos citar los hallazgos de algunos yacimientos lacustres, como los fragmentos de cestería recuperados en los yacimientos de la Marmotta en el lago Bracciano (Italia), datado entre el 5960 – 5260 BC (Fugazzola, 1998), La Draga

(Banyoles, España), datados entre 5300 – 5000 cal BC (Romero-Brugués et al., 2021), o las ocupaciones neolíticas datadas entre 4000 – 2400 BC en el entorno del Lago Constanza, como por ejemplo Arbon-Bleiche 3 (Suiza) (Médard, 2003) o Wangen, Allensbach y Sipplingen (Körber-Grohne y Feldtkeller, 1998), Honstaad Hörnle I A (Alemania) (Maier, 1999).

En la península ibérica, son pocos los ejemplos directos recuperados de cestería, además del citado yacimiento de La Draga. Entre estos, cabe destacar el yacimiento funerario de Cueva de los Murciélagos de Albuñol (Granada), donde se recuperaron varios objetos elaborados con fibras vegetales que incluían algunos ejemplos de cestería de esparto (*Stipa tenacissima*) datados entre 5200 – 4600 cal. BC (Cacho et al., 1996), conservados gracias a las condiciones excepcionales de sequedad constante.

Dados los escasos restos de cestería neolítica conocidos en la península ibérica, no es posible por ahora abordar su origen y desarrollo. Sin embargo, los hallazgos de cestería en espiral cosida realizados en los niveles epicardiales (4941 – 4545 cal BC) (Palomo et al., 2018) de Coves del Fem (Ulldemolins, Tarragona), constituyen un valioso material para conocer las tecnologías aplicadas en la manipulación de plantas y fibras vegetales. Se presentan aquí los resultados del análisis morfotécnico de los restos cesteros y de cordería de Coves del Fem, la identificación de las plantas utilizadas en el proceso de creación de los objetos vegetales y se discute la funcionalidad tanto de la cestería, como de la cordelería recuperados. Con este trabajo se pretende ampliar el conocimiento de las técnicas de cestería cosida empleadas en las primeras etapas del neolítico en la península ibérica. Así mismo, se pretende aportar nuevos datos a partir de la técnica cestera de espiral cosida, y ampliar el conocimiento de la funcionalidad de los objetos cesteros entre las primeras comunidades campesinas, así como aportar nuevos datos sobre la explotación de los recursos vegetales para cestería.

<u>El yacimiento de Coves del Fem.</u>

El yacimiento de Coves del Fem se localiza en el término municipal de Ulldemolins (Priorat, Tarragona). Se trata de un amplio abrigo rocoso situado en el margen izquierdo del río Montsant, a poco más de 10 metros por encima del mismo (Figura 1). La cavidad se ha formado por la acción erosiva del río sobre los conglomerados. Fue descubierto de forma casual en 1997 y se ha excavado de forma intermitente desde el 2013. Las excavaciones realizadas han permitido documentar una amplia estratigrafía que abarca ocupaciones atribuidas al Mesolítico (6065 – 5718 cal BC), la primera fase del Neolítico Antiguo Cardial (5667 – 5476 cal BC) y la última fase del Neolítico antiguo o Epicardial (4941 – 4545 cal BC) (Bogdanovic et al., 2017; Palomo et al., 2018) (Figura 2). La secuencia está formada por una sucesión de arenas, acumuladas como consecuencia de desbordes e inundaciones del río Montsant, en combinación con otros con sedimento de aportación eólica.

Figura 1. Localización del yacimiento de Coves del Fem. / Figure 1. Location of the site of Coves del Fem.

Tanto los estudios palinológicos como los antracológicos de los niveles epicardiales han permitido documentar un paisaje dominado por pinares de pino silvestre (*Pinus sylvestris-nigra*), bosques de robles y encinas (*Quercus* sp.), tilos (*Tilia* sp.) y avellanos (*Corylus* sp.), con presencia de varias plantas herbáceas (Poaceae, Asteraceae y Cyperaceae) y de otras especies de ribera características del río Montsant, como sauces (*Salix* sp.), olmos (*Ulmus* sp.), alisos (*Alnus* sp.) o fresnos (*Fraxinus* sp.) (Alcolea et al., 2019, Piqué et al., 2021). Los restos carpológicos por su parte determinan el aprovechamiento de los recursos silvestres del entorno, entre ellos bellotas (*Quercus* sp.), piñas (*Pinus* sp.), uvas silvestres (*Vitis vinifera* var. *sylvestris*), así como el cultivo de cereales (Palomo et al., 2018). Los restos faunísticos, indican la importancia de la caza durante las ocupaciones neolíticas, así como la presencia de ovicápridos domésticos.

El contexto arqueológico de los restos de cestería.

Los restos de cestería se localizaron en una subestructura ubicada en el interior de la gran estructura E5, sellada por la Unidad Estratigráfica (UE) 1001 (Figura 2). Esta estructura ha sido parcialmente excavada y documentada, debido a que su límite oriental se adentra en el perfil de la zona no excavada y su límite septentrional se halla destruido debido a la acción de excavaciones clandestinas. A pesar de estas circunstancias, las características generales de la E5 permiten interpretarla como un área doméstica bien definida y coherente con las características de una estructura de hábitat. Presenta una acumulación de guijarros y conglomerado fragmentado procedente de la propia roca del abrigo que define un suelo preparado –a modo de encachado– de unos cinco metros cuadrados, una estructura de sostenimiento y dos subestructuras en fosa tipo cubeta. De estas dos fosas, la estructura E5A es la que ha proporcionado los restos de cestería que aquí presentamos.

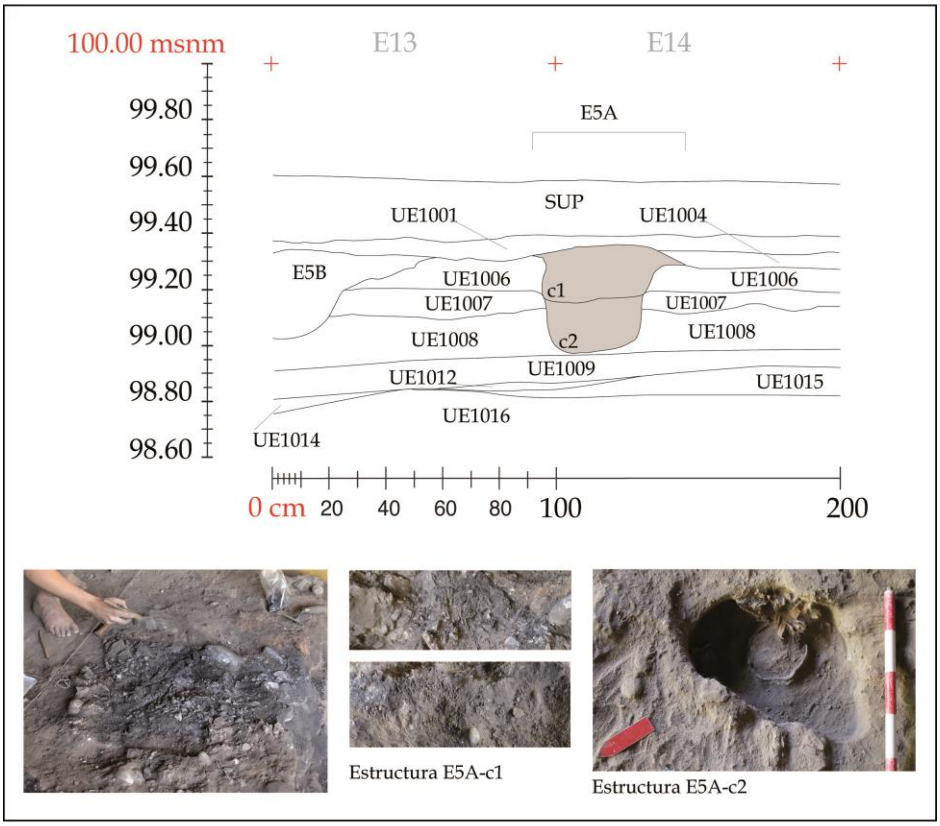

Figura 2. Secuencia estratigráfica del yacimiento de Coves del Fem y contexto de localización de los fragmentos de cestería y cordelería. / Figure 2. Stratigraphic sequence of Coves del Fem site and location context of basketry and cordage fragments.

La subestructura E5A presenta en su parte superior una planta ovalada de sección irregular, y base convexa con una potencia máxima de 40 cm. Su relleno presenta dos capas, la superior tiene 20 cm de potencia y en ella se ha hallado un elemento macrolítico con restos de ocre, así como un fragmento de ocre de 4 cm. Otros materiales recuperados en esta capa son diversos fragmentos de cerámica muy termoalterados que formarían parte de un mismo recipiente. Es en la base de esta capa dónde aparecen fibras vegetales carbonizadas que formarían parte de los restos de cestería que analizamos en este artículo. La capa inferior está compuesta por arenas finas y poco compactas. Del material arqueológico recuperado en su interior, además de restos líticos abundantes, ha aparecido una importante concentración de semillas carbonizadas, también destacan los restos de un fragmento cerámico. Por debajo de este elemento y en el límite oriental de la estructura, se encuentra un cráneo de cerdo completo apoyado en la pared de la fosa. Entre estos restos faunísticos y la base de la estructura, en su parte central, se extrajo un perfil completo de un recipiente cerámico. Finalmente, y en contacto con la base de la fosa se hallaron restos de material vegetal carbonizado entre el que se apreciaba la presencia de tallos.

Materiales

El conjunto de producciones vegetales recuperado en Coves del Fem está compuesto por 53 fragmentos de pequeñas dimensiones que corresponden a restos de cestería y un elemento de cordelería. A pesar de la elevada fragmentación del conjunto se ha partido de la hipótesis que todo el conjunto de cestería procede de un único objeto, ya que todos los fragmentos recuperados provienen de la misma estructura arqueológica.

Las piezas de cestería se conservan carbonizadas en casi su totalidad, a excepción de algunas fibras. Algunas de ellas conservan restos de sedimento de un color ferruginoso, que recuerda al del óxido y también ciertas manchas de sedimento blanquecino, que podría corresponder a restos de caliza calcinada hallada en la estructura. De hecho, las fibras se encontraron en la base de la capa superior de la citada subestructura E5A donde también se documenta la aparición de un nivel de arena quemada con manchas de caliza calcinada.

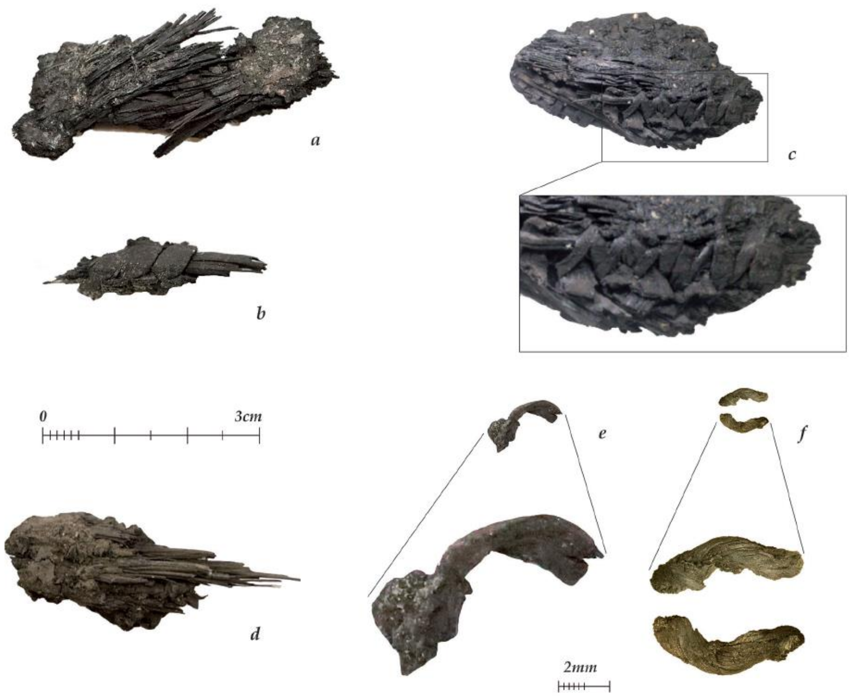

Figura 3. Fragments of basketry with a greater range of representative characteristics and the cordage fragment. / Figure 3. Fragments of basketry with a greater range of representative characteristics and the cordage fragment.

Para su análisis morfotécnico, se ha optado por el estudio de aquellos fragmentos más relevantes. Así pues, se han estudiado y descrito de forma separada los 12 fragmentos de cestería que conservan un mayor rango de características representativas y el fragmento de cordelería (Tabla I, Figura 3). Estas características representativas se basan en las mayores medidas conservadas, identificación de algún tipo de parte funcional del objeto y medidas necesarias para su estudio morfotécnico.

Metodología.

El análisis técnico y morfológico de los restos de cestería llevado a cabo se fundamenta en los trabajos de Adovasio (1977) y Croes (1977). Entre las técnicas cesteras se distinguen la cestería tejida o trenzada, la cestería cordada o ligada y la cestería en espiral cosida o en espiral verdadera (Alfaro 1984). La cestería recuperada en Coves del Fem se engloba dentro de la técnica de espiral cosida, la cual está formada por una trama (elementos horizontales pasivos) y por una urdimbre (elementos verticales activos). Los haces de la trama se van acumulando en forma de espiral para crear el objeto cestero, mientras se van uniendo entre sí a través de las puntadas en forma perpendicular de la urdimbre, las cuales rodean o envuelven cada haz de la trama (Croes, 1977).

Se ha medido la longitud y la anchura de cada fragmento, así como la anchura mínima y máxima tanto de los haces como del cosido (elementos pasivos y activos respectivamente), a fin de obtener datos sobre la confección y consistencia final de la pieza. Así mismo, en los casos que ha sido posible, se ha determinado el número de haces conservados y el tipo y forma de la puntada, para ello se ha seguido la propuesta de Adovasio (1977).

Según Adovasio (1977), la puntada del cosido puede ser simple, intrincada/compleja o envuelta. Las puntadas simples resultan en espirales cerradas, donde los haces adyacentes están bien unidos y sin espacio entre ellos. Las puntadas intrincadas o complejas suelen dejar espaciado entre haces, ya que en la unión de los mismos las puntadas realizan un falso nudo entre el haz nuevo y el antiguo. Finalmente, en el caso de las puntadas envueltas el haz nuevo se ve envuelto por la puntada varias veces.

Asimismo, la forma de la puntada puede ser entrelazada o unida, no entrelazada o separada y atravesada (Adovasio 1977) (Figura 4). Las puntadas entrelazadas o unidas buscan el haz superior a través de entrelazarse en diagonal con la puntada del haz anterior. Las puntadas no entrelazadas o separadas hacen lo mismo pero sin entrelazarse con la puntada del haz anterior, o sea, que no pasa a través de ninguna otra puntada. Por último, las puntadas atravesadas buscan el haz superior después de atravesar la puntada del haz anterior, esta perforación provoca un efecto de bifurcación en la puntada atravesada. Cada tipología de puntada puede perforar o rodear el haz anterior.

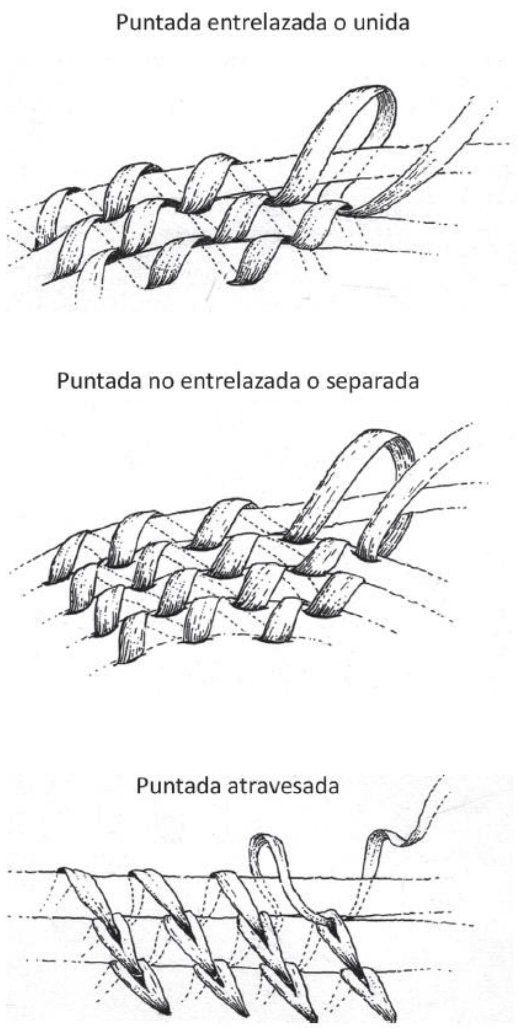

Figura 4. Forma de la puntada en cestería de espiral cosida: entrelazada o unida, no entrelazada o separada y atravesada (extraído de Romero-Brugués et al. 2021). / Figure 4. Sewn spiral basketry stitch shape: interlocking stitch, non-interlocking stitch and split sitch (taken from Romero-Brugués et al. 2021).

En el caso de la cordelería el análisis morfotécnico se basa en el trabajo de Hurley (1979) y en el de Carr y Maslowski (1995). El fragmento de cordelería se ha clasificado según sus características morfológicas y técnicas. Para caracterizar el tipo de producción se ha tenido en cuenta el número de cordeles o elementos utilizados para producir la cuerda, el ángulo de torsión y la dirección de la torsión. El ángulo de torsión mide la inclinación de la torsión respecto al eje vertical de la cuerda, diferenciando entre ángulos suaves (menores de 10º), medianos (entre 10º y 25º) y cerrados (entre 25º y 45º). Mientras que la dirección de la torsión distingue entre cuerdas con torsión hacia la izquierda (de tipo Z) o con torsión hacia la derecha (de tipo S). Una cuerda de tipo Z tiene el segmento más largo inclinado desde la parte superior derecha hacia la parte inferior izquierda, mientras que la de tipo S presenta la inclinación de izquierda a derecha. Asimismo se registra la torsión de los cabos que componen la cuerda, Se han tomado también las medidas mínima, máxima y media de largo y ancho.

Por último, la materia prima usada para la confección de los restos de cestería y cordelería ha sido identificada mediante la observación de la estructura anatómica y la comparación con colecciones de referencia modernas y bibliografía especializada (Brinkkemper y van der Heijden, 2012; Evert, 2006; Schweingruber et al., 2011). Para la observación se ha utilizado un microscopio óptico de campo de luz oscura reflejada (BF-DF). Con el objetivo de minimizar el impacto y garantizar la integridad del objeto, la observación de los rasgos anatómicos de la cuerda se ha llevado a cabo directamente sobre la superficie y las fracturas que presentaba, sin ningún tipo de preparación de la muestra. En el caso de las fibras de cestería se aprovecharon las fracturas de los elementos de cestería.

Resultados. El conjunto del material vegetal

<u>Características morfotécnicas: la cestería y la cordelería</u>

Por lo que respecta a las dimensiones de los fragmentos de cestería conservados, éstos oscilan entre los 7 y 47 mm, con una anchura comprendida entre los 2 y 27 mm (Tabla I, Figura 5). El espesor no se ha podido determinar en ninguno de los restos cesteros, dado que se presentan compactados con sedimentos. La alta fragmentación del conjunto no permite obtener datos del tamaño original de las piezas. Aun así, destacan cinco fragmentos por sus medidas. Por un lado, tenemos lo que podrían corresponder a dos fragmentos de haz: el registro 1 que conserva una longitud de 45 mm y una anchura de 21 mm y el registro 9 con una longitud de 47 mm y una anchura de 16 mm. Por otro lado, tres fragmentos de lo que podrían ser fragmentos de borde o base: el registro 10 con una longitud de 38 mm y una longitud de 23 mm, el registro 11 con una longitud de 39 mm y una anchura de 24 mm y el registro 12 con una longitud de 34 mm y una anchura de 27 mm. Los registros 1, 7 y 9 presentan fibras de haz poco compactadas, aunque conservan una misma dirección. Estos tres fragmentos tienen las fibras del haz unidas por bloques sólidos de sedimento y fibras sueltas, en las partes distales o proximales de las piezas. El registro 8, el único haz conservado de forma individualizada, podría corresponder a parte de estas fibras de haces. Los registros 3, 4 y 5 representan 3 puntadas de cosido individualizadas. Cabe resaltar en el registro 4 la existencia de ciertas marcas superficiales, seguramente resultado de haber envuelto algún material. Solo el registro 6 conserva un haz que aún sigue envuelto por 3 puntadas del cosido (Figura 5).

En lo que respecta al fragmento de cuerda se trata de un pequeño elemento conservado de 6,6 mm de largo y un diámetro medio entorno a los 1,3 mm (entre 0,9 mm diámetro mínimo y 1,6 mm diámetro máximo) (Tabla 1). Se encuentra carbonizado con un buen estado de conservación. Se aprecian las líneas de división de las fibras de sus cordeles, así como un fragmento del posible segundo cordel de la cuerda en un extremo del objeto. No se aprecian cubrimientos o trazas de ningún tipo, su textura superficial se aprecia lisa, sin rugosidades, y sus extremos se encuentran fragmentados (Figura 6).

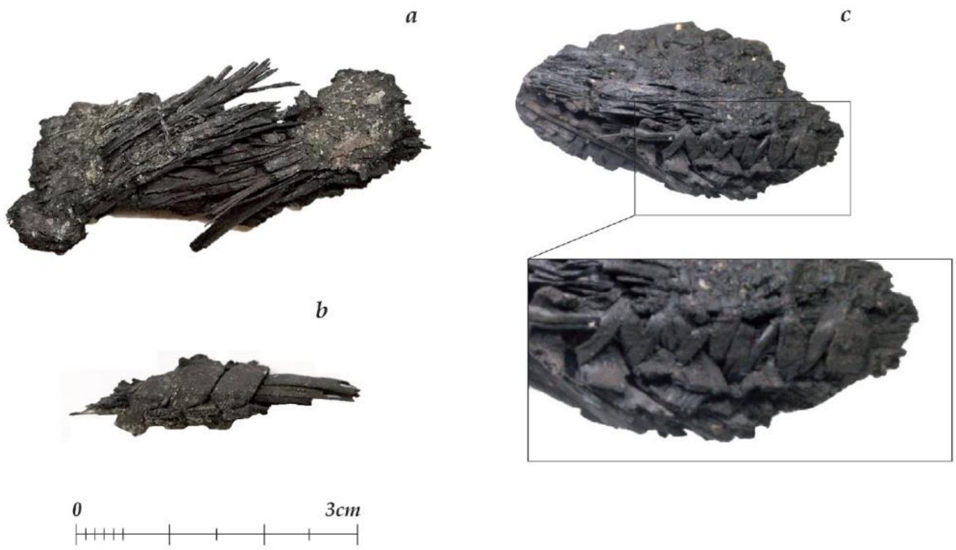

Figura 5. Fragmentos de cestería que conservan un mayor rango de características representativas. a) Fragmento de fibras del haz con una ligera torsión S (registro 1), b) detalle de puntada simple entrelazada (registro 6), c) puntada simple atravesada (registro 10). / Figure 5. Basketry fragment with representative features: a) Slight S-twisted bundle fibres (Reg. 1), b) Simple interlocking stitch (Reg. 6), c) Simple split stitch (Reg. 10).

Figura 6. Vista anterior y posterior del fragmento de cuerda de Coves del Fem. / Figure 6. Anterior and posterior views of the cordage fragment.

Tabla I. Características representativas del conjunto de cestería de Coves del Fem. / Table I. Characteristic features of the basketry assemblage from Coves del Fem.

Reg.	Nº inventario	Tipo de resto	Tipo elemento analizado	Tipo especie	Nombre científico	Parte anatómica	Ancho. mínimo haz (mm)	Ancho. máximo haz (mm)	Ancho mínimo puntada (mm)	Ancho máximo puntada (mm)	Número haces conservados	Longitud por Anchura (mm)	Espaciado espiral	Tipo y forma puntada
1	CDF2019	HAZ	cosido	Monoc. (herbácea)	Cyperaceae	No det.	17	19	-	-	No det.	45*21	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
2	CDF2019	RESTO INFORME	cosido	Monoc. (herbácea)	Cyperaceae	No det.	No det.	No det.	4	5	No det.	18*9	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
3	CDF2019	PUNTADA COSIDO	cosido	Monoc. (herbácea)	Cyperaceae	hoja	No det.	No det.	2	3	No det.	10*6	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
4	CDF2019	PUNTADA COSIDO	cosido	Monoc. (herbácea)	Cyperaceae	hoja	No det.	No det.	3	5	No det.	8*5	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
5	CDF2019	PUNTADA COSIDO	cosido	Monoc. (herbácea)	Cyperaceae	hoja	No det.	No det.	1	2	No det.	7*2	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
6	CDF2019	HAZ	cosido	Monoc. (herbácea)	Cyperaceae	No det.	3	4	5	6	1	31*8	-	Simple entrelazada
	261		haz	Monoc. (herbácea)	No det.	No det.								
7	CDF2019	HAZ	cosido	Monoc. (herbácea)	Cyperaceae	No det.	6	9	No se conserva	No se conserva	No det.	27*9	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
8	CDF2019	HAZ	cosido	Monoc. (herbácea)	Cyperaceae	No det.	-	-	-	-	-	35*3	-	-
	261		haz	Monoc. (herbácea)	No det.	No det.								
9	CDF2019	HAZ	cosido	Monoc. (herbácea)	Cyperaceae	hoja	9	19	No det.	No det.	No det.	47*16	-	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
10	CDF2019	BASE O BORDE?	cosido	Monoc. (herbácea)	Cyperaceae	hoja	4	6	4	5	No det.	38*23	No det.	Simple atravesada
	261		haz	Monoc. (herbácea)	No det.	No det.								
11	CDF2019	BASE O BORDE?	cosido	Monoc. (herbácea)	Cyperaceae	hoja	No det.	No det.	No det.	No det.	No det.	39*24	No det.	No det.
	261		haz	Monoc. (herbácea)	No det.	No det.								
12	CDF2019	BASE O BORDE?	cosido	Monoc. (herbácea)	Cyperaceae	hoja	No det.	No det.	No det.	No det.	No det.	34*27	No det.	No det.
	E5A fondo cubeta		haz	Monoc. (herbácea)	No det.	No det.								
13	CDF2019 E5A	CUERDA	cordeles	Moonoc. (herbácea)	No det.	No det.	-	-	-	-	-	6,6*1,3	-	-

Materia prima.

Todos los fragmentos de cestería estudiados de Coves del Fem han sido identificados como fibras de monocotiledóneas. Concretamente, las fibras del cosido han sido identificadas como ciperáceas (familia Cyperaceae), muy probablemente juncos, mientras que no ha sido posible llegar a este nivel de determinación en el caso de las fibras del haz. Además, se ha determinado la parte anatómica de la planta utilizada que en todos los casos corresponde a la parte de las hojas (Herrero-Otal et al., 2021) (Figura 7a).

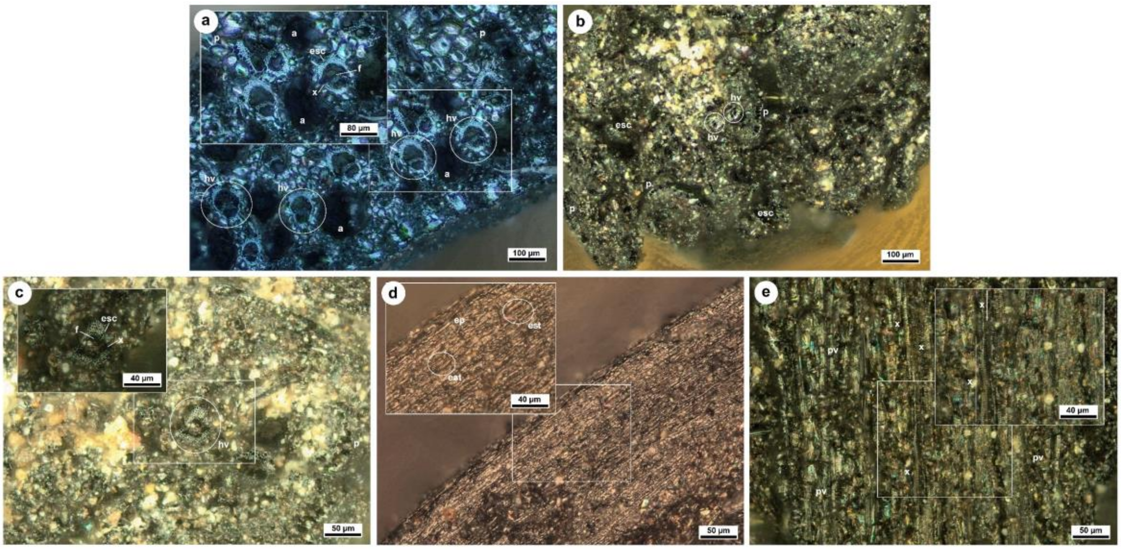

Figura 7: Imágenes de microscopia óptica de los restos vegetales de Coves del Fem (a: cestería, b-e: cordelería). a) Visión transversal de una puntada (familia Cyperaceae), b) Visión transversal general, c) Visión transversal al detalle de los haces vasculares de monocotiledóneas, d) Visión longitudinal de la epidermis y los estomas, e) Visión longitudinal de los haces vasculares (xilema) y parénquima asociado. (a: aerénquima, ep: epidermis, esc: esclerénquima, est: estomas, f: floema, hv: haces vasculares, p: parénquima, pv: parénquima vascular, x: xilema). / Figure 7. Optical microscopy images of vegetal remains from Coves del Fem (a: basketry, b-e: cordage): a) Cross-section view of a stitch (Cyperaceae family), b) General cross-section view, c) Detailed cross-section view where monocots vascular bundles are observed, d) Longitudinal view of the epidermis and stomata, e) Longitudinal view of vascular bundles (xylem) and vascular parenchyma. (a: aerenchyma, ep: epidermis, esc: sclerenchyma, est: stomata, f: phloem, hv: vascular bundles, p: parenchyma, pv: vascular parenchyma, x: xylem).

A diferencia de las fibras utilizadas para la confección del cesto, en el caso del fragmento de cuerda, encontramos un posible tratamiento previo de la fibra antes de la fabricación del cordel. Éste consistiría en la división del tallo o la hoja de la planta en diversas unidades hasta conseguir fibras más delgadas y maleables. Esto se evidencia por la observación de diferentes elementos tanto en el corte transversal y en la superficie del objeto. En el primero observamos una clara distinción de fibras más pequeñas obtenidas a partir de la división física de una de mayor tamaño (Figura 7b). Además, en estos cortes observamos también los haces vasculares de morfología típica de plantas monocotiledóneas, siendo independientes los unos de los otros (Figura 7c). La división de la hoja o tallo en unidades más pequeñas dificulta la determinación de la materia primera a partir del plano transversal, ya que no se aprecia la estructura natural de la planta. Las observaciones más informativas en el caso del cordel son las que se obtienen de su superficie longitudinal. Se aprecia, por una parte, la organización celular de la epidermis de la planta, que se puede diferenciar por unidades celulares de pared sinuosa cómo las que presentan los fitolitos de epidermis de herbáceas. Además, se observan unos elementos con tipologías celulares distintas correspondientes a los estomas. Estos son válvulas que permiten el intercambio gaseoso entre el interior y el exterior de la planta a través del poro central llamado ostiolo. Los estomas están presentes en los tallos y en las hojas de las plantas siendo en estas últimas mucho más abundantes, sobre todo en la cara adaxial. Su disposición típica es longitudinal y se alternan a lo largo de epidermis (Figura 7d). En otras zonas de la superficie de la cuerda, observamos también los haces vasculares, ya mencionados, pero en corte longitudinal, juntamente con células de gran tamaño correspondientes al tejido parenquimático. Por lo tanto, en este caso observamos partes internas de la planta. Esto no sería posible sin la torsión a la que han estado sometidas las fibras para confeccionar la cuerda y que permite la visualización de los elementos tanto internos como externos de la hoja o tallo de la planta utilizada. En este caso, lo que se observa de los haces vasculares es el xilema que se presenta en forma de elementos largos con líneas transversales relativamente juntas en su interior, envueltas de células del parénquima vascular (Figura 7e). A pesar de haber identificado diferentes características de la materia prima utilizada para la manufacturación de la cuerda, no se observan elementos determinantes a nivel de familia, más allá de pertenecer al grupo de las monocotiledóneas.

Técnica y categorías morfotécnicas.

El tipo de técnica empleada en la cestería de Coves del Fem es la técnica de espiral cosida. Las características técnicas documentadas se presentan en la Tabla I. En particular, cabe destacar las fibras del haz del registro 1, las cuales presentan una ligera torsión S (izquierda), que podría corresponder a la torsión que reciben los haces en la cestería de paja o de espiral cosida en el proceso de elaboración (Figura 5). El grueso de los haces y de las puntadas del cosido muestran medidas variadas; con respecto a los haces, éstos están comprendidas entre los 3 – 4 mm y 19 mm; y, en cuanto las puntadas del cosido, entre los 1 – 2 mm y 5 – 6 mm. Cabe mencionar que los haces no conservan su forma original por haber sufrido deformaciones post-deposicionales y, por este motivo, sus medidas son estimativas. Se ha podido determinar la tipología de las puntadas del cosido en 2 registros. Todas corresponden a puntadas simples con 2 variantes en cuanto a forma de la puntada: puntada simple entrelazada (simple interlocking) en el registro 6 (3 puntadas) y puntada simple atravesada (simple split) en el registro 10 (5 puntadas) (Figura 5). No ha sido posible determinar la curvatura horizontal ni la curvatura vertical, así como tampoco el espaciado de la espiral de las piezas. Por lo que respecta a las categorías morfotécnicas se han conservado fragmentos de haz (5 de 12, el 41,7%), fragmentos de puntada de cosido (3 de 12, el 25%), fragmentos de base o borde (3 de 12, el 25%) y un fragmento de resto informe (1 de 12, el 8,3%)

En lo que respecta al fragmento de cuerda se trata de una cuerda confeccionada mediante la técnica de la torsión, con una dirección de torsión tipo Z. La cuerda solo conserva uno de sus cabos que presenta una torsión inicial en s y una hipotética torsión final en Z, el resultado sería una cuerda de tipo Zs,s con dos cabos. Su ángulo de torsión oscila entre los 20° y los 25°, por lo que se encuentra dentro de los ángulos medios.

Discusión.

<u>Materia prima en su contexto vegetal.</u>

Entre los restos de cestería y cordelería de Coves del Fem se ha identificado exclusivamente el uso de monocotiledóneas. La clase de las monocotiledóneas se compone de numerosas especies de amplia distribución, entre las que destacan diversas especies herbáceas. Muchas de ellas presentan tallos flexibles, propiedades muy adecuadas para la cestería y la cordelería. En el caso de la cestería tanto los haces como las puntadas se manufacturaron con este tipo de fibras, si bien se pudo precisar que pertenecían a la familia de las ciperáceas (Cyperaceae), probablemente juncos. Estos resultados indican que entre las especies vegetales al alcance se seleccionaron un determinado tipo de plantas para la elaboración de estos productos. Además, se pudo determinar con una preferencia por la elección de hojas (Herrero-Otal et al., 2021)

Como se ha señalado, el registro antracológico y palinológico de Coves del Fem indica que durante la fase epicardial, a la que corresponden los restos de cestería y cordelería, el paisaje estaría dominado por pinares de pino tipo albar (*Pinus* sp. tipo *sylvestris-nigra*) bosques mixtos de *Quercus* sp. caducifolio y *Quercus* sp. tipo *ilex-coccifera*, y especies higrófilas que crecerían en los ambientes de ribera. El registro polínico ha revelado además la presencia de ciperàcies y otras monocotiledóneas en el entorno de Coves del Fem (Palomo et al., 2018). Las ciperàcies, al igual que otras familias de monocotiledóneas, crecen en ambientes húmedos y por tanto habrían encontrado un habitat favorable en las inmediaciones del río Montsant, donde se localiza el yacimiento. Los datos arqueobotánicos corroboran, por lo tanto, la disponibilidad de esta familia en el entorno.

Esto permite plantear que la materia prima para la confección de objetos cotidianos de fibras vegetales como cestería y cordelería se pudo obtener a nivel local.

De acuerdo a la investigación etnográfica, plantas herbáceas como el junco, las juncias o la enea son plantas muy aptas para hacer esteras, cubiertas, cordelería o cestería. Aunque en la actualidad se conoce poca cestería hecha de herbáceas, históricamente sí se documenta la cestería hecha de juncos, probablemente trabajados en espiral (Kuoni, 1981).

El uso de monocotiledóneas está bien documentado en otros contextos arqueológicos, así como en algunas de las primeras evidencias textiles y de cestería provenientes de la cuenca mediterránea oriental y del Oriente Próximo. Este es el caso de los restos vegetales encontrados en Jericó (Crowfoot, 1982), Nahal Hemar (Schick, 1988) o Tell Halula (Alfaro, 2012). También los cestos documentados en la península ibérica fueron elaborados principalmente con fibras de monocotiledóneas (Herrero-Otal et al., 2021). Las fibras monocotiledóneas están presentes entre la cestería de La Draga, tanto para los haces como las puntadas, aunque también se usaron fibras de líber de tilo (*Tilia* sp.) para las puntadas y varitas de avellano como haces (Romero-Brugués et al., 2021).

Juntamente con La Draga, Coves del Fem constituye el único caso en el que el material vegetal escogido es totalmente diferente al identificado en otros yacimientos neolíticos de la península ibérica. Las diferencias en el uso de las materia primas vegetales en el neolítico peninsular sin duda están relacionados con la disponibilidad de la materia prima. El material vegetal que se documenta mayormente en el sur y levante peninsular es el esparto, siendo el ejemplo más ilustrativo la cestería de Cueva de los Murciélagos. El esparto actualmente tiene su área de distribución natural en las zonas más áridas del sur y el este peninsular, en cambio no se documenta en el Nordeste de la Península, donde no se dan condiciones ambientales favorables para su crecimiento. Durante el Neolítico los registros arqueobotánicos de Coves del Fem y La Draga (Piqué et al., 2021) indican que el clima era más húmedas que en la actualidad, lo que sugiere que el esparto no habría encontrado en el nordeste peninsular las condiciones adecuadas para su crecimiento. En cambio, tanto Coves del Fem como la Draga se localizan en ambientes húmedos, ya sea por su proximidad a cursos de agua, en el caso de Coves del Fem, o del lago de Banyoles en el caso de la Draga, lo que habría favorecido el crecimiento de plantas como las ciperáceas que tiene su hábitat en estos ambientes húmedos. Estas monocotiledóneas son actualmente abundantes en las inmediaciones de estos yacimientos, donde están representadas por diversas familias botánicas.

La elección de la materia prima y la selección de las partes más propicias para cestería en Coves del Fem es el resultado de un alto conocimiento de los recursos vegetales del entorno, sus propiedades y manejo de las mismas para la manufacturación de objetos. En otros yacimientos del Neolítico antiguo, como el asentamiento de La Draga (Banyoles), se han identificado herramientas relacionadas con el procesado de fibras vegetales a través del análisis funcional practicado sobre instrumentos de diversa naturaleza, como láminas de sílex (Gibaja, 2011), conchas marinas (Clemente y Cuenca, 2011) y punzones de hueso (De Diego et al., 2018). En este sentido, en Coves del Fem se han recuperado punzones de hueso que podrían haber sido utilizados para el trabajo de materias vegetales, entre otras funciones, aunque su análisis se halla todavía en curso.

La cestería y la cordelería de Coves del Fem en el contexto de las producciones en base a fibras vegetales neolíticas: cronología, técnica de producción y funcionalidad

Como ya se ha mencionado, los restos vegetales raramente se conservan en el registro arqueológico, por lo que tenemos un conocimiento limitado de las tecnologías perecederas, tanto en los que se refiere a los procesos de producción como de los usos a los que se destinaron entre las sociedades prehistóricas (Hurcombe 2014). Las escasas evidencias de cestería y cordelería recuperadas en contextos arqueológicos permiten indagar en la gestión y aprovechamiento de fibras vegetales para la elaboración de objetos y contribuir a conocer mejor el rol que estos tuvieron. En este sentido, los hallazgos de Coves del Fem contribuyen al conocimiento de las técnicas de cestería y cordelería neolítica de la península ibérica y aportan datos sobre su posible función.

A nivel cronológico, el nivel donde se han localizado los restos de cestería y cordelería se sitúa en la primera mitad del V milenio en cronología calibrada BC y, por lo tanto, se trata de unos de los materiales cesteros más antiguos de la península ibérica. Las características morfotécnicas y la identificación de las materias primas sugieren que todo el conjunto de cestería correspondería a una sola pieza. Todos los fragmentos provienen de la misma subestructura arqueológica E5A y el grosor de los haces y de las puntadas del cosido son similares. Así mismo, todos los restos analizados han sido determinados como fibras de monocotiledóneas y, concretamente, las fibras del cosido como hojas de Cyperaceae. Los restos corresponden a fragmentos de haz que conformarían la espiral, diversas puntadas sueltas y algunos fragmentos mejor conservados que corresponderían a parte del borde o de la base de la misma pieza de cestería. El estado de carbonización, fragmentación y tamaño de los restos no permite vislumbrar la forma original de la pieza ni el tamaño de la misma, pero el hecho de que todos los fragmentos estaban asociados permiten plantear que probablemente proceden de un único objeto.

En lo que respecta a la técnica de producción, se ha podido determinar que el objeto fue elaborado mediante la técnica de espiral cosida. Esta técnica cestera es una de las más arcaicas de nuestro pasado (Kuoni, 1981). Con este procedimiento es posible elaborar objetos planos o con volumen con multitud de utilidades y formas a partir de un punto central, donde se cosen haces de fibras entre sí a través de una espiral. Por ejemplo, es conocida la técnica en espiral cosida en yacimientos del Próximo Oriente, como Nahal Hemar (8200 – 7300 cal BC) (Shick, 1988) o Kefar Samir en Israel (5517 – 5038 cal. BC) (Galili y Schick, 1990), Çatal Hüyük en Turquía (7400 – 6200 cal. BC) (Mellaart, 1967, Wendrich y Ryan, 2012) o El Fayum y Badari en Egipto (4000 cal. BC) (Lucas, 1948). En el noreste de la península ibérica, en el yacimiento lacustre de La Draga (Banyoles), los 8 cestos individualizados se adscriben a la técnica en espiral cosida y se han distinguido diferentes usos según el tipo de puntadas para la confección de la espiral, entre ellos el transporte y el almacenaje de alimentos (Romero-Brugués et al., 2021). En la Cueva de los Murciélagos de Albuñol (Granada), en el sur peninsular y en un contexto funerario, también se documentan las técnicas de cestería en espiral cosida, así como la tejida y la trenzada. En este caso se han documentado numerosos objetos producidos con técnicas cesteras, determinados como parte de los objetos funerarios y de uso cotidiano del Neolítico antiguo (Cacho et al., 1996).

Por lo que respecta a la funcionalidad de los restos de cestería de Coves del Fem, la técnica documentada como cestería en espiral cosida permite elaborar multitud de formas, con amplias funcionalidades, ya que la técnica es suficientemente versátil para producir objetos tanto planos, como con volumen. No obstante, se propone un posible uso relacionado con el almacenaje subterráneo de alimentos. Esta hipótesis surge del contexto de procedencia de los restos y de las características técnicas documentadas. Los fragmentos se recuperaron en la base de la primera capa de una pequeña fosa que se interpretó como una estructura de almacenamiento, dónde los restos del cesto podían haber formado parte de un posible revestimiento de la misma. Sin embargo, debido al estado de fragmentación del objeto, no se puede descartar que los restos representen el cesto de almacenaje mismo. Es decir, los restos de cestería pueden no indicar el revestimiento, sino la estructura de almacenamiento real colocada en el interior de la fosa.

El tipo de puntadas documentadas en el cosido de los restos de cestería son no entrelazadas y atravesadas. Este tipo de cosido permite confeccionar trabajos prietos y construir objetos compactos, densos y pesados. Estas características se relacionan con recipientes inmóviles destinados al almacenamiento, lo que parece reforzar la hipótesis de que el objeto de cestería estaría relacionado con el almacenaje.

La funcionalidad de almacenamiento de los restos cesteros se atribuye por lo tanto a las características morfotécnicas y su ubicación en el interior de una fosa. El objeto cestero habría servido bien como protección de las paredes de la estructura o bien como dispositivo de almacenamiento en sí mismo, sin que sea posible poder precisar más debido al estado de fragmentación. Cabe señalar que en la citada fosa, junto a los restos de cestería, se recuperaron semillas de cereal carbonizadas, así como restos cerámicos y fragmentos de tallos vegetales carbonizados, lo que hace pensar que podría haber servido como lugar de almacenamiento en sus orígenes, acción continuada en el tiempo hasta su desuso final.

La identificación de instalaciones de almacenaje prehistóricas, como pueden ser los silos revestidos con cestería, proveen de pruebas indirectas de estructuración del espacio, en el sentido de organización y gestión de la extensión habitacional. En el caso de Coves del Fem cabe señalar que la reducida superficie excavada hasta la fecha no permite todavía definir como se organizó el espacio durante la fase epicardial. La reiteración de estructuras subterráneas relacionadas con el almacenaje en esta fase permite platear un uso reiterado del espacio para esta finalidad. Se han documentado diversas estructuras de almacenaje, una de ella de grandes dimensiones y otras, como la que presentamos en este trabajo, de pequeño tamaño. Estas estructuras difieren en su uso temporal y en base a sus dimensiones muy posiblemente en el material almacenado. Las paredes de las estructuras, excavadas en estratos compuestos de limos finos poco consistentes, podrían haberse visto reforzadas por los elementos de cestería.

El uso de elementos de cestería para revestimiento de paredes de estructuras de almacenamiento es una funcionalidad que está bien documentada en el registro arqueológico. A modo de ejemplo podemos citar las fosas de almacenamiento bien conservadas con forro de cestería de espiral cosida (*coiled basketry*), datados entorno 4295 – 4467 cal BC, del yacimiento de El Fayum (Egipto) (Wendrich y Holdaway, 2017). Por otra parte, en la prehistoria europea, también se conocen varios ejemplos similares. Por ejemplo, en el yacimiento de Gearraidh na h'Aibhne, en la isla de Lewis (Escocia), se han determinado restos de ramas de avellano retorcidas que forraban un silo ovalado y que se interpretaron como una estructura cestera de mimbre de la Edad del Bronce (2815 – 2780 cal BP) (Duffy, 2006). Asimismo, en el poblado del Bronce Final de Lavra (Portugal), se documentaron silos con ramas carbonizadas entrecruzadas que parecían elementos de protección de paredes forradas (Sanches, 1987).

Así mismo se han documentados silos forrados con cestería o estructura vegetal a partir de hallazgos indirectos. En el yacimiento de Gussage All Saints (Salisbury, Inglaterra) se han descubierto huecos en las paredes de algunos silos que podrían formar parte de un recubrimiento de cestería, datados en la Edad del Hierro, entorno al 500 – 450 BC (Wainwright, 1973).

Etnográficamente, el revestimiento de cestería en los silos para conseguir un mejor aislamiento se ha descrito en diversas comunidades. Por ejemplo, los silos *borno* y belaá ngawuli del norte de Nigeria, o en Madagascar, en Sudáfrica o Suazilandia donde se usan esteras de tejidos vegetales para las paredes (Miret, 2009).

En el pasado, seguramente esta utilidad habría sido una práctica habitual, tal y como se documenta arqueológicamente y etnográficamente. Sin embargo, en la península ibérica solo se conoce este uso de forma arqueológica a través de los restos de cestería de Cova de les Cendres, datado en 4510 ± 40 cal. BC., donde se documentó el revestimiento de un silo con esparto trenzado, que tendría la función de reforzar su estructura (Bernabeu-Aubán y Fumanal-García, 2009). Es importante destacar, no obstante, que la técnica utilizada difiere; mientras que en la Cova de les Cendres se usó la cestería trenzada, en Coves del Fem la técnica determinada es la espiral cosida y, por lo tanto, el hallazgo que aquí se presenta es único a nivel peninsular. Cabe mencionar como otro gran ejemplo del uso de la cestería para la conservación de alimentos el ya mencionado yacimiento de La Draga. Aunque el almacenamiento de alimentos no es subterráneo, se interpreta que los 8 cestos individualizados tendrían como una de sus funciones el almacenar alimentos aislándolos de la humedad ambiental.

El pequeño tamaño del fragmento de cuerda no permite extraer conclusiones sobre su función, tan solo describir el objeto como una cuerda de pequeño diámetro y con un ángulo de torsión mediano. Por lo tanto, se trataría de una cuerda fina y resistente. Este tipo de cuerdas son usadas por ejemplo para el almacenaje o para la fabricación de trampas, así como para urdimbres o tramas en ciertos tipos de cestería trenzada (Andrews, Adovasio y Carlisle, 1986). Sin embargo, el hecho de que se encontró asociado a la concentración de semillas y a los fragmentos de cestería hace plantear que podrían estar relacionados, pero no se tienen más datos para determinar la función de la cuerda.

Conclusiones

En el presente estudio se ha expuesto un ejemplo singular de cestería en espiral cosida y cordelería provenientes de un contexto neolítico del noreste peninsular. Los restos de cestería recuperados en el interior de una fosa excavada en sedimentos muy poco compactados podrían haber formado parte de un mismo elemento utilizado como recipiente y armazón de las paredes y la base. El hecho de haber documentado varios tipos de puntadas (no entrelazadas y atravesadas) se puede relacionar con la función de conservación y/o almacenamiento de alimentos. En el caso del cordel recuperado, se trata de un pequeño fragmento de cuerda torsionada hecha con fibras previamente manipuladas sin que se pueda establecer una función en concreto.

La funcionalidad relacionada con la conservación y/o almacenaje de alimentos, así como su contexto en una cavidad aportan nuevos datos al conocimiento de la manufactura cestera del Neolítico, la cual se encuentra bien representada en Europa y Próximo Oriente. Así mismo, la cestería de Coves del Fem, juntamente con el conjunto recuperado en el yacimiento de La Draga, se desmarca del resto de cestería ibérica por el material vegetal escogido, ya que se utilizaron ciperáceas y/u otras herbáceas para su elaboración. Es notable remarcar también la selección de las partes del material vegetal para la manufactura cestera, como son las hojas, por lo cual se desprende que la comunidad de Coves del Fem tenía un alto conocimiento del entorno más inmediato, así como de las técnicas para la elaboración de cestos.

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Bibliografía.

Adovasio, J.M., 1977. Basketry Technology: a guide to identification and analysis. Aldine Publishing Company, Chicago.

Agustí, B., Alcalde, G., Burjachs, F., Buxó, R., Juan-Muns, N., Oller, J., Ros, M.T., Rueda, J.M., Toledo, A., 1987. Dinàmica de l'ocupació de la Cova 120 per l'home en els darrers 6.000 anys. Museu d'Arqueologia, Girona.

Alcolea, M., Revelles, J., Berihuete, M., Piqué, R., Dufraisse, A., Terradas, X., Palomo, A., Bogdanovic, I., Rosillo, R., 2019. Forest resource management during Mesolithic-Neolithic transition: archaeobotanical studies in Coves del Fem site (NE Iberia). 1st Conference on the Early Neolithic of Europe : 78-79. CSIC – Institución Milá y Fontanals (IMF).

Alfaro Giner, C. 1984. Tejido y cestería en la península ibérica. Historia de su técnica e industrias desde la prehistoria hasta la romanización. Consejo Superior de Investigaciones Científicas (CSIC). Instituto español de prehistoria. Madrid 1984.

Alfaro, C., 2012. Textiles from the Pre-pottery Neolithic site of Tell Halula (Euphrates Valley, Syria). Paléorient 38 (1–2), 41–54.

Andrews, R. L., Adovasio, J. M., Carlisle, R. C., 1986. Cordage. In: Perishable industries from dirty shame Rockshelter. Ethnology monographs 9 & University of Oregon Antrhopological Papers 34, 51–91.

Aura-Tortosa, J., Pérez-Jordà, G., Carrión-Marco, Y., Seguí-Seguí, J.R., Jordá-Pardo, J.F. Miret-Estruch, C., Verdasco-Cebrián, C.C., 2019. Cordage, basketry and containers at the Pleistocene–Holocene boundary in southwest Europe. Evidence from Coves de Santa Maira (Valencian region, Spain). Vegetation History and Archaeobotany, 1–14. https://doi.org/10.1007/s00334-019-00758-x

Bernabeu-Aubán, J., Fumanal-García, M. P., 2009. La excavación, estratigrafía y dataciones C14. In: Bernabeu-Aubán, J., Molina-Balaguer, L. (Eds.), La Cova de les Cendres (Moraira-Teulada, Alicante), 31–52 MARQ, Diputació d'Alacant, Alacant.

Bogdanovic, I., Palomo, A., Piqué, R., Rosillo, R., Terradas, X., 2017. Los últimos cazadores-recolectores en el NE de la península ibérica: evidencias de ocupaciones humanas durante el VI milenio cal BC. In: Barceló, J.A., Bogdanovic, I., Morell B. (Eds.) Actas del Congreso de Cronometrías Para la Historia de la península ibérica (IberCrono 2017) Barcelona, Spain, September 17-19, 2016, 35-45. CEUR-WS, Barcelona.

Bosch, A., Chinchilla, J., Tarrús, J., 2000. El poblat lacustre neolític de La Draga: excavacions de 1990 a 1998. Museu d'Arqueologia de Catalunya, CASC, Girona.

Brinkkemper, O., van der Heijden, E., 2012 Appendix A: fibre identification criteria. In: Wendrich, W. (Ed) The world according to basketry. An ethno-archaeological interpretation of basketry production in Egypt, 429–440. Leiden University, Cotsen Institute of Archaeology Press, Los Angeles.

Cacho, C., Papi, C., Sánchez-Barriga, A., Alonso, F., 1996. La cestería decorada de la Cueva de Los Murciélagos (Albuñol, Granada). Complutum extra 6 (1), 105–122.

Carr, C., Maslowski, R. F., 1995. Cordage and fabrics: relating form, technology and social processes. In: Carr, C. Neitzel, J. E. (Eds.) Style, society and person, Archaeological and Ethnological perspectives, 297-343. Plenum Press, New York.

Clemente, I., Cuenca, D., 2011. Instrumentos de trabajo de concha. In: Bosch, A., Chinchilla, J., Tarrús, J. (Eds.), El poblat lacustre del Neolític antic de La Draga. Excavacions 2000–2005, 137–145. Museu d'Arqueologia de Catalunya, CASC, Girona.

Croes, D. R., 1977. Basketry from the Ozette village archaeological site: a technological, functional and comparative study. Washington Archaeological Research Center, Washington State University, Pullman, Washington.

Crowfoot, E., 1982. Textiles, matting and basketry.I In: Kenyon, K. M., Hoiland, T. A. (Eds.), Excavations at Jericho 4, 546–550. British School of Archaeology in Jerusalem, Oxford.

De Diego, M., Palomo, A., Piqué, R., Saña, M., Terradas, X., Clemente, I., Mozota, M., 2018. Fibre production and incipient textile technology in the Early Neolithic site of La Draga (Northeastern Spain, Banyoles - Catalonia; 5300-4900 BC. In: Bravermanová, M., Březinová, H., Malcolm-Davies, J. (Eds.), Archaelological Textiles - Links between past and present, 293–302. Technical University of Liberec, Praga.

Duffy, P. R. J., 2006. Excavation of a Bronze Age wicker container, Gearraidh na h'Aibhne, Isle of Lewis. Scottish Archaeological Internet Report, 19.

Evert, R.F., 2006. Esau's plant anatomy: meristems, cells and tissues of the plant body: their structure, function, and development. Wiley, Hoboken.

Fugazzola, M.A., 1998. La vita quotidiana del neolítico. Il sitio della Marmotta sul lago di Bracciano. In: Pesina, A., Muscio, G (Coord). Settemila anni fa. Il primo pane. Ambienti e culture delle società neolitiche, 185-192. Museo Fliulano di Storia Narurale, Comune di Udine.

Galili, E., Schick, T., 1990. Basketry and a wooden bowl from the Pottery Neolithic submerged site of Kefar Samir. Mitekufat Haeven: Journal of the Israel Prehistoric Society 23, 142–151.

Gibaja, J. F., 2011. La función de los instrumentos líticos tallados. In: Bosch, A., Chinchilla, J., Tarrús, J. (Eds.), El poblat lacustre del Neolític antic de La Draga. Excavacions 2000–2005, 91–100. Museu d'Arqueologia de Catalunya, CASC, Girona.

Herrero-Otal, M., Romero-Brugués, S., Piqué, R., 2021. Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula. Vegetation History and Archaeobotany. https://doi.org/10.1007/s00334-021-00826-1

Hurley W. M., 1979. Prehistoric cordage: Identification of impressions of pottery. Taraxacum, Toronto.

Hurcombe, L.M., 2014. Perishable Material Culture in Prehistory. Investigating the Missing Majority. Routledge, Londres.

Körber-Grohne, U., Feldtkeller, A., 1998. Pflanzliche Rohmaterialien und Herstellungstechniken der Gewebe, Netze, Geflechte sowie anderer Produkte aus den neolithischen Siedlungen Hornstaad, Wangen, Allensbach und Sipplingen am Bodensee. In: Siedlungsarchäologie im Alpenvorland V. Forschungen und Berichte zur Vor- u. Frühgeschichte in Baden-Württemberg, Band 68, 131–242.

Kuoni, B., 1981. Cestería tradicional ibérica. Ediciones del Serbal, Barcelona.

Lucas, A., 1948. Ancient Egyptian Materials and Industries, third ed. Edward Arnold, University of California.

Maier, U., 1999. Agricultural activities and land use in a Neolithic village around 3900 BC: Hornstaad Hörnle I A, Lake Constance, Germany. Vegetation History and Archaeobotany 8, 87–94.

Médard, F., 2003. Vestiges textiles et activités de filage sur le site néolithique d'Arbon-Bleiche 3 (TG Suisse). Bulletin de la Société préhistorique française 100 (2), 375–391.

Mellaart, J., 1967. Çatal Huyuk: A Neolithic Town in Anatolia. McGraw Hill (Ed.), New York.

Miret, J., 2009. Sistemes tradicionals de conservació dels aliments en fosses i sitges. Un enfocament multidisciplinar. Documento accesible en www.scribd.com

Palomo, A., Terradas, X., Piqué, R., Rosillo, R., Bogdanovic, I., Bosch, A., Saña, M., Alcolea, M., Berihuete, M., Revelles, J. 2018. Les Coves del Fem (Ulldemolins, Catalunya). Servei d'Arqueologia i Paleontologia – Tribuna d'Arqueologia 2015–2016, 88–103.

Peña-Chocarro, Guillem-Pérez, L., Morales-Mateos, J., Zapata, L., 2015. Storage in traditional farming communities of the western Mediterranean: Ethnographic, historical and archaeological data. Environmental Archaeology 20:4, 379–389.

Piqué, R.; Alcolea, M.; Antolín, F.; Berihuete-Azorín, M.; Berrocal, A.; Rodríguez-Antón, D.; Herrero-Otal, M.; López-Bultó, O.; Obea, L.; Revelles, J., 2021. Mid-Holocene Palaeoenvironment, Plant Resources and Human Interaction in Northeast Iberia: An Archaeobotanical Approach. Applied Sciences 11, 5056.

Romero-Brugués, S., Piqué, R., Herrero-Otal, M., 2021. The basketry at the early Neolithic site of La Draga (Banyoles, Spain). Journal of Archaeological Science: Reports, Volume 35. https://doi.org/10.1016/j.jasrep.2020.102692

Sanches, M. J. 1987. O Buraco da Pala. Um abrigo pré-histórico no concelho de Mirandela (noticia preliminar das excavações de 1987). Arqueologia, 16, 58–77.

Schick, T., 1988. Nahal Hemar Cave, cordage, basketry and fabrics. Atiqot 18, 31–43.

Schweingruber, F.H., Börner, A., Schulze, E. D., 2011. Atlas of stem anatomy in herbs, shrubs and trees. Springer, Berlin.

Wainwright, G. J., Spratling, M., 1973. The Iron Age settlement of Gussage All Saints. Antiquity 47, 109–130.

Wendrich W., Ryan P., 2012. Phytoliths and Basketry Materials at Çatalhöyük (Turkey): Timelines of growth harvest and objects life histories. Paléorient 38 (1-2), 55–63.

Wendrich, W., Holdaway, S., 2017. Basket use, raw materials and arguments on early and Middle Holocene mobility in the Fayum, Egypt. Quaternary International 30, 1–10.

6.2.3. Describing neolithic cord production process: raw materials, techniques and experimental archaeology in La Draga (Girona, Spain; 5207-4862 cal BC).

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This paper deals with the identification of the whole set of cord materials from the Early Neolithic site of La Draga (5207-4862 cal BC; Banyoles, Girona), following the preliminary identifications published in Piqué et al. (2018). In addition, an experimental archaeological approach is included to the cord production process, which has helped to understand craft production processes in the past, oferring an overview of different aspects that should be consideres such as the time required, the tools and number of people needed, the acquisition and processing of raw materials, among others. The results highlighted a preferred selection of lime tree bark (*Tilia* sp.) and stinging nettle bast (*Urtica* sp.) for cord production, both easy to obtain from the surroundings of the site. Although different technological cords were found at the site -twisted and braided- no specific relationship could be established between the raw material and the technology used. However, the widespread use of lime bark in the production of cordage is striking and could be related to the physical properties of these plant fibres.

Describing the Neolithic cord production process: raw materials, techniques and experimental archaeology in La Draga (Girona, Spain; 5207-4862 cal BC)

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Abstract.

Cordage is related to daily activities and as such has been a basic element for self-suffiency since Prehistory. Due to the lack of their preservation in most archaeological contexts, the knowledge of these technologies in the past is limited. This paper analyses the production process through an experimental program of the cordage assemblage from La Draga (Girona, Spain; 5207-4862 cal BC). The site is an Early Neolithic site from north-eastern Iberia, where a wide vegetal set of fibre-based craft was recovered in waterlogged preservation conditions. First, a systematic identification of raw materials used for cord production is done. Subsequently an experimental approach to these cords, considering both the raw materials used and their properties, has been developed. The study aims to infer raw material selection for producing cords, as well as the importance of raw material and group standards involved in the final objects. The results showed a preferable selection of lime tree bark (*Tilia* sp.) and nettle bast fibre (*Urtica* sp.), which may be obtained from the surroundings of the site. Both were used to produce different types of cords, twisting preferred above braiding, which should be related to cultural standards and traditional learning processes.

Keywords: Vegetal fibres; Raw materials; Cordage; Experimental archaeology; Early Neolithic.

Introduction.

Preservation of perishable material in archaeology limits our knowledge of plant crafts in the past. This is the case of vegetal fibre-based objects; although we know they existed, direct evidence is scarce (Hurcombe 2014). While their use is well documented since Palaeolithic chronologies (Barber 1994; Soffer 2004; Hardy 2008; Kvavadze et al. 2009), the knowledge of this perishable technology usually comes from fibre imprints in durable materials such as clay or pottery (Soffer et al. 1998; Soffer et al. 2000; Wigforss 2014). Although these imprints let an approach to the technique used to make these objects, they do not allow the species of the raw material to be recognised. The identification of plants by the study of indirect evidence is challenging because of the lack of reference material, but also because the features shared between plants do not permit specific differentiation.

A wide diversity of plants offers fibre for crafts production, and they can be both monocotyledon and dicotyledon families. Moreover, both groups are anatomically easy to distinguish observing their cross-section. Monocots present scattered vascular bundles all around the section, while dicots present their bundles arranged in a ring during the secondary growth (Evert 2006). Fibres from monocot families are usually leaves and stems from grasses, cattails, sedges or palms, while the dicot fibres are extracted from the stems from different herbs such as nettle, hemp, and linen or the bark of trees. The fibres extracted from both types, need different processing to be used. Monocots are dried after gathering the plant and moisturized closer to their use. Dicot families need a more detailed preparation that consists in general terms of extracting the bast fibres which corresponds to the phloem fibres of the vascular system (Evert 2006). In this paper we refer to “bast fibres” as the fibres obtained from the stems of dicots herbs, and “bark” to cite the materials obtained from trees.

Mesolithic and Neolithic sites from wetlands in northern Europe have provided several examples of braided cords and nets. This is the case of the nets and cords made of lime tree bark (Tilia sp.) found at the Friesack-4 site (Germany; 7700 BC) (Gramsch 1992), or those made of bark fibres of lime, willow (*Salix* sp.) and nettle (*Urtica dioica*) found at the site of Antrea (Finland; 8400-8300 cal BC) (Bender Jørgensen 1992; Miettinen et al. 2008; Wigforss 2014). Other sites, such as Dejrø and Skjoldnæs (Denmark; 6500 BC) provided strands and twisted nettle cords (Bender Jørgensen 1992; Wigforss 2014). For Neolithic chronologies, there are noteworthy plant craft remains at the lacustrine settlements in Central Europe, such as those in the Circum-Alpine zone. They have provided cordage materials from sites like Arbon-Bleiche (Switzerland, 3384-3370 BC) where the materials were made of lime tree bark and flax (Linum usitatissimum) (Médard 2003), and the Wetzikon-Robenhausen site (Switzerland, 3700-3300 BC), where the lime tree was also used (Altorfer and Médard 2000). The cordage remains of these sites documented a diversity of plant raw materials used in the production of cordage, mainly bast fibre of dicot families.

In more southern latitudes, archaeological sites in wetlands and lacustrine environments are less common and preservation of the plant crafts is rarer. The earliest direct materials known are three partially charred fragments of a braided cord recovered in the Coves de Santa Maira site (Alacant, Spain; 12,900-10,200 cal BC). The identification of the plant fibres showed that they were made of leaves from a Poaceae species, more specifically from esparto grass (*Stipa tenacissima*) (Aura-Tortosa et al. 2019). The few lacustrine sites in the Mediterranean region have also provided evidence of Early Neolithic plant crafts. This is the case of La Marmotta (Italy, 5690-5260 BC), which has yielded a huge amount of vegetal remains (Bazzanella 2012; Mineo et al. 2023), and La Draga (Girona, Spain; 5207-4862 cal BC), where charred and waterlogged plant crafts were recovered (Piqué et al. 2018, Romero-Brugués et al. 2021). The present study focuses on the materials from La Draga, and their description is given below. In addition, some other remains had been recovered in specific scattered archaeological sites in the Iberian Peninsula. In chronological order, the archaeological site of Cueva de Los Murciélagos (Granada, Spain; 5200-4600 cal BC) should also be mentioned. In this case, the materials are preserved by dehydration and consist of an extended collection of organic objects, both fibre and wooden based. Regarding the cordage materials, there were ropes themselves, but also parts of sandals made of esparto grass (Alfaro-Giner 1980; 1984; Cacho et al. 1996). Late Neolithic-Chalcolithic esparto grass ropes were also recovered in some archaeological sites in southern Spain, where the preservation was basically by carbonization. Some of these remains were found in the archaeological sites of Campos (Almería), Cueva Sagrada (Murcia) (Papí Rodes 1992-1994), Cueva de Nerja (Málaga), and Sima de la Curra (Málaga) (Jordà Cerdà et al. 1983), among others.

Although esparto grass was extensively used in southern and eastern Iberia, a greater diversity of raw materials has been documented in the north. An example is the Cueva del Moro site (Huesca; 1530-1423 cal BC) where an indeterminate monocot and willow were identified in fibre-based objects (Alcolea and Rodanés 2019). Previous studies of La Draga site have documented a wide variety of manufacturing techniques among the cordage remains (Piqué et al. 2018, Herrero-Otal et al. 2021; Romero-Brugués 2021). Despite the huge diversity of vegetal taxa identified in palynological (Revelles et al. 2014; 2015; Revelles and van Geel 2016), anthracological (Caruso-Fermé and Piqué 2014), and carpological studies (Antolín 2013) and the analysis of wooden objects (López-Bultó and Piqué 2018), monocot and dicot families were determined as raw materials for fibre-based cords and baskets (Piqué et al. 2018, Herrero-Otal et al. 2021). Plant availability may be an important factor for taxa selection but the use of specific families with mechanical and physical properties may bear on the technique used in production.

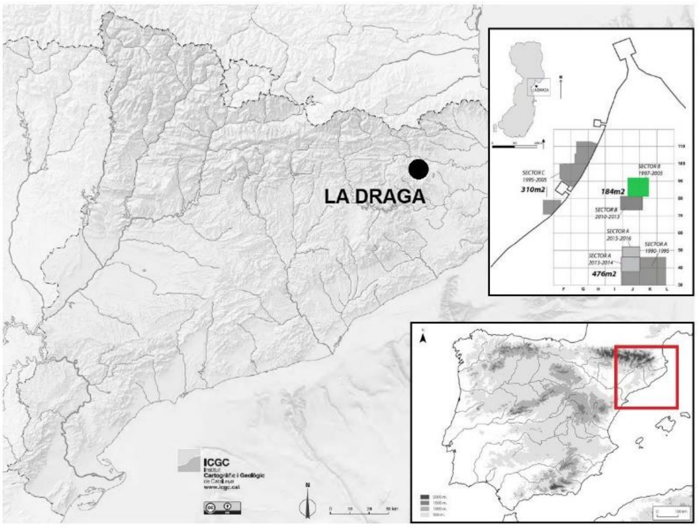

Figure 1. Location of La Draga archaeological site in the North-East of the Iberian Peninsula. Details of the excavation sectors, Sector B is highlighted in green.

In this work, we present the results of the systematic identification of raw materials used for cord production in La Draga, as well as an experimental reproduction of these cords considering both their use and properties. Through an experimental approach to the manufacturing processes, we aim to understand how raw materials were acquired and transformed to produce the ropes at the La Draga site in the Neolithic, and how the properties of raw materials or cultural preferences were considered in obtaining determined typology of objects. This study will therefore infer the raw material selection for producing different types of cords, previously documented in La Draga, as well as the importance of raw material and group standards involved in resultant cords.

Materials.

The archaeological site of La Draga is located on the eastern shore of Lake Banyoles at 172 m.a.s.l. in northeastern Iberia (Banyoles, Girona, Spain). It has been excavated for more than thirty years and it is considered the only evidence of a Neolithic Lake dwelling in the Iberian Peninsula (Palomo et al. 2014; Terradas et al. 2017). Two occupations are detected at the site: the first one dated in 5309-5247 cal BC related to the use of wooden platforms and their successive repairs, and a second occupation associated with pavements formed by travertine slabs dated in 5207-4862 cal BC (Andreaki et al. 2022). Although it is suggested that the real site covers an area of about 15,000 m2, 1000 m2 have been excavated and three different sectors have been identified. Sector A is found above the water table and organic materials are only preserved when they are charred, Sector B/D is located in the water table, and Sector C is currently under water but was exposed in prehistoric times. Sectors B/D and C have preserved organic materials because of the anaerobic conditions (Figure 1).

The cordage set analyzed in this study was recovered in the archaeological fieldwork from 1998 to 2005 in Sector B, where organic remains were conserved by waterlogged conditions. The remains were recovered directly in the field or in the later wet-sieving, then cleaned and restored by the method of freeze-drying (Piqué et al. 2014).

Figure 2. Cordage remains from La Draga: a) roll of S z,z twisted cord (reg. D04 JI92-9); b, c) S z,z twisted cords (regs. D05 JJ92-16 and D05 R-8); d) S z,z twisted cord (reg. D02 KA88-14); f) braided cord (reg. D98 JF86-13); e) Z s,s,s twisted cord (reg. D01 KA87-27) (modified from Piqué et al. 2018).

The cords were previously technologically analysed and an approach to the raw material used was carried out for a few of the remains (Piqué et al. 2018). The total sample has 75 remains, including twisted and braided cord, two single fibres, a knot and three non-processed rolls of liana (Figure 2). Considering similarities between the individual fragments (morphology and technology) and location in the site, several associations were made, resulting in 22 different registers. Each register corresponds to either a single cord element or a group of fragments of similar characteristics associated. Although small strand fragments may be detached from the larger ones, it was not always possible to relate them to specific cord element. Even in the fragmentary state of conservation, several morphological and technical features of the remains could be observed and measurements were taken (cord and strand size and angle of torsion) to describe the process of cord production and associations between fragments. The results of this study revealed that most of the cords from La Draga were made by twisting, and the dominant pattern was S (S z,z), but also the Z pattern (Z s,s,s) was recorded, as well as a single case of braided cord (Romero-Brugués 2022). The authors also worked on the raw materials used in four of the registers (references D01 JJ87-22, D02 JI88-15, D04 JF72-1, and D04 JI92-9) using an optical and electronic microscope. They identified the use of bast stem fibres, lime tree bark fibres (Tilia sp.), and Clematis sp. corresponding to a roll of liana, which was not included in the current study (Piqué et al. 2018).

Methods.

Twenty-two samples of each reference number corresponding to the cords set from La Draga were taken and analysed in this study. Sampling archaeological materials is a destructive process, but the current technologies need samples for analyses. However, due to the fragility of the materials studied in this paper, it was possible to use fragments detached from the materials during the excavation and conservation processes, or even during their storage, so no further damage was caused to the archaeological objects. Besides, only small fragments are needed for this study.

Although the restoration processes add rigidity to the objects, they change the properties of the organic remains and hamper the sampling and the anatomical analysis of the fibres. For this reason, it is preferable to sample the objects before the application of consolidants. The cordage remains from La Draga were excavated many years ago and were consolidated after the excavation; for this reason, sampling for this study was carried out on restored material. Even though Polyethylene Glycol (PEG) treatment was used, a dry cutting method breaking the samples by hand or with a razor blade offered quality surfaces to be observed microscopically both optically (OM) and by scanning electron microscope (SEM) to obtain better-quality images. In this sense, transversal and longitudinal surfaces of the samples were used for identifying the raw materials used. The OM analyses were performed using a reflected optical microscope for the opaque samples, and a transmitted light microscope for samples mounted in slides, at the Archaeobotanical Laboratory of the Department of Prehistory at the Universitat Autònoma de Barcelona (UAB). Olympus BX51 and Olympus BX43 microscopes coupled with an Olympus DP26 camera and linked to Olympus cellSens software were used. The SEM analysis was conducted at the Microscopy Services in the same university. The samples were mounted on stubs using double-sided carbon tape and coated with a 15 nm layer of gold using an Emitech K550 Sputter Coater Unit and were examined using a Zeiss EVO® MA 10 SEM.

Vegetal identifications were based on anatomical and histological descriptions of the archaeological samples compared with contemporary species identified around the site by other archaeobotanical and ecological studies. This also implies the use of a local and specific reference collection of modern plants, the consideration of historical and popular knowledge, and the use of specific microanatomical atlases of plant histology and physiology, and other accessible reference collections.

Experimental archaeology is a basic methodological tool that enables quantitative and qualitative variables to be recorded and provides empirical data. It has an important role in understanding the technological parameters involved in the diversity of activities and makes it possible to connect the past and the present. The research group working on La Draga site has a long tradition and expertise of working on experimental archaeology regarding the materials recovered on the site (Palomo 2012; Palomo et al. 2021). The experimentation followed in this paper was focused on testing the ways that archaeological materials were produced and assessing the function of the tools. In this sense, ethnography is essential to formulate a hypothesis of the ways of production and functionality of cordage. Regarding vegetal fibre use, experimental archaeology includes the raw material selection, the preparation of the fibres and, the production of the final objects, as well as the use of other elements. The diversity of production processes followed by each artisan, who may not use the same tools, techniques and materials, is quite challenging for applying experimentation. In the current paper, an experimental approach was applied to reproduce the fabrication of the cords, measuring different aspects such as the raw material, the replicated product (measurements and twist typology), the time devoted to their production, the tools needed, and the number of people necessary to produce the cord.

Results.

Raw material identification.

Regarding the 22 samples, 18 were identified as dicotyledon families, and in a single case, both types (dicotyledon and monocotyledon) were used. Features were not clearly visible to identify 3 of the remains (Table 1). Two types of dicot fibres were identified in cordage production in La Draga. Tree bark strips were identified in 16 remains, whereas bast fibres were identified in 2 of the remains.

Through OM, the second phloem is visible in the transversal section of bark strips. Alternate layers of fibres with the sieve tubes and parenchymatic tissue with expanding cells are visible (Figure 3a). The longitudinal section permits the observation of different rays immersed in the parenchyma tissue (Figure 3b). Figures 3c and 3d show the same features but observed in an electron microscope. The features observed are similar to those lime tree fibres (Tilia sp.) The only monocot identified in the current study was identified by the isolated vascular bundles visible in the transversal section of the sample (Figure 3e). It corresponds to a leaf of Poaceae, which is also confirmed on its surface where round epidermal cells are visible (Figure 3f).

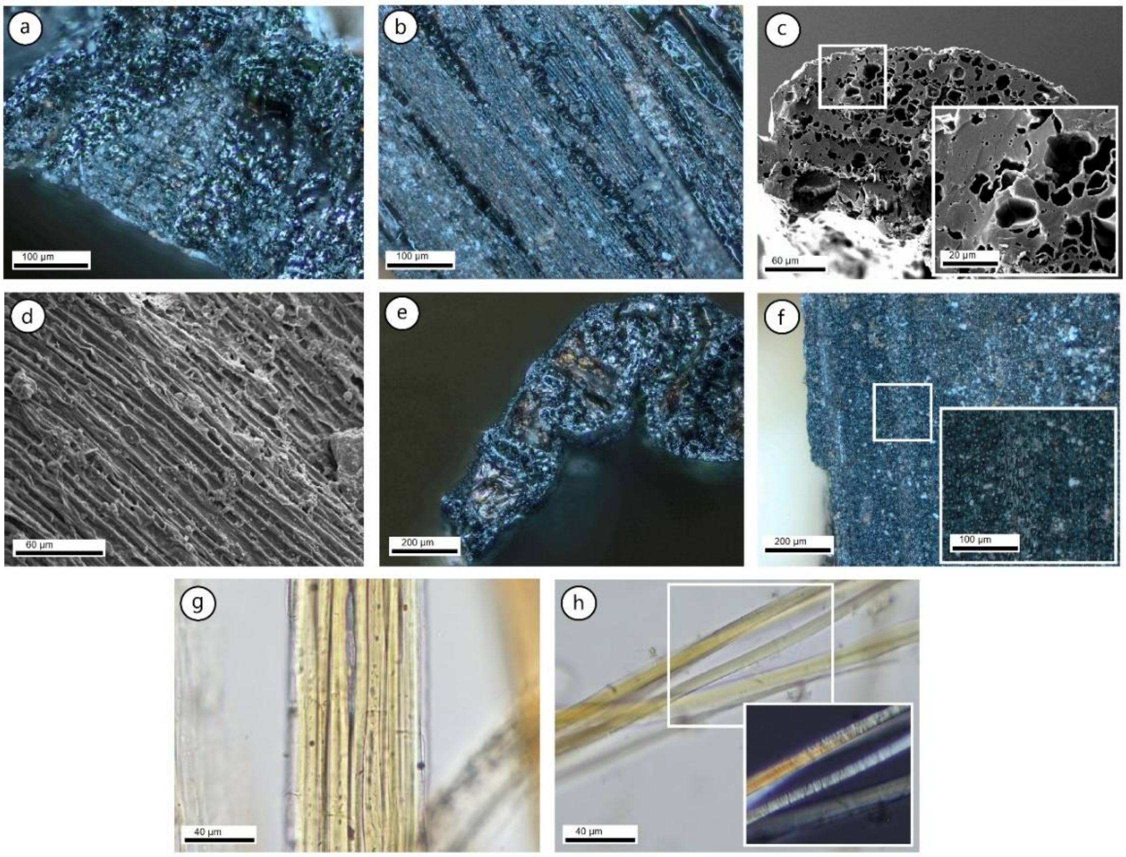

Figure 3. Archaeological samples from La Draga: a, b) transversal and longitudinal view of Tilia sp. bark with OM; c, d) transversal and longitudinal view of Tilia sp. bark with SEM; e, f) probably *Urtica* sp. fibres with OM and polarised the light; g, h) transversal and epidermal view of a Poaceae leaf with OM.

In two cases, bast fibres were identified. They present long and thin fibres with cross-sections inside (Figure 3g). These cross marks are easier to observe under polarization (Figure 3h). These are distinctive features of bast fibres: the fibrous material from the stem of dicotyledons such as flax (*Linum* sp.), hemp (*Cannabis sativa*), nettle (*Urtica* sp.), jute (*Corchorus capsularis*) and ramie (*Boehmeria nivea*), among others. Some of these species are out of the context studied in the present paper, so they have not been taken into consideration. In this sense, hemp, flax, and nettle are difficult to distinguish because of their similarity in appearance, but several researchers have focused their studies on bast fibres differentiation (Bergfjord and Holst 2010; Haugan and Holst 2014; Lukešová et al.

2017; Suomela et al. 2017; among others). Regarding the materials in this study, one of the remains (D02 JI88-15) was identified as bast fibre in previous studies (Piqué et al. 2018), but no more information could be described. Even so, visible features in fibres from sample D04 JI92-9, such as the cross marks, their measurements, and the direction of the microfibrillar structure, suggest this remain was made of nettle.

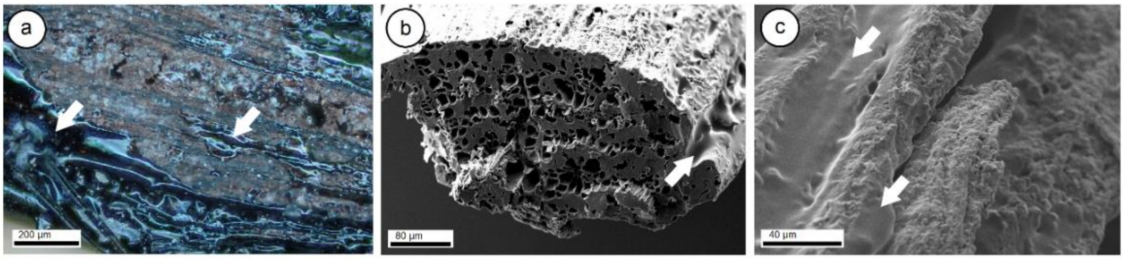

Figure 4. Microscopy images showing consolidants affectating the observation of the samples. Arrows show where the products are present: a) OM; b, c) SEM.

Unfortunately, anatomical features were not clearly visible to identify three of the samples. This may be related to taphonomic processes which acted on the materials for thousands of years, as well as the consolidation processes they were subjected to. As mentioned above, sampling the materials before the restoration processes is essential for the following analyses, and this should be highlighted. The use of consolidants, such as PEG or Paraloid®, makes the identification more difficult. They affect the surface of the samples and produce a bright layer hiding anatomical features which must be visible for the identification of raw materials (Figure 4).

<u>Experimental cordage production with the bark of Tilia sp.</u>

Since most of the cords from La Draga were made using lime tree bark, we selected this raw material for the experimental approach. Tilia cordata was used because it is the lime tree species available in the surroundings of the site. The experimentation consisted in producing a 2-ply cord with S-twist (two-strand cord S z,z) which is represented in almost four individualized cords from the site. Characteristics of remain D02 KA88-14 were the ones replicated during the experimental approach. It presents a Z-spun twisting of each strand, and a final S-twist, 5 mm thickness and 3 twists per centimetre (approximately). A rope-making tool, similar to the bone tools recovered at the site, was used for the production process. This is a fragment of a cow long-bone shaft with two holes. Use-wear analysis on it has been carried out and is part of another research line and will not be developed in the current paper.

The raw material used in the experimentation was gathered during the early summer (month of June) from branches of Tilia cordata tree. The bark was stored and let dry until the cord was produced during the month of September. The raw material was submerged in water for approximately 12 hours until it was soft enough to be manipulated. A piece of 130x4 cm of bark was stripped into thin threads by the hand and by using a sharp tool which allowed to obtain thinner strips (Figure 5a, 5b). The preparation of the threads involved four people. Finally, the strips obtained were used to produce an S z,z cord with a rope-making tool, which needed the participation of three people. Two of them carried out the manual twisting of each strand (Z-spun) while the third person made, at the same time, the torsion of the two strands creating the cord (S-twist) (Figure 5c). The function of the holed tool was to tighten the cord after each twisting movement which helps in the final cord production.

Figure 5. Experimental approach: a) wide strips of lime tree bark; b) lime tree bark after stripping; c) S z,z cord making with a rope-twisting tool ; d, e) the final rope.

The resultant cord measured 6 m long and 6-7 mm thick (Figure 5d, 5e). The cord production lasted approximately an hour and a half from the very beginning of stripping the fibres in small units. This first part was about 25 minutes, and one hour to twist 6 m of cord.

Discussion.

<u>The raw materials.</u>

The palaeoenvironment at La Draga is one of the best-known in the Iberian Peninsula because of the preservation of organic materials at the site. The identification of plants used for craft productions provides new data about the past landscape and complements previous archaeobotanical studies. The vegetal species identified in the current study are compatible with the results of previous data regarding the past vegetation that surrounded the settlement and the evidence of plant use for fibre-based craft production by the population of the site.

Regarding the use of lime tree bark, its regional availability was detected by palynological (Revelles et al. 2014; 2015; Revelles and van Geel 2016) and carpological (Antolín and Buxó 2011) studies at the site. Moreover, the study of the baskets found in the site in very similar conditions to the materials analyzed in this paper also detected the use of lime tree bark for stitching three of the eight identified coiled baskets (Herrero-Otal et al. 2021). In addition, an unshaped fragment of wood of *Tilia* sp. was also identified. Thus, the archaeobotanical data confirms the availability of *Tilia* sp. in the settlement surroundings during the Neolithic. Today, the lime tree family is represented by *Tilia platyphyllos* and *Tilia cordata* in the proximities of Lake Banyoles. The fact that lime tree bark appear in a large part among the fibre-based crafts suggests a selection and particular use of this natural resource in the archaeological site of La Draga.

Due to the volume, strength, and pliability of its fibres, lime has been one of the most important material sources in Europe. The selection of this material has been usually determined by practical factors such as suitability and availability similar to other plants like oak (*Quercus* sp.), juniper (*Juniperus* sp.), and willow, which have also been used since antiquity. The use of lime as fibres supplier has been detected in several locations since Mesolithic chronologies as in the Antrea site (Finland, 8400-8300 cal BC), where net fragments made with twisted cords and other typologies were found (Bender Jørgensen 1992; Miettinen et al. 2008; Wigforss 2014). Similar examples of twisted cords forming fishing nets and braided cords were recovered in the Friesack-4 site (Germany, 7700 BC) (Gramsch 1992) made with the same material, or the fishing nets and string at the site of Zamostje-2 (Russia, 7000-5400 cal BC) made of dicot families (Berihuete-Azorín et al. 2023). Nonetheless, some of the elements found in these two sites have also been identified as the bark of other trees, such as willow, or bast fibres like nettle. Examples of twisted cords made with lime fibres are those S-twisted from Wetzikon-Robenhausen (Switzerland, 3700-3300 BC), the Z-twisted from Arbon Bleiche (Switzerland, 3385-3370 BC) (Altorfer and Médard 2000), and the ones associated with the Tisenjoch Iceman (Junkmanns 2019).

Considering that bast fibre use is well documented since Palaeolithic chronologies, flax is not documented until the second half of the 6th millennium cal BC in the Iberian Peninsula (Peña-Chocarro 1999; Pérez-Jordà and Carrión-Marco 2011; Rovira 2007; Stika 2005); thus there was no evidence of flax cultivation in La Draga. Regarding the use of bast fibres in La Draga, nettle was available in the palaeoenvironment around the site (Antolín 2013; Antolín and Buxó 2011). There are different ways to obtain the fibres from stems of plants. The traditional way of extraction may differ depending on the specialization of the artisans. However, they are similar and consist of harvesting them manually and defoliating the stems (by dehydration or by hand), which makes the stem touchable and workable. But the material can be rinsed and ret for the same purpose. Then, the fibres can be manually extracted by breaking the bark parts from the stem by barking with different objects such as a wooden mallet and schutching the fibres. The resultant soft and resistant fibres are ready to be used for making different objects (Andersson Strand 2012; Viotti et al. 2022).

Although we have no archaeological evidence, ethnographical and experimental data reveal that raw materials used for crafting with fibres can be dried from harvesting to the moment of manufacturing the objects. This is a way to prevent materials from shrinking as they dry out, avoid loss of quality, and facilitate their handling. This dehydration of the materials means that the time of harvesting and procurement of the material is not necessarily related to the moment when the implements are manufactured. The bark strips can be stored for long periods, and just need to be slightly rehydrated before manufacture. This allows a delay in manufacturing the implements, after harvesting and gathering the plants when they have reached the optimal quality (Wendrich and Ryan 2012).

The availability of raw materials in the immediacies of the site and the functional analysis of objects found suggest a local production fibre crafting in La Draga. Use-wear studies detected that awls, needles, spindles and combs were used for processing fibres in La Draga (De Diego et al. 2017; 2018, De Diego 2023), and *Mytilus galloprovincialis* seemed to be used for similar purposes (Clemente and Cuenca 2011), as well as some other lithic pieces (Gibaja 2011). Moreover, several bone tools recovered at the site could act as thread tensioners. They are fragments of bone shafts with two holes similar to those used in our experimentation.

The twisting technique is predominant in the cordage set from La Draga, where a single piece of braided cord was recorded. Moreover, S-twist is more common than Z-twist (Piqué et al. 2018, Romero-Brugués 2021). S z,z is the predominant twisting pattern and lime is used in most of the cords examples from La Draga. The only cord that does not present this pattern is the only 3-ply cord with Z s,s,s torsion. There are no differences between S-twist and Z-twist cords regarding their size and type. Table 1 shows the non-selection of the raw materials used for each type of cord, either two or three strands, twisted or braided. Lime tree seems to be used indistinctively regarding the typology of the technologies used for cords and their thickness. Lime was the main raw material and the most versatile according to the variability of cords made with this material.

Although the presence of a preferable torsion pattern could be related to the raw material used in cord production and the direction the fibres adopt when they are twisted, several researchers demonstrated ropes twist direction is directly related to cultural influence (Carr and Maslowski 1995; Johnson and Speedy 1992; Petersen and Wolford 2000). As an example, Minar (2001) demonstrated a wide range of factors are involved in the final cord considering cultural material factors as learning processes, so the transmission of specific attributes. Three different hypotheses to explain the final direction of twist in cordage remains from the Alachua culture (north-central Florida). These scenarios consider the spinning method, the type of fibre, and the handedness. After the pertinent observations, the three scenarios were rejected, and the study concluded with the premise that it exists a preferable twisting related to community practice and learning processes within a community related to a common learning origin in the different individuals. Thus, cordage production processes may be conservative within a group because of cultural preferences (Minar 2001). We assumed this is what happened in La Draga. There should be culturally preferred standards that made most of the cords of the site were made with the same technique and pattern.

Table 1. Cords typology and raw material used.

Register	Typology (Piqué et al. 2018)	Technology	Raw material	
D98 JF83-4	-	-	Dicotyledon	*Tilia* sp.
D98 JF86-13	Cord	Braided	Dicotyledon	*Tilia* sp.
D98 JG85-29	-	-	Non-identified	Non-identified
D01 JJ87-22	String	S	Dicotyledon*	*Tilia* sp.*
D01 JJ87-7	String	Z and S	Dicotyledon	*Tilia* sp.
D01 KA87-13	String	S	Dicotyledon	*Tilia* sp.
D01 KA87-22	String	S	Dicotyledon	*Tilia* sp.
D01 KA87-27	Cord String	Z s,s,s S	Dicotyledon Dicotyledon	*Tilia* sp. *Tilia* sp.
D01 KA87-32	-	-	Non-identified	Non-identified
D01 KB87-15	String S	S	Dicotyledon	*Tilia* sp.
D02 JI88-15	Fibre	-	Dicotyledon*	Bast fibre*
D02 KA88-14	Cord	S z,z	Dicotyledon	*Tilia* sp.
D02 KA88-15	String	S	Dicotyledon	*Tilia* sp.
D02 KA89-21	String	S	Dicotyledon	*Tilia* sp.
D02 KA89-5	String	S	Dicotyledon	*Tilia* sp.
D02 KA89-8	String	S	Non-identified	Non-identified
D02 KB90-7	String	S	Dicotyledon	*Tilia* sp.
D03 JH85-6	String	S	Dicotyledon Monocotyledon	*Tilia* sp. Poaceae
D04 JI92-9	Roll of cord Knot	S z,z -	Dicotyledon* -	Probably *Urtica* sp.* -
D05 JJ92-16	Cord	S z,z	Dicotyledon	*Tilia* sp.

*Samples identified in Piqué et al. 2018

The single object which presents a different raw material, probably *Urtica* sp., is the case of the roll of cord which had been related to a bowstring function. This register was found near three fragments of bows on the site, and although it was not tied to the wooden weapon, authors suggested it could be used as a bowstring (Piqué et al. 2015; 2018). The measurements of the length and thickness enhance this possibility, as well as its similarity to the twisted bowstring of the Tisenjoch Iceman, although it was made of different raw materials. The use of nettle has been documented in other Neolithic contexts, like the Sweet Track site (England; 4000-3500 BC), where nettle was used without much pre-treatment (Edom 2019).

<u>Cord production.</u>

The experimental approach to cord production allowed us to determine the amount of raw material needed to produce the cord, the time involved in the different steps, and the technique needed to obtain a cord with homogeneous thickness.

The acquisition of strips from lime tree is complex (Médard 2008; Myking et al. 2005). It generally consists of cutting the branches in the spring or early summer, when the tree has reached its maturity, leaves have grown to full size and the bark is easily removable thanks to the sap which has risen. The material is usually obtained from young lime trees or new straight shots resulting in thicker branches of old pollarded or coppiced trees because this influences the fibres quality. The bark is stripped or removed from the wood and submerged in freshwater or seawater for several weeks for retting: soaking to make it softer by bacterial decay and pectin and lignin degradation. This induces the natural fibres separation in layers. Nevertheless, some experimental archaeology works suggest the use of inner bark without retting for craft purposes.

There is no evidence for the bark strip acquisition process in La Draga, where only final products have been recovered. The absence of *Tilia* sp. in the charcoal remains and its scarce presence among the wooden remains suggest that inhabitants from of La Draga transported just the strips to the site. Even so, stored bark strips have not been found at La Draga.

The results of our experimentation demonstrate the amount of raw material needed and the time invested in producing a S z,z cord 6 meters long. A piece of lime bark130x4 cm in size was necessary, previously immersed in water. In this way, the preparation of the threads can be done easily by hand, although the use of a sharp tool can help to obtain thinner threads. The use of the bone rope-making tool for tightening the cord allowed us to obtain a homogeneous thickness and maintain the torsion angle and rigidity. Similar items are known since Palaeolithic chronologies, such as the one found in a cave in Swabian Jura in Germany (Conard and Malina 2016).

Although a cord can be made by a single person, the use of this sort of tool required the cooperation of three people, but less time is consumed. The presence of a perforated diaphysis at La Draga, suggests that cord production could have been carried out with this item. This hypothesis is confirmed by use-wear observed on the tools, demonstrating their efficiency (De Diego 2023). The time required to produce a cord from the very beginning of the process (excluding the acquisition of fibres), was approximately an hour and a half. However, three or four people were involved in the process.

Conclusions.

The Early Neolithic site of La Draga, an archaeological settlement in the Iberian Peninsula, has provided one of the oldest fibre-based assemblages thanks to the preservation conditions at the site. The raw material used for cordage production has been identified systematically here. The importance of sampling the vegetal-based materials after their recovery and before their consolidation should be emphasised, to improve and facilitate the identification of their nature, as well as the performance of other studies.

The results showed an almost total selection of lime bark (*Tilia* sp.) and nettle stem fibre (*Urtica* sp.) to produce different types of cords, both twisted and braided. In a single case, a fragment of Poaceae was detected but it seems to be a fortuitous case. Previous archaeobotanical studies have identified the presence of these plants in the immediacies of Lake Banyoles in Neolithic chronology, so they were available raw materials from the surroundings of the site. This, together with other use-wear analysis, suggests a local production of the cords in La Draga. Cultural standards related to traditional or common learning processes should be involved in a predominant S-twist typology of cord examples.

Moreover, contextualization with other Neolithic cord remains, which is limited by the scarcity of known examples, shows that the variability in the materials is similar to that at other sites in Europe, but different from southern latitudes, as it also occurs with basketry remains. Regarding the functionality of the cords in relation to the raw material used, no specific pattern was detected, except for the use of nettle to make what is considered a bowstring.

The experimental approach was performed to replicate the elaboration of cords regarding the raw material selection, their processing and the final cord production. This aimed to replicate cord-making at La Draga by measuring such aspects as the time consumed, the tools needed, and the number of people necessary to produce a cord, among others. These experimental programmes may help to understand crafts production processes which took place in the past and give us an overview about which aspects may be considered.

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References.

Alcolea, M., Rodanés, JM. (2019) Ephemeral Archaeology South of the Central Pyrenees (Huesca, NE Iberia): The Exceptional Preservation of Woody Objects in Moro de Alins Cave-site. Environ Archaeol, DOI: 10.1080/14614103.2019.1654642.

Alfaro Giner, C. (1980) Estudio de los materiales de cestería procedentes de la cueva de los Murciélagos (Albuñol, Granada). Trabajos de Prehistoria 37:109-139.

Alfaro Giner, C. (1984) Tejido y cestería en la Península Ibérica. Historia de su técnica e industrias desde la prehistoria hasta, la romanización. Bibliotheca Praehistorica Hispana 21. CSIC Instituto Español de Prehistoria, Madrid.

Altorfer, K., Médard, F. (2000) Nouvelles découvertes textiles sur le site de Wetzickon-Robenhausen (Zürich, Suisse). Sondages 1999. Montagnac. Mergoil, 35-75.

Andersson Strand, E. (2012) The textile chaîne opératoire: Using a multidisciplinary approach to textile archaeology with a focus on the Ancient Near East. Paléorient, 38-1-1: 21-40. DOI: 10.3406/paleo.2012.5456

Andreaki, V., Barceló, JA., Antolín, F., Gassman, P., Hajdas, I., López-Bultó, O., Martínez-Grau, H., Morera, N., Palomo, A., Piqué, R., Revelles, J., Rosillo, R., Terradas, X. (2022) Absolute chronology at the waterlogged site of La Draga (Lake Banyoles, NE Iberia): Bayesian chronological models integrating tree-ring measurement, radiocarbon dates and microstratigraphical data. Radiocarbon: 1-42. DOI: 10.1017/RDC.2022.56

Antolín, F. (2013) Of cereals, poppy, acorns and hazelnuts. Plant economy among early farmers (5500-2300 cal BC) in the NE of the Iberian Peninsula. An archaeobotanical approach. PhD Dissertation. Barcelona, Universitat Autònoma de Barcelona.

Antolín, F., Buxó, R. (2011) L'explotació de les plantes al jaciment de La Draga: contribució a la historia de l'agricultura i de l'alimentació de l'agricultura i de l'alimentació vegetal del Neolític a Catalunya. In: Bosch A, Chinchilla J, Tarrús J (eds) El poblat lacustre del Neolític Antic de La Draga: Excavacions de 2005-2005. CASC Museu d'Arqueologia de Catalunya, Girona: 147-174.

Aura Tortosa, JE., Pérez-Jordà, G., Carrión Micó, Y., Seguí Seguí, JR., Jordá Pardo, JF., Miret i Estruch, C., Verdasco Cebrián, CC. (2019) Cordage, basketry and containers at the Pleistocene–Holocene boundary in southwest Europe. Evidence from Coves de Santa Maira (Valencian region, Spain). Veg Hist Archaeobot, 29, 581-594. DOI: 10.1007/s00334-019-00758-x

Barber, EW. (1994) Women's work: the first 20.000 years. Women, cloth and society in early times. Norton & Company, New York.

Bazzanella, M. (2012) Italy: Bronze Age. In Gleba, M., Mannering, U. (eds). Textiles and Textile Production in Europe. From Prehistory to AD 400. Ancient Textiles Series 11. Oxford. Oakville: 203-214.

Bender Jørgensen, L. (1992) North European textiles until AD 1000. Aarhus: Aarhus University Press. ISBN: 87-72888-416-9.

Bergfjord, C., Holst, B. (2010) A procedure for identifying textile bast fibres using microscopy: Flax, nettle/ramie, hemp and jute. Ultramicroscopy, 110(9): 1192-1197. DOI: 10.1016/j.ultramic.2010.04.014

Berihuete-Azorín, M., Lozovskaya, O., Herrero-Otal, M., Piqué i Huerta, R. (2023) Fishing nets and strign at the Final Mesolithic and Early Neolithic Site of Zamostje 2, Sergiev Posad (Russia). Open Archaeology, 9(1): 20220283. DOI: 10.1515/opar-2022-0283.

Cacho, C., Papí, C., Sánchez-Barriga, A., Alonso, F. (1996) La cestería decorada de la Cueva de Los Murciélagos (Albuñol, Granada). Complutum 6(1), 105-122.

Carr, C. Maslowski, RF. (1995) Cordage and fabrics: relating form, technology and social processes. In Carr, C., Neitzel, J. E. (eds.). Style, society and person. Archaeological and Ethnological perspectives. Plenum Press, Nova York: 297-343.

Caruso-Fermé, L., Piqué, R. (2014) Landscape and forest exploitation at the ancient Neolithic site of La Draga (Banyoles, Spain). Holocene, 24(3): 266-273. DOI: 10.1177/0959683613517400

Clemente, I., Cuenca, D. (2011) Instrumentos de trabajo de concha en el yacimiento neolítico de La Draga. In Bosch, A.; Chinchilla, J., Tarrús, J. (coords.) El poblat lacustre del neolíticantic de La Draga. Les campanyes dels anys 2000-2005. Museud'Arqueologia de Catalunya-CASC (Monografies del CASC, 9): 137-145.

Conard, NJ., Malina, M. (2016) Außergewöhnlicheneue Funde aus den aurignacienzeitlichen Schichtenvom Hohle Felsbei Schelklingen. Archäologische Ausgrabungen Baden-Württemberg, 2015: 60-66.

De Diego, M. (2023) Tecnología textil y del trabajo de la piel en el Neolítico Antiguo de La Draga, Banyoles (España) (5.300-4.900 cal BC). Aproximación funcional y experimental a los instrumentos óseos y de madera. PhD Dissertation. Barcelona, Universitat Autònoma de Barcelona.

De Diego, M., Piqué, R., Palomo, A., Terradas, X., Clemente, I., Mozota, M. (2017) Traces of textile technology in the Early Neolithic lakeside settlement of La Draga (Banyoles, Catalonia) from an experimental perspective. In

Universidad Autónoma de Madrid (ed). Playing with the time. Experimental archaeology and the study of the past: 139-144.

De Diego, M., Piqué, R., Palomo, A., Terradas, X., Saña, M., Clemente, I., Mazota, M. (2018) Evidence of textile technology in the Early Neolithic site of La Draga (Banyoles, Spain). Some hypotheses. In First Textiles. The beginnings of textile manufacture in Europe and the Mediterranean: 69-80. ISBN: 978-1-78570-798-8

Edom, G. (2019) From Sting to Spin: A History of Nettle Fibre. Urtica Books

Evert RF (2006) Esau's plant anatomy: meristems, cells and tissues of the plant body: their structure, function, and development, 3rdedn. Wiley, Hoboken.

Gibaja, JF. (2011) La función de los instrumentos líticos tallados. In Bosch, A., Chinchilla, J. and Tarrús, J. (coord.). El poblat lacustre del neolític antic de La Draga: excavacions 2000-2005, Monografies del CASC, vol. 9, Girona: 91-100.

Gramsch, B. (1992). Friesack Mesolithic wetlands. In Coles, B. (Ed) The Wetland revolution in prehistory: proceedings of a conference held by the Prehistoric Society and WARP at the University of Exeter. London, 65-72.

Hardy, K. (2008) Prehistoric String Theory. How Twisted Fibers Helped to Shape the World. Antiquity 82 (316): 271–280. DOI: 10.1017/S0003598X00096794

Haugan, E., Holst, B. (2014) Flax look-alikes: pitfalls of ancient plant fibre identification. Archaeometry, 56(6):951-960. DOI: 10.1111/arcm.12054

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R. (2021) Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula. Vegetation History and Archaeobotany. DOI: 10.1007/s00334-021-00826-1

Hurcombe, LM. (2014) Perishable material culture in Prehistory. Investigating the missing majority. Routledge, London.

Johnson, WC., Speedy, DC. (1992) Cultural continuity and Change in Middle and Lade Woodlant Periods in the Upper James Estuary, Prince George County, Virginia. Journal of Middle Atlantic Archaeology, 8:91-106.

Jordà Cerdà, F., Jordá Pardo, J., González-Tablas, F J., Aura, JE., Sanchidrián, JL. (1983) La cueva de Nerja. Revista de Arqueología, 29: 58-65.

Junkmanns, J., Klügl, J., Schoch, W., Di Pietro, G., Hafner, A. (2019) Neolithic and Bronze Age archery equipment from Alpine Ice-Patches: a review on components, construction techniques and functionality. Journal of Neolithic Archaeology 283-314. DOI: 10.12766/jna.2019.10

Kvavadze, E., Bar-Yosef, O., Belfer-Cohen, A., Boaretto, E., Jakeli, N., Matskevich, Z., Meshveliani, T. (2009) 30 000-year-old wild flax fibers. Science 325 (5946), 1359. DOI: 10.1126/science.1175404

López-Bultó, O., Piqué, R. (2018) Wood Procurement at the Early Neolithic site of La Draga (Banyoles, Barcelona). J Wet Archaeol. DOI: 10.1080/14732971.2018.1466415

Lukešová, H., Salvador Palau, A., Holst, B. (2017) Identifying plant fibre textiles from Norwegian Merovingian Period and Viking Age graves: The Late Iron Age Collection of the University Museum of Bergen. Journal of Archaeological Science: Reports, 13: 281-285. DOI: 10.1016/j.jasrep.2017.03.051

Médard, F. (2003) Vestiges textiles et activités de filage sur le site néolithique d'Arbon-Bleiche 3 (TG Suisse), Bull Soc préhistfr, vol. 100(2): 375-391. DOI: 10.3406/bspf.2003.12874

Médard, F. (2008) L'acquisition des matières textiles d'origine végétale en préhistoire. L'apport des données expérimentales et ethnographiques. Les nouvelles de l'archéologie. DOI: 10.4000/nda.602

Miettinen, A., Sarmaja-Korjonen, K., Sonninen, E., Junger, H., Lempiäinen, T., Ylikoski, K., Mäkiaho, JP., Carpelan, C., Jungner, H. (2008) The palaeoenvironment of the Antrea Net Find. Karelian Isthmus. Finnish Antiquarian Society, 16: 71-87.

Minar, CJ. (2001) Motor Skills and the Learning Process: The Conservation of Cordage Final Twist Direction in Communities of Practice. Journal of Anthropological Research, 57:4.

Mineo, M., Mazzuco, N., Rottoli, M., Remolins, G., Caruso-Fermé, L., Gibaja, J.F. (2023) Textiles, basketry and cordage from the Early Neolithic settlement of La Marmotta, Lazio. Antiquity, 1-17. DOI: 10.15184/aqy.2023.21.

Myking, T., Hertzberg, A., Skrøppa, T. (2005) History, manufacture and properties of lime bast cordage in northern Europe. Forestry, 78(1). DOI:10.1093/forestry/cpi006

Nadel, D., Danin, A., Werker, E., Schick, T., Kislev, ME., Stewart, K. (1994) 19000 year old twisted fibers from Ohalo II. Current Anthropology 35:4, 51-458. DOI: 10.1086/204303

Palomo, A. (2012) Tecnologia lítica i de la fusta de la prehistòria recent al nord-est peninsular. Anàlisi tecnomorfològica i experimental. PhD Dissertation. Barcelona, Universitat Autònoma de Barcelona.

Palomo, A., Piqué, R., Terradas, X., Bosch, A., Buxó, R., Chinchilla, J., Saña, M., Tarrús, J. (2014) Prehistoric occupation of Banyoles lakeshore: results of recent excavations at La Draga site, Girona, Spain. J Wetl. Archaeol, 14, 58-73. DOI: 10.1179/1473297114Z.00000000010

Palomo, A., Terradas-Batlle, X., Piqué, R., López-Bultó, O., De Diego, M., Clemente-Conte, I. (2021) Experimentación en torno al proyecto de investigación sobre el yacimiento neolítico de la Draga (Banyoles-Girona). Boletín de Arqueología Experimental, 14: 85-101. DOI: 10.15366/baexuam2020.14.005

Papí Rodes, C. (1992-1994) Improntas de esterillas en cerámicas del Bronce Final de la Peña Negra (Crevillente, Alicante). Campañas de 1983 y 1984. Lvcentvm 11-13: 39-49.

Peña-Chocarro, L. (1999) Prehistoric agriculture In Southern Spain during the Neolithic and the Bronze Age. The application of ethnographic models. Oxford. BAR International Series S818.

Pérez-Jordà, G., Carrión-Marco, Y. (2011) Los recursos vegetales. A: Pérez Jordà, G.; Bernabeu Aubán, J.; Carrión Marco, Y.; García Puchol, O.; Molina Balaguer, L., Gómez Puche, M. (eds.). La Vital (Gandía, València). Vida y muerte en la desembocadura del Serpis durante el III y el I Milenio a.C. Serie Trabajos Varios del SIP. Servei d'Investigacions Prehistòriques. Diputació de València. València.

Petersen, JB., Wolford, JA. (2000). Spin and Twist as Cultural Markers: A New England Perspective on Native Fiber Industries. In Drooker, PB., Webster, LD. (eds): Beyond Cloth and Cordage: Archaeological Testile Research in the Americas, 101-1017. Salt Lake City: University of Utah Press.

Piqué, R., Palomo, A., Terradas, X. Aguer, C., Bogdanovic, I., Chinchilla, J., García, I., Jover, A., López, O., Moitinho, V., Buxó, R., Bosch, A., Tarrús, J., Saña, M., Vivar, G. (2014) Registro, análisis y conservación de los objetos de madera del yacimiento neolítico de La Draga Banyoles, Catalunya. AA.VV. Arqueología subacuática española: actas del I Congreso de Arqueología Náutica y Subacuática Español. Cartagena, marzo de 2013. Ed. Cartagena. ARQUA Museo Nacional de Arqueología Subacuática.

Universidad de Cádiz. 978-84-9828-472-0: 1141-1151.

Piqué, R., Palomo, A., Terradas, X., Tarrús, J., Buxó, R., Bosch, À., Chinchilla, J., Bogdanovic, I., López, O., Saña, M. (2015) Characterizing prehistoric archery: technical and functional analyses of the Neolithic bows from La Draga (NE Iberian Peninsula). J Archaeol Sci 55:166-173. DOI: 10.1016/j.jas.2015.01.005

Piqué, R., Romero, S., Palomo, A., Tarrús, J., Terradas, X., Bogdanovic, I. (2018) The production and use of cordage at the early Neolithic site of La Draga (Banyoles, Spain). Quat Int 468:262–270. https://doi.org/10.1016/j.quain t.2016.05.024

Revelles, J., Antolín, F., Berihuete, M., Burjachs, F., Buxó, R., Caruso, L., López, O., Palomo, A., Piqué, R., Terradas, X. (2014) Landscape transformation and economic practices among the first farming societies in Lake Banyoles (Girona, Spain). Environ Archaeol, 19(3): 298-310. DOI: 10.1179/1749631414Y.0000000033

Revelles, J., Cho, S., Eriarte, E., Burjachs, F., van Geel, B., Palomo, A., Piqué, R., Peña-Chocarro, L., Terradas, X. (2015) Mid-Holocene vegetation history and Neolithic land-use in the Lake Banyoles area (Girona, Spain). Palaeogeogr Palaeoclimatol Palaeoecol, 435: 70-85. DOI: 10.1016/j.palaeo.2015.06.002

Revelles, J., van Geel, B. (2016) Human impact and ecological changes in lakeshore environments. The contribution of non-pollen palynomorphs in Lake Banyoles (NE Iberia). Rev Palaeobot Palyno, 232: 81-97. DOI: 10.1016/j.revpalbo.2016.05.004

Romero-Brugués, S. (2022) Cordes i cistells elaborats amb fibres vegetals entre el 2300-800 cal BC al Nord-Est peninsular i Balears: Tecnología, materia prima i funció. PhD Dissertation. Barcelona, Universitat Autònoma de Barcelona.

Romero-Brugués, S., Piqué Huerta, R., Herrero-Otal, M. (2021) The basketry at the early neolithic site of La Draga (Banyoles). Journal of Archaeological Sciences: Reports, 35(102692). DOI: 10.1016/j.jasrep.2020.102692

Rovira, N. (2007) Agricultura y gestión de los recursos vegetales en el sureste de la Península Ibérica durante la Prehistoria reciente. PhD Dissertation. Barcelona, Universitat Pompeu Fabra.

Soffer, O. (2004) Recovering Perishable Technologies Through Use Wear on Tools: Preliminary Evidence for Upper Paleolithic Weaving and Net Making. Current Anthropology 54(3): 407-413.

Stika, HP. (2005) Early Neolithic agriculture in Ambrona, Prov. Soria, central Spain. Vegetation History and Archaeobotany 14: 189-197.

Suomela, JA., Vajanto, K., Räisänen, R. (2017) Seeking nettle textiles – Utilizing a combination of microscopic methods for fibre identification. Studies in Conservation, 63:7, 412-422. DOI: 10.1080/00393630.2017.1410956

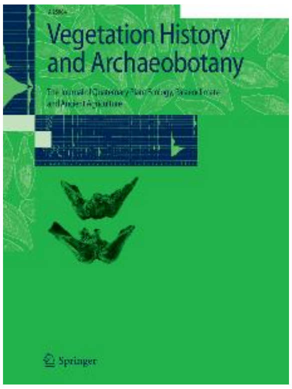
Terradas, X., Piqué, R., Palomo, A., Antolín, F., López, O., Revelles, J., Buxó, R. (2017) Farming Practices in the Early Neolithic According to Agricultural Tools: Evidence from La Draga Site (Northeastern Iberia). In García-Puchol, O., Salazar-García, DC. (eds) Times of Neolithic transition along the Western Mediterranean. Fundamental issues in archaeology. Springer, Cham, 199-220. DOI: 10.1007/978-3-319-52939 -4_8

Viotti, C., Albrecht, K., Amaducci, S., Bardos, P., Bertheau, C., Blaudez, D., Bothe, L., Cazaux, D., Ferrarini, A., Govilas, J., Gusovius, HJ., Jeannin, T., Lühr, C., Müssig, J., Pilla, M., Placet, V., Puschenreiter, M., Tognacchini, A., Yung, L., Chalot, M. (2022) Nettle, a Long-Known Fiber Plant with New Perspectives. Materials, 15, 4288. DOI: 10.3390/ma15124288

Wendrich, W., Ryan, P. (2012) Phytoliths and Basketry Materials at Çatalhöyük

(Turkey): Timelines of growth, harvest and objects life histories. Paléorient, 38, n°1-2: 55-63. DOI: 10.3406/paleo.2012.5458

Wigforss, E. (2014) Perished material-vanished people. Understanding variation in Upper Paleolithic/Mesolithic textiles technologies, Department of Archaeology and Ancient History, Lund Universitet.



6.2.4. Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula.

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The present paper presents the first systematic raw material identification of basket remains from two archaeological sites from the northeastern part of the Iberian Peninsula that have provided the oldest evidence of fibre-based productions in the area: the Early Neolithic sites of La Draga (5324-4977 cal BC; Banyoles, Girona) and Coves del Fem (6065-4545 cal BC; Ulldemolins, Tarragona). The sampling of different parts of the coiled baskets allowed the identification of three different species of cereals (Poaceae A, B and C), sedges (Cyperaceae) and cattails (Typhaceae) and *Tilia* sp. (Malvaceae) in the case of La Draga, and sedges and other unidentified monocots in the case of Coves del Fem. The results show a selection of raw materials and a probable collection of them from the surroundings of the site, suggesting a local production of baskets, supported by other functional studies of wooden, faunal, lithic and malacological tools. The paper also places the finds from both sites in the context of ancient basketry remains from the Iberian Peninsula and Europe.

Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula.

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Abstract

Plant-based implements are rarely preserved in archaeological contexts in the Iberian Peninsula. Very few sites with specific conditions, like waterlogging, aridity, or carbonization, have preserved organic material. The aim of this paper is to establish an identification criterion for identifying organic raw materials used for manufacturing plant-based artifacts by using optical microscopy. The coiled basketry remains found in La Draga (Banyoles, Girona) and Coves del Fem (Ulldemolins, Tarragona) have been studied using this method. The materials were exceptional preserved by waterlogging in the case of La Draga and carbonized or dehydrated in Coves del Fem. Samples of both coils and stitches from all the basket remains were analysed. The anatomy of their cross-sections was observed under a transmitted light bright-dark field (BF-DF) optical microscope and compared with modern reference collections. The results show the use of at least five species corresponding to four families: three monocotyledons (Poaceae, Cyperaceae and, Typhaceae) and a dicotyledon (Malvaceae). Moreover, it has been possible to distinguish the part of the plant used. Variability in raw materials implied extensive environmental knowledge. Moreover, functional studies of wooden, faunal, lithic, and malacological tools suggest a local production of baskets. This paper expands the current knowledge of raw materials used for basketry purposes during prehistory in the Mediterranean area as the examples from La Draga and the Coves del Fem are the oldest basketry remains that have been studied in depth in the Iberian Peninsula and Europe.

Keywords: vegetal fibres, raw material, optical microscopy, coiled basketry, Early Neolithic.

Introduction.

Plant implements are rarely preserved in archaeological contexts in the Iberian Peninsula. The specific environmental conditions that permit the preservation of organic material, such as waterlogging or aridity, are unusual and restricted to very few sites. Consequently, in the Iberian Peninsula, this perishable material is scarce, and our knowledge of prehistoric crafts is limited, as in many other regions of the world (Hurcombe 2014). Therefore, prehistoric plant-fibre use is not fully taken into consideration in archaeological research in specific locations. The determination of the plants used is an objective of study that can help to understand human-environmental relationships, as well as the social and economic relations of human societies. In most cases, the raw materials have basically been studied by macroscopic observation, which is imprecise, but detailed studies provide relevant information about technology in past societies (Barber 1994; Hardy 2008; Médard 2012; Soffer 2004). In order to clarify the nomenclature in the present paper, the word “fibre” is used in its broadest sense, referring to plant materials such as leaves or stems of herbaceous plants, which has been historically used to produce daily objects as basketry or cordage.

Arid preservation conditions in the Iberian Peninsula are restricted to the south-eastern part and some scattered cave sites in other regions. Cueva de los Murciélagos (Albuñol, Granada; 5200-4600 cal BC) is probably the most singular example. In this site, the raw material used to make the baskets and sandals recovered was identified as esparto grass (*Stipa tenacissima*) (Alfaro Giner 1980). It is suggested that esparto grass would also be used in later periods in the same region, but no artefacts have been analysed in detail. Esparto grass grows naturally in this region and, according to the archaeological evidence, has enjoyed a long history of exploitation. The environmental conditions are quite different in the North of the Iberian Peninsula, where the climate is more humid, and the biodiversity is completely different. In this context, such sites are scarcer. The site of Cueva del Moro (Alins del Monte, Huesca; 1530-1425 cal BC) is one of the few that have preserved basket remains due to the dry environment. The fibres were determined as monocotyledons plants and *Salix* sp. (Alcolea and Rodanés 2019). Another exceptional site is La Draga, where materials were preserved in waterlogged conditions and dated to 5324-4977 cal BC (Bosch et al. 2000, 2006; Piqué et al. 2018). The preliminary publication of the basket remains from La Draga indicated the probable use of *Carex* sp. and *Juncus* sp. according to their macroscopic appearance. However, the remains were not analysed anatomically and the raw material identification remained uncertain. The preservation by carbonization and the presence of imprints of vegetal fibres is also extremely rare in prehistoric archaeological contexts in the region. However, partially charred fragments of plaited or braided cord of esparto grass, dated 10780-10760 cal BC, and fragments of clay with basketry imprints dated 13200-10200 cal BC, were recovered at Coves de Santa Maira in the eastern Iberian Peninsula (Aura Tortosa et al. 2019). Similarly, the remains of an object made of braided vegetable fibres were found inside a pit in Cova de les Cendres in the same region (ca. 7500-6900 cal BC) (Fumanal García and Badal García 2009). The fact that most studies of raw materials used in basketry production in the prehistory of the Iberian Peninsula were published thirty years ago attests the necessity of revising and carrying out new analysis to obtain more precise knowledge of this sort of material.

Most of the Neolithic and later baskets cited in this paper were manufactured with the coiling technique. There is no consensus in the description of basketry methods, but all authors define coiling technique, widely expanded worldwide, as a very versatile one. Terminology differs according the authors, but coiling method consists of a passive element called foundation element/coil/bundle, forming a spiral, and an active element that attaches the coil, called sewing element/winder/stitch. The foundation accumulates energy and resistance and offers strength and solidity to the resultant artefacts (Adovasio 1977; Croes 1977; Wendrich 1989). In this technique, the mechanical properties of the raw material are very important, although there is no specific definition of the properties that they must possess. Plant properties are determined by the taxonomical species, geographic location, climate, anatomical part, and structure. Accordingly, variations in chemical and physical composition also lead to variations in the mechanical properties of the fibres. The most important mechanical properties are tensile strength, stiffness, moisture resistance and elongation, among others, while the chemical composition is mostly cellulose, hemicellulose and lignin (Da Costa et al. 2014; Panshin and de Zeeuw 1980; Rowell et al. 2000).

Those fibrous materials should be easy to obtain from nature and need simple processing and transformation to make them malleable. This makes plant-based technology easily accessible in many areas and those elements can be used for multiple purposes. The variability in artefact morphology, manufacture technique, and raw material indicates functional specialization. Historical documents mention similar plants to esparto grass, such as other monocotyledons (Kuoni 1981), which suggests long continuity of craft traditions regarding raw materials, probably because of their suitable technical properties. Nonetheless, modern ethnobotanical research documents a large diversity of plants that, based on their properties, can be used for manufacturing plant-based implements; they include grasses, rushes, cattails, sedges, and the bark of trees like lime or willow. Some of their mechanical properties have been tested and discussed in Harris et al. (2016). Despite the importance of the raw material properties, the lack of taxonomical determinations is striking. When the identification is provided, it is quite often based on macroscopic features, which is an unreliable method taking into account such taphonomic processes as deformation, loss of colour and dehydration. Moreover, when a more precise method is used, the level of determination is low, mainly because this type of basket is made with monocots with very similar features, which limits the possibility of more specific determination. This overlapping of characteristics makes identification difficult, and these complexities are reflected in the lack of specialized bibliography. The fact that this sort of element is rarely found in archaeological research plus the absence of monographs with proper in-depth studies makes research as presented in this paper even more difficult. Even so, differences are visible, and they permit the discrimination of plant groups. While specific anatomical atlases are available for the identification of European wood, there is a lack of specific reference literature for the identification of bark, non-woody, and herbaceous species, except for some families that have been studied in detail (Benahmed-Bouhafsoun et al. 2007; Bergfjord and Holst 2010; Brinkemper and van der Heijden 2012; Florian 1990; Thomas and De Franceschi 2013; Thomas 2013; Schweingruber 2011). In this sense, the construction of local reference collections, considering several features, becomes indispensable for accurate raw material identification.

The aim of this paper is to develop and establish an identification criterion for identifying organic raw materials used for manufacturing plant-based artifacts by observing microscopically their cross-sections. Its implementation on the coiled basketry remains found in two settlements of the north-eastern Iberian Peninsula contributes to a better understanding of plant resource management and technological development during the Early Neolithic in the Mediterranean area.

Material and methods.

The site of La Draga.

La Draga is an Early Neolithic site located on the shore of Lake Banyoles at approximately 170 metres above sea level (Fig. 1). Excavated since 1991, different sectors in the site are distinguished by their conditions for the preservation of organic material. Sector A is in the highest part of the site where the archaeological layers are above the water table; in this sector organic material is only preserved by charring. In Sector B the archaeological layer is in the water table, closer to the lake, and Sector C is currently under the water of the lake. Sectors B and C present extraordinary preservation of organic material.

The site is considered the only evidence of a Neolithic lake dwelling in the Iberian Peninsula, and one of the earliest in Europe (Palomo et al. 2014; Terradas et al. 2017).

Radiocarbon dates show two occupation phases during the Early Neolithic, differentiated also in building traditions. During the first phase, corresponding to 5324-4977 cal BC, constructions were mostly made with wood, while a stone pavement was built during the second phase dated to 5210-4796 cal BC. This pavement covered the wooden collapse of previous structures. The earliest phase has provided an extensive collection of plant implements, among them wooden, baskets and ropes (Bosch et al. 2006; López-Bultó 2015; López-Bultó and Piqué 2018; Palomo et al. 2013; Piqué et al. 2015).

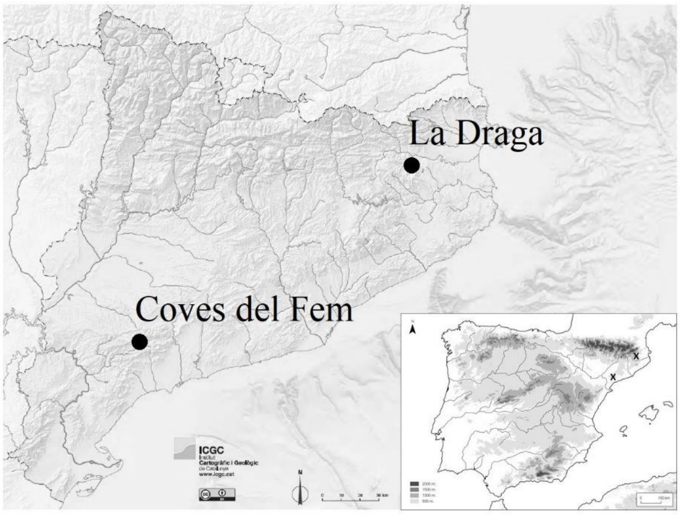

Fig. 1 Location of La Draga and Coves del Fem archaeological sites.

The basket remains at La Draga (Fig. 2a-c) were recovered in the archaeological fieldwork from 1990 to 2005, in Sectors B and C. Although they were all waterlogged, only a few of them were preserved organically and most were carbonized. Their recovery was in situ during excavation or posterior wet-sieving and they were immediately restored and consolidated by freeze-drying to prevent damage and loss of integrity. Later they were treated with polyethylene glycol (PEG). Bosch et al. (2006) presented preliminary observations and measurements of a part of the recovered basketry fragments, and also provided a very generic identification based on macroscopic features. The morphological and technical description has also been carried out by Romero-Brugués et al. (2021). This has classified the thirty-four basketry fragments as bases, handles, knobs, and bundles of at least eight items. Regarding manufacturing techniques, the whole sample is determined as coiled basketry with variations in the type of stitches.

The site of Coves del Fem.

Coves del Fem is a Mesolithic and Early Neolithic cave located near the Montsant river and range at about 530 metres above sea level and oriented towards the North-East (Fig.

1). The site is a rock shelter preserved thanks to fallen rock blocks. The site has been excavated since 2013 (Bodganovic et al. 2017; Palomo et al. 2018).

The site has been dated chronologically between 6065-4545 cal BC, covering different periods: Mesolithic (6065-5718 cal BC), the first Early Neolithic phase (5667-5476 cal BC) and the final phase, also known as the Epicardial (4941-4545 cal BC). The archaeological levels provide good preservation of archaeobotanical remains, which are basically carbonized but also dehydrated. Basketry remains were recovered during archaeological fieldwork in 2019 in the final Early Neolithic or Epicardial levels. Fragments of coiled basketry (Fig. 2d) were recovered inside a pit in contact with the bottom as if they were lining a storage structure, such as a bin or silo. The morphotechnical study, which is currently being performed, describes it as a single basket. The state of preservation unfortunately prohibits whether the remains represented an additional layer of the pit itself protecting the structure or were fragments of discarded baskets used to line the pit. The remains were carbonized, although uncharred fibres were also observed. In this case, as in the previous case of La Draga, the basketry had been manufactured with coiling techniques. The preliminary analysis suggests the presence of characteristic features as sewing and foundation elements of a base or a rim.

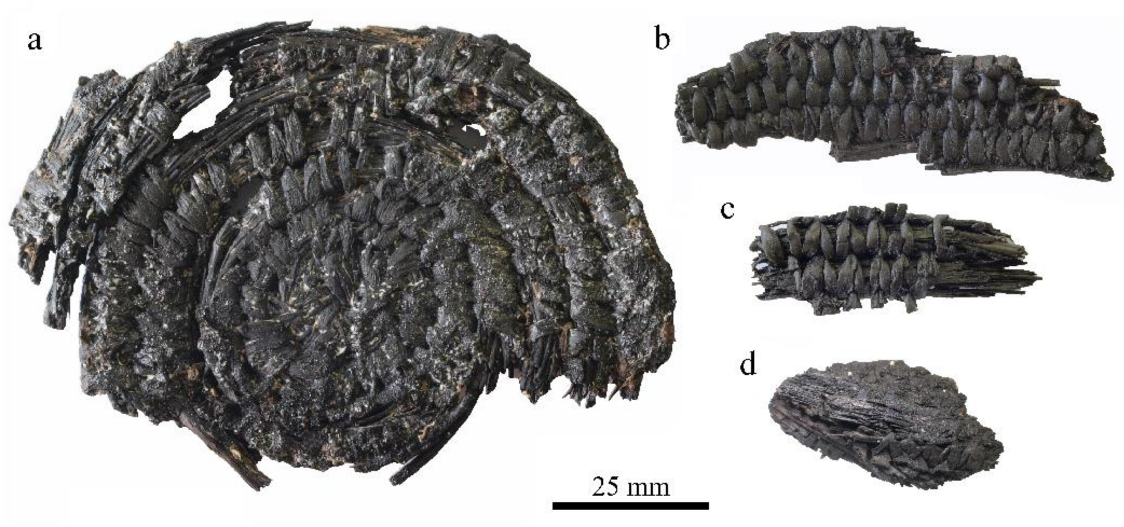

Fig. 2 Basketry remains from La Draga (2a, 2b, 2c) and Coves del Fem (2d).

<u>Sampling and identification.</u>

Samples of thirty basketry fragments (twenty-five from La Draga and five from the Coves del Fem) have been analyzed. In the case of La Draga all the individuals identified by Romero-Brugués et al. (2021) were sampled. Moreover, in order to document the variability in the use of raw material in a single object, and, in some cases, to verify whether all the fragments came from the same item, several fragments were sampled for the individual. In the case of Coves del Fem all the fragments came from the same structure, and probably were part of the same implement. When coils and stitches were easily distinguishable, they were sampled separately. Thus, the complete assemble offers almost sixty analysed samples regarding both coils and stitches. Sampling plant-based archaeological materials is a destructive method. Though the complexity in their recovery from the field, restore and storage makes little fragment break up by their selves. These were the materials used for performing the microscopic analyses presented in this paper. Therefore, the archaeological object was not even more destructed. Moreover, it is noteworthy the minimum size required by the microscopic observation, being a highlight of this method.

Descriptions and identifications were based on comparing the general appearance and microscopic shape and cells from the vascular system elements (visible on cross-section views) of the archaeological remains with contemporary genera that previous archaeobotanical works documented at La Draga and Coves del Fem. The reference material was modern plants collected and some other specialized literature containing specific descriptions of cross-sections microscopical views. As a consequence to the complexity to find literature of transverse section view of the botanical families that we were interested in, a reference collection that includes families or species of interest was created. The families included were those suitable for basketry purposes (Juncaceae, Poaceae, Typhaceae, Cyperaceae) as herbaceous and *Tilia* sp., *Salix* sp., *Corylus* sp. as woody species).

Due to dehydration, carbonization and PEG treatment, the samples acquired certain solidity which facilitates their preparation for microscopic analyses. A dry cutting method was consequently performed, so the possibility of disintegration when rehydrating ancient samples was avoided. Cross-sections preparation was conducted by breaking the samples by hand or with a razor blade. Despite taphonomy and carbonization is supposed to aggravate the difficulty of observing plant archaeological materials by transferred optical light microscopy, this method permits obtaining good quality surfaces avoiding changes in the structures, as is also carried out in anthracology. The identifications were performed by observing the archaeological samples under 50-500X magnifications using a transmitted light bright field-dark field (BF-DF) optical microscope. The analyses were accomplished at the Archaeobotanical Laboratory of the Department of Prehistory at the Universitat Autònoma de Barcelona (UAB) using an Olympus BX51 microscope coupled with an Olympus DP26 camera and linked to Olympus cellSens software.

From a botanical point of view, monocotyledons and dicotyledons are easily distinguishable anatomically in their cross-section observation. Monocots do not present secondary growth and their vascular bundles appear scattered, while dicots present a secondary growth known as bark, and their vascular system is arranged in a ring (Evert 2006). This is the main way to differentiate between those plants. Moreover, differences in vascular bundles can discriminate taxonomical families and species which allows the materials to be identified taxonomically. The anatomical parts can be distinguished from the patterns of arrangement of vascular bundles and by the presence of specific features: epidermis, medulla, aerenchyma, and papillae, among others. Most of publications tried to distinguish families regarding not visible features in their cross-sections, e.g. general appearance of single fibres in polarized light and Herzog test (Bergfjord and Holst 2010; Haugan and Holst 2013, Lukešova et al. 2017; Suomela et al. 2017), paradermal view of the epidermis (Borojevic and Mountain 2013), calcium oxalate crystals (Francheschi and Horner 1980), or micro-computed tomography (Smith et al. 2013). Thomas and De Franceschi (2013) and Thomas (2013) did observe cross-sections and the vascular bundles of Aracaceae as Schweingruber et al. (2011) also did of other families. More specifically, Brinkemper and van der Heijden (2012) provide the identification criteria of the botanical families and species usually used for basketry artefacts. They describe cell pattern of the epidermis including the morphology of cell walls, presence of appendix and stomata, and silica cells, which have distinct shapes according to taxonomic significance. Even so, these descriptions were based on the appearance of the paradermal view and not the cross-section one. They used a chemical procedure to extract the epidermises of modern collection in order to visualize them using both optical and electronical microscope.

Results.

Taxonomical identification.

Through the microscopic observation of samples, it has been possible to identify five morphotypes of monocotyledons (86% of the identified samples) and one dicotyledon (14%) (Table 1). The highest variability is documented at La Draga, surely related to the larger number of remains, where a total of four families have been identified: Poaceae/Gramineae (10 of the sampled fragments), Cyperaceae (18 identified fragments), Typhaceae (2 fragments), and *Tilia* sp. (Malvaceae/Tiliaceae) (7 fragments). In the case of Coves del Fem the fragments have all been identified as Cyperaceae (2 fragments). A total of 16 fragments were not possible to identify (13 from La Draga and 3 from Coves del Fem).

Table 2 summarizes the features observed and used in the current study to classify the samples taxonomically. Other features that do not appear on the table as stomata and prickles presence have been discarded because they are usually not visible on transversal sections. The difference between types of Poaceae family has been determined regarding the general shape of the sample (bulges, papillae, among others) because the other characteristics were very similar. The overlapping of features amongst families and species makes its identification even more difficult. As previously commented, the identifications described here were the results of combining specific botanical references and a modern reference collection. In the archaeological remains, the plants do not present their natural morphology because of their process to manufacture the items. Twisting and pressing them would change the general appearance. Hereby not all features in Table 2 could be visualized. Nevertheless, due to the morphology of vascular bundles, epidermis, mesophyll and sclerenchyma tissues along with the presence of aerenchyma, the families could be positively identified.

Table 1. Taxonomical and anatomical identifications of sewn and foundation elements from La Draga and Coves del Fem.

Site	Individual[a]	Sewing elements		Foundation elements	
		Taxonomical identification	Anatomical part	Taxonomical identification	Anatomical part
La Draga	A	*Carex* (Cyperaceae)[b]	No information	*Juncus* (Juncaceae)[b]	No information
	B	Cyperaceae	Leaves	Non-determined monocot	Leaves
	C	Typhaceae	Leaves	Typhaceae	Leaves
	D	Tilia sp. (Malvaceae)	Bark	Non-determined monocot	Leaves
	E	*Tilia* sp. (Malvaceae)	Bark	Poaceae A, non-determined monocot	Leaves
	F	*Tilia* sp. (Malvaceae)	Bark	Poaceae A + non-determined monocot Non-determined monocot	Leaves Stems
	G	Cyperaceae	Leaves	Poaceae B, Cyperaceae	Leaves
	H	Poaceae B, Cyperaceae, non-determined monocot	Leaves	Poaceae B, C, Cyperaceae, non-determined monocot	Leaves
Coves del Fem		Cyperaceae	Leaves	Non-determined monocot	Leaves

[a] Determined by Romero-Brugués et al. (2021).

[b] Individual A has not been studied in this paper. It was analysed in previous works (Bosch et al. 2006).

Three types of Poaceae (grasses) have been identified at La Draga. They have been named Poaceae A, Poaceae B and Poaceae C. Grasses are present in four of the individualized baskets of La Draga (individuals E, F, G and H), mostly being part of the bundles. The principal criteria for differentiating these types are described below. The first morphotype (Poaceae A) displays long narrow elements with protuberances along them. Vascular tissue inside those bulges presents the typical structure of monocot bundles (Fig. 3a). They are independent of each other and scattered along the parenchyma. Xylem is very clear, as two big tracheas (metaxylem) and a big ligneous cavity (protoxylem). Phloem is also visible, and all the vascular bundles are surrounded by sclerenchyma tissue or bundle sheath. A single layer of cells forms the epidermis and the natural end of the leaf is visible in some samples. Poaceae B type resembles Poaceae A, but the elements are not as narrow and the bulges with vascular bundles are less noticeable (Fig. 3b). Xylem and phloem are easily distinguished and appear scattered in the element, which has a single-cell layer. Typology Poaceae C contains long elements different from those seen in previous morphotypes. No bulges or protuberances are present, but vascular tissues are concentred in clear papillae (Fig. 3c). The sample seems to draw a spiral around itself. Xylem (metaxylem and protoxylem), phloem and multi-layered epidermis are also visible. Cyperaceae (sedges) is the most common taxa in the analysed samples. They are present in four of the eight individuals from La Draga (Individuals A, B, G and H) mainly in the sewing elements. It is also the only positively identified taxa in the Coves del Fem assemblage. The samples identified as belonging to this family present a typical morphology of vascular bundles that resemble those seen in the typologies described above, but the general structure is different (Fig. 3d, 3e). A particularity of these samples is the aerenchyma, the dark chambers filled with air that allow the leaves of aquatic plants to drift on the water. Aerenchyma is not exclusive to sedges but, owing to the structure of vascular bundles, the samples resemble the Cyperaceae family. Typhaceae (cattails) is only identified in a few samples from La Draga, in both the sewing and bundle parts of a single individual (C). In this case, vascular bundles are scattered all along the sample, but their appearance is different from those types described above. Xylem and phloem are as clear as in the other taxa, but their particular morphology is different from all the other typologies described in this study. The vascular bundles appear surrounded by a thick sclerenchyma tissue and dark chambers are visible as empty holes corresponding to aerenchyma tissue (Fig. 3f). Due to these features, we suggest these samples are from Typhaceae plants.

The only dicotyledonous taxa identified is *Tilia* sp. (lime tree), which corresponds to the Malvaceae family. It is only represented in the sewing elements of three individuals from La Draga (individuals D, E and F). What is microscopically visible on the images corresponds to the secondary phloem and the outer bark (Angyalossy et al. 2016; Schweingruber et al. 2011). The secondary phloem derived from the vascular cambium and the outer bark is formed by sequent peridermis corresponding to the white lines we see on the Fig. 3g.

Anatomical identification.

In addition to the taxonomical identification, the anatomical features have been used to distinguish elements that are characteristics of different parts of plants. It is worth noting that it is not necessary to undertake microscopic analysis to see the variations in samples of coils and stitches between baskets, but for more precise information it is better to visualize them under magnification. Those elements with a circular and oval form and a filled or empty medulla have been determined as stems or culm, depending on the plant (Fig. 3h). In the same way, irregular shapes found with a specific distribution of elements (vascular bundles, parenchyma, epidermis, and aerenchyma among others) have been determined as leaves and that enabled the differentiation between Poaceae (A, B and C), Cyperaceae and Typhaceae taxa (Fig. 3a-e). However, these features are not visible in all the samples. Counting the samples and excluding those categorized as unidentified, we see a greater use of leaves than of stems (Table 1).

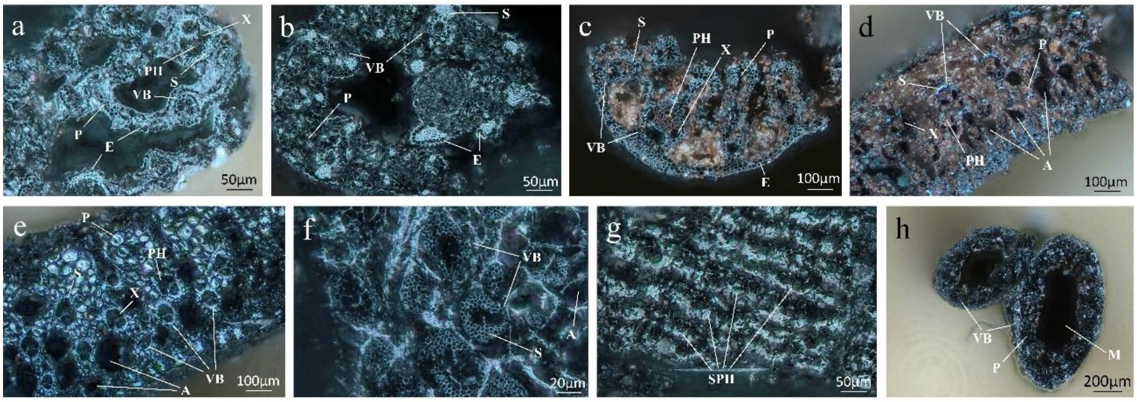

Fig. 3 Optical microscope images of samples of basketry from La Draga and Coves del Fem. 3a) Poaceae A (La Draga); 3b) Poaceae B (La Draga); 3c) Poaceae C (La Draga); 3d) Cyperaceae (La Draga); 3e) Cyperaceae (Coves del Fem); 3f) Typhaceae (La Draga); 3g) *Tilia* sp. (La Draga); 3h) Non-defined stem (La Draga) (A-aerenchyma, E-epidermis, M-medulla, P-parenchyma, PH-phloem, S-sclerenchyma, SPH-secondary phloem, VB-vascular bundles, X-xylem).

Discussion.

Origin, variability, and availability of raw material.

The analysis of basket remains from La Draga and Coves del Fem has provided evidence of the use of at least five species corresponding to four families. Three of them correspond to monocotyledonous plants (Poaceae, Cyperaceae, Typhaceae) while one is a dicotyledon (Malvaceae, *Tilia* sp.). We should also bear in mind the Juncaceae family identified in previous studies (Bosch et al. 2006). Previous archaeobotanical studies at La Draga and

Coves del Fem have provided a good picture of the vegetal landscape in the surroundings of the sites and allow a discussion of the availability of the determined taxa around the sites during the Neolithic occupations. Archaeobotanical data suggest a selection of raw materials, implying an extensive and discriminatory utilization and exploitation of environmental resources.

La Draga.

In the case of La Draga, a variety of archaeobotanical remains have been recovered and analysed, which has provided a significant amount of palaeoenvironmental data. Palynological studies at the site revealed that during the Early Neolithic the vegetal landscape was characterized by deciduous forest in which oak was dominant (Revelles et al. 2014, Revelles et al. 2015; Revelles and van Geel 2016). However, riparian and aquatic plants and woodland were also abundant along the lake shores. A decrease in *Quercus* sp. and *Corylus* sp. values is recorded, coinciding with the Neolithic occupation, while *Pinus* sp. and *Abies* sp. increased in the nearby mountains. *Tilia* sp. appeared as a continuous curve reaching its maximum value at 5200-5150 cal BC and, along with Cyperaceae, gained importance. Non-arboreal pollen like Poaceae expanded, as did such other herbs and shrubs as Asteraceae, *Artemisia* sp., Apiaceae, Chenopodiaceae, *Erica* sp., and *Plantago* sp.

The charcoal analysis identified eighteen trees and shrub taxa systematically used as firewood (Caruso-Fermé and Piqué 2014). These included *Quercus* sp. deciduous as the dominant taxa. Shrubs were represented in small proportions with the most represented taxa being Buxus sempervirens and Rosaceae/Maloideae, along with *Acer* sp., *Taxus baccata*, *Pinus sylvestris-nigra* type and *Juniperus* sp. The riparian forest was also represented mainly by *Laurus nobilis*, as well as *Ulmus* sp., *Fraxinus* sp., *Corylus avellana*, *Salix* sp. *Alnus glutinosa*, *Sambucus* sp., *Populus* sp., *Clematis vitalba*, and *Cornus sanguinea*. Mediterranean vegetation was also evidenced by the limited presence of *Quercus* sp. evergreen and *Arbutus unedo*.

The analysis of wooden implements also registered the use and exploitation of deciduous, riparian, and Mediterranean forests (López-Bultó and Piqué 2018). La Draga is the Early Neolithic archaeological site in the northeast of the Iberian Peninsula with the highest number of identified botanical taxa. Deciduous *Quercus* sp. and *Buxus sempervirens* were the most often used raw materials to make tools, but many other taxa were used for specific implements: *Corylus avellana*, *Laurus nobilis*, *Acer* sp., *Arbutus unedo*, *Clematis* sp., *Cornus sanguinea*, *Fraxinus* sp., *Juniperus* sp., *Pinus* sp., *Quercus* sp. evergreen, Rosaceae/Maloideae, *Salix* sp., *Sambucus* sp., *Taxus baccata*, and *Ulmus* sp.

Table 2. Histological features found in Poaceae, Cyperaceae and Typhaceae families regarding specific references and a modern reference collection.

Family	General shape	Epidermis	Parenchyma	Vascular bundles	Sclerenchyma	Aerenchyma	Reference
Poaceae	Flat or V-shaped with protuberances, bulges and papillae along its surface	Single or multi-layered and regular forms and size	Homogeneous	Arranged in the centre of the section, approximately equidistant from both epidermis, and in a single layer parallel to the adaxial and abaxial surfaces. Xylem and phloem easily to distinguish	Discontinuous, subepidermal, around the vascular bundles	-	Aliscioni et al. 2016; Martínez-Segarra et al. 2017; Mavi et al. 2011; Okagaki et al. 2018
Cyperaceae	Flat shaped with no specific features along its surface	Single-layered with lignified walls in specific places, thicker in the adaxial surface	Heterogeneous	Large ones arranged in 2-3 rows. Small vascular bundles within the chlorenchyma	Circular around the vascular bundles, columns also associated with them	Present	Amini Rad and Sonboli 2008; Llamas et al. 1993; Martins and Alves 2009
Typhaceae	Flat shaped with columns of parenchyma connecting both adaxial and abaxial surfaces	One-seriated epidermis followed by three layered palisade parenchyma	Heterogeneous	Small ones near the epidermis, large ones in the columns of parenchyma along the aerenchyma chambers	Thick layers surrounding the vascular bundles (3/4 cell layered)	Present	Corrêa et al. 2016; Liu et al. 2017; McManus et al. 2002

The study of charcoal and wooden artefacts indicates extensive use of wooden materials that were acquired mainly at local level. However, some taxa could be obtained at longer distances. It is noteworthy that some taxa are documented only among the artefactual remains and are absent in the charcoal, which is supposed to represent the local vegetation. In this sense the only woody taxa identified in the basketry raw material (*Tilia* sp.) is completely absent from the charcoal and wooden remains record. However, strips of lime bark were also identified as cordage raw material (Piqué et al. 2018). The fact that forests provided a selection of timber of several families including lime bark, is a sort of forest management which has also been detected in other European regions in Neolithic chronologies (Coles et al. 1978). Palynological studies indicates lime tree presence at regional level, what suggests that the inhabitants of La Draga could have acquired and transported to the site only the strips of bark. Lime bark is relatively easy to extract, so it is not necessary to cut and transport the whole trunk or branches, and this would have facilitated its use. Besides, in the case of basketry at La Draga, *Tilia* sp. was only used for sewing elements, which would explain a precise selection of raw materials. The fact that it was not available in the immediacies of the settlement and the lake, would explain the dosage in its use.

In addition, several charred and uncharred seeds and fruit remains were also recovered in the systematic procedure of recovering and wet-sieving sediment from La Draga (Antolín 2013). Some of the taxa identified have been traditionally used in plant implements production because of their suitable properties. More specifically, these are five cereal taxa corresponding to such cultivars as *Hordeum* sp. (*H. distichum*) and *Triticum* sp. (*T. durum/turgidum*, *T. aestivum*, *T. dicoccum*, and *T. monococum*), and the four lakeshore and aquatic plants *Carex* sp., *Juncus* sp., *Typha* sp. and *Cyperus* sp. Additionally, fruits of *Corylus avellana* and *Tilia platyphyllos* agg. were also identified and related to edible, infusion, and medical economic value (Antolín and Buxó, 2011). Finally, a fragment of a tuber, probably of a *Cyperus*, was recovered (Piqué et al. in press) and *Urtica dioica* and *Clematis vitalba* have been identified in seed remains and in cordage at La Draga (Piqué et al. 2018).

The analysis of macrobotanical remains determined that a high diversity of herbaceous and monocot plants, both cultivated and wild, were available in the area. The wide availability of Poaceae around the site of La Draga and its surroundings points to the consumption of cereals for multiple purposes as other species as lime tree or hazel. They could have been used as food for the inhabitants and their livestock and they could provide additional raw material to manufacture plant implements. From the point of view of basketry, the cultivars were not the only group suitable for their production. The positive identification of sedges and cattails among the basket remains indicates that other local available resources were also used. In fact, the proximity of the lake suggests that cattails and sedges had a large area of expansion in the settlement surroundings. They are commonly known as aquatic plants. Despite the difficulty in discriminating them, both were recorded in previous archaeobotanical analyses, as lime tree, which indicates their presence in the surroundings. They grow in waterlogged or fluctuating water niches and marsh shores with different climatically-conditioned soils, so they grow near lakes and rivers. As mentioned above, some of them colonize sites after natural or anthropic disturbance and they are mostly perennial (Bús et al. 2018; Dahlgren et al. 1985; Svedarsky et al. 2019). Raw material availability and functional analyses indicate a local production of basketry in La Draga. On the one hand the use-wear analysis of sickle blades indicates that the straw was harvested as a secondary product of the cereal. The use-wear analyses detected striations on lithic pieces related to harvesting and cutting unripe cereals and other wild plants, such as reeds (Gibaja 2011). Use-wear on other implements made of different materials, such as bone awls and needles (De Diego et al. 2017), boxwood spindles and combs (De Diego et al. 2018), show they were used to process non-woody plants. Finally, the use of *Mytilus galloprovincialis* for similar purposes has also been identified (Clemente and Cuenca 2011).

Coves del Fem.

The site of Coves del Fem has provided a singular archaeobotanical record (Palomo et al. 2018), but the plant remains appeared mainly carbonized, and only a few wooden remains have been preserved by dehydration. Palynological studies of the Neolithic layers indicate a landscape dominated by Pinus sylvestris nigra, Quercus sp. deciduous and Quercus sp. evergreen. However, herbaceous plants like Poaceae, Asteraceae, hydrophytes like Cyperaceae and such trees as *Salix* sp., *Ulmus* sp., *Alnus* sp., *Fraxinus* sp., *Tilia* sp., *Corylus* sp. and *Betula* sp. have also been registered. It is suggested that the vegetation during the Early Neolithic was like the current one in this area, influenced by a continental Mediterranean climate. Generally, there was dense vegetation slightly altered by anthropogenic factors.

Charcoal analyses have provided evidence of the exploitation of Pinus sp. and Quercus sp., which are represented in the whole cave sequence in different concentrations. During the Neolithic phases, other Mediterranean shrubs like Prunus sp. and Rosaceae/Maloideae are present along with such riparian vegetation as *Acer* sp., *Ulmus* sp., *Ilex aquifolium*, *Fraxinus* sp., *Populus/Salix* and *Vitis* sp.

Carpological identification determined the use and exploitation of wild species found in the immediacies of the archaeological site (Palomo et al. 2018). The presence of these macroremains is scarce and only a few remains have been identified, but *Pinus* sp., *Quercus* sp. and *Vitis vinifera* var. *sylvestris* were recorded. Regarding domesticated species, *Hordeum vulgare* was found.

The fact that carpological and palynological studies identified the taxa recorded in basketry production points to the use of a local raw material. While useful and suitable plants for basketry production are abundant in the surroundings of the cave, only the Cyperaceae family has been identified. The site is located near the River Montsant, a place where sedges find their ecological requirements.

<u>Raw material at La Draga and Coves del Fem in the context of Neolithic basketry.</u>

A large variety of species were used to produce plant-based tools during the Neolithic. Archaeobotanical studies have identified grasses, cattails, and other monocotyledons as raw materials in basketry production (Schick 1988, 2002). Rushes have rarely been found in archaeological contexts but owing to their suitable features, they have been considered a possible plant to use in basketry production. The use of vegetal fibres in prehistory probably implied a larger variety of plants, but issues in their preservation prevent their corroboration and proper documentation. Even so, it is evident that fibre technology and uses have not changed and possess a worldwide distribution (Kuoni 1981; Jover and López 2012). The difficulty in contextualizing the raw materials used to manufacture the basket remains studied here should be taken into account in other Neolithic sites. Table 3 presents a summary of artefacts manufactured with the coiling technique recovered in the Middle East, Europe and the Iberian Peninsula and dated in the Neolithic and proximate chronologies. Fibre-based implements manufactured by other techniques and evidence of pottery impressions have been excluded because they are non-informative regarding the materials analysed here.

The geographical situation of the sites is directly related to the climatological conditions which are also implied in the preservation of organic material and the availability of plants. Thus, fragments of baskets were recovered in the archaeological site of Çatalhöyük (Turkey) (Mellaart 1967). The analyses of phytoliths extracted from clay impressions and plant-based implement fragments, followed by their taxonomical identification, succeeded in determining the raw materials used. In this case, coiled baskets were made of wild panicoid grasses, sedges and cereal straw while mats were basically made of sedges and occasionally of common reeds (*Phragmites australis*) (Wendrich and Ryan 2012). In the desertic site of the Fayum (Egypt) (Lucas 1948), baskets were usually used to line silos, and it was determined that wheat straw and grasses were the main materials. It is also suggested that *Typha* sp. would be used because its suitability, but it has not been positively determined (Wendrich and Holdaway 2018; Wendrich et al. 2017). Both archaeological sites were preserved by dehydration due to the climatic aridity of their locations.

Currently available results of the identification of basketry raw materials in Central Europe, in the immediacies of Lake Constance and the Circum-Alpine region point to the use of two categories of fibres in basketry during the Neolithic: fibres from trees or shrub bark, such as lime, oak (*Quercus* sp.) and willow (*Salix* sp.), and bast fibres from flax (*Linum usitatissimum* L.). At the waterlogged Swiss sites of Arbon-Bleiche 3 and Robenhausen, the archaeological remains were taxonomically identified in both cases as Tilia sp. (Altorfer and Médard 2000; Médard 2003; Médard 2012; Rast-Eicher and Dietrich 2015). The Neolithic pile-dwellings in the pre-Alpine region, both in Germany and Switzerland, have provided an extended inventory of textile remains. Their analyses documented the processing of flax, which is considered the most significant finding in the wetland settlements. Even though, they are still unusual compared to bast fibres. The traditional way to process linen may include several steps as harvesting, threshing capsules, retting stems, among others, which have been registered during the Neolithic (Leuzinger and Rast-Eicher 2011; Maier and Schlichtherle 2011). Regarding the northern Europe, the Twyford, Co. site in Ireland has provided eight fragments of a circular or oval object made of thin rods arranged in a spiral probably of Alnus bound by strips of an indeterminate ligneous plant. Besides, it also presents handles made of straw.

At Iberian archaeological sites, basketry remains have been found mainly in the Mediterranean region, except in the case of Cueva del Moro (Alins del Monte, Huesca) near the Pyrenees. Climatic conditions differ longitudinally across the Iberian Peninsula so that aridity is prevalent in eastern and south-eastern regions, where several of the sites in Table 3 are located. This climatic aridity results in the preservation of the remains by dehydration, and in some cases, carbonization is also implied. The case of Cueva del Moro is singular due to its location. The site is located near the Pyrenees and organic material was conserved by dehydration. In this case anatomical analysis was carried out and undetermined monocot and willow (*Salix* sp.) were identified (Alcolea and Rodanés 2019). In turn, the site of Cueva de los Murciélagos (Albuñol, Granada) is the most singular case because of the well-preserved elements employing many basketry techniques including coiling, such as sandals, among others, conserved by dehydration. Raw material was determined as esparto grass (*Stipa tenacissima*) (Alfaro Giner 1980), a Poaceae plant with very similar properties to those detected in La Draga and the Coves del Fem. The use of this family has expanded geographically and temporally, which implies their properties have been found useful since prehistoric times. Even so, no published studies explain the method used in their identification.

Table 3. Plant-fibre coiled production in the Iberian Peninsula, Europe and Middle East.

Location	Archaeological site	Place	Chronology	Preservation conditions	Taxonomical identification	Reference
Middle East	Catalhöyük	Turkey	ca. 7400-6000 BC	Dehydrated	Panicoid grasses, Cyperaceae, Poaceae, *Phragmites australis*	Wendrich and Ryan 2012
	Fayum	Egypt	ca. 5450-4400 BC	Dehydrated	Wheat straw, grasses, Typhaceae	Wendrich and Holdaway 2018; Wendrich et al. 2017
Europe	Arbon-Bleiche 3	Switzerland	3384-3370 BC	Waterlogged	*Tilia* sp., Flax	Altorfer and Médard 2000; Médard, 2003; Médard 2012; Rast-Eicher and Drietrich 2015
	Wetzikon-Robenhausen	Switzerland	ca. 3900-1000 BC	Waterlogged	*Tilia* sp., Flax	
	Twyford, Co.	Ireland	3800-2500 BC	No determined	Probably *Alnus,* Straw	Raftery, 1970
Iberian Peninsula	Cova de les Cendres	Eastern Spain	ca. 7500-6900 cal BC	Charred	No information	Fumanal García and Badal García 2009
	Cueva de los Murciélagos	Southern Spain	5200-4600 cal BC	Dehydrated	*Stipa tenacissima*	Alfaro Giner 1980
	Terlinques El Oficio Cueva del Moro Castellón Alto Ifré Cabezo Redondo Los Millares	Eastern Spain	Bronze Age	Charred or dehydrated	*Stipa tenacissima,* monocots, *Salix* sp.	Alfaro Giner 1984; Alcolea and Rodanés 2019; Jover et al. 2001; Jover and López 2012
	La Draga	Girona	5324-4977 cal BC	Waterlogged	Poaceae, Cyperaceae Typhaceae, *Tilia* sp.	Current study
	Coves del Fem	Tarragona	4941-4545 cal BC	Charred and dehydrated	Cyperaceae	Current study

The sites of La Draga and Coves del Fem present totally different raw materials compared with the other Early Neolithic sites in the Iberian Peninsula that have provided evidence of basketry. As mentioned above, in Cueva de los Murciélagos baskets were made with esparto grass as in most of the Iberian cases except at Cueva del Moro. The raw materials used in each site seem to vary accordingly to the availability of plants in the surroundings. This reflects the profound knowledge Neolithic societies possessed of the natural resources around their territory. As summarized in Table 3, the lack of research in some locations hinders the proper study of these archaeological remains, their comparison, and contextualization with parallel cases. The variability of families used in European and Middle East sites is noteworthy compared with most sites in the Iberian Peninsula. In this sense, the coiled basketry at La Draga and Coves del Fem differs clearly from other Iberian sites as a wider spectrum of different taxa have been documented. Nevertheless, the taxa identified in La Draga and Coves del Fem have been recorded in European contexts or the Near East for similar purposes.

Conclusions.

Plant-based implements are an uncommon archaeological record owing to their perishability. The fact that special preservation conditions permit organic material preservation makes their study an important archaeology research line that has not been well-developed in the Iberian Peninsula. La Draga and Coves del Fem have yielded examples of the most extraordinary early Neolithic basketry production in the Iberian Peninsula and they represent an exceptional opportunity to analyse this sort of material. Here we suggest the use of optical microscopy as an accurate method to identify taxonomically organic raw materials highlighting its simplicity.

The samples collected from basket remains have been identified basically as monocotyledons plants. They have been specifically determined as the Poaceae, Cyperaceae and Typhaceae families, plus Juncaceae which was determined in previous studies. Even so, herbaceous taxa were not the only plants used for coiled basketry. Dicotyledons plants like *Tilia* sp. (Malvaceae) have also been also identified in a few sewn elements. The identification of those families enhances previous archaeobotanical and ecological studies at Lake Banyoles and in the Montsant range. All the identified families would be easy to obtain in the surroundings of both sites, which implies comprehensive environmental knowledge of their inhabitants. The exception is lime bark, which the inhabitants from La Draga would have needed to obtain further away. The availability of raw materials suggests a local production of plant-based implements in both settlements. Moreover, functional studies of wooden, faunal, lithic, and malacological tools in La Draga are consistent with the local plant-fibre processing.

Contextualizing the basketry remains studied here with other Neolithic cases is complex because of the lack of parallel cases. In Europe and the Middle East, the variability in raw materials is similar to the one found in this paper, but it differs from other Iberian cases.

Finally, this study has addressed some difficulties with taxonomical identifications and has suggested different taxa used during prehistory in the north-eastern Iberian Peninsula. In conclusion, several families were selected from the environment for their properties to manufacture plant-based artefacts as basketry. Further studies should be performed to improve and perfect taxonomical identification to species level if possible, by combining different analyses.

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References

Adovasio JM (1977) Basketry Technology: a guide to identification and analysis Chicago: Aldine Publishing Company.

Alcolea M, Rodanés JM (2019) Ephemeral Archaeology South of the Central Pyrenees (Huesca, NE Iberia): The Exceptional Preservation of Woody Objects in Moro de Alins Cave-site. Environ archaeol, DOI: 10.1080/14614103.2019.1654642.

Alfaro Giner (1984) Tejido y cestería en la Península Ibérica. Historia de su técnica e industrias desde la prehistoria hasta la romanización. Consejo Superior de Investigaciones Científicas (CSIC), Instituto Español de Prehistoria. Madrid. ISBN: 84-00-05710-4.

Alfaro Giner C (1980) Estudio de los materiales de cestería procedentes de la cueva de los Murciélagos (Albuñol, Granada). Trabajos de Prehistoria 37, 109.

Aliscioni SS, Ospina JC, Gomiz NE (2015) Morphology and leaf anatomy of Setaria s.l. (Poaceae: Panicoideae: Paniceae) and its taxonomic significance. Plant Syst Evol: Published online. DOI: 10.1007/s00606-015-1251-9.

Altorfer K, Médard F (2000). Nouvelles découvertes textiles sur le site de Wetzikon-Robenhausen (Zürich, Suisse). Sondages 1999. Montagnac. Mergoil, 35-75.

Amini Rad M, Sonboli A (2008) Leaf and stem anatomy of the Cyperus subgenus Cyperus in Iran. Rostaniha, 9(1): 7-21.

Angyalossy V, Pace MR, Evert RF, Marcati CR, Oskolski AA, Terrazas T, Kotina E, Lens F, Mazzoni-Viveiros SC, Angeles G, Machado SR, Crivellaro A, Rao KS, Junikka L, Nikolaeva N, Baas P (2016). IAWA List of Microscopic Bark Features. IAWA Jour 37(4): 517-615. DOI: 10.1163/22941932-20160151.

Antolín F (2013) Of cereals, poppy, acorns and hazelnuts. Plant economy among early farmers (5500-2300 cal BC) in the NE of the Iberian Peninsula. An archaeobotanical approach. Dissertation. Barcelona, Universitat Autònoma de Barcelona.

Antolín F, Buxó R (2011) L'explotació de les plantes al jaciment de La Draga: contribucio a la historia de l'agricultura i de l'alimentació de l'agricultura i de l'alimentació vegetal del Neolític a Catalunya. In Bosch A, Chinchilla J, Tarrús J (eds.) El poblat lacustre del Neolític Antic de La Draga: Excavacions de 2005-2005. CASC-Museu d'Arqueologia de Catalunya, Girona.

Aura Tortosa JE, Pérez-Jordà G, Carrión Micó Y, Seguí Seguí JR, Jordá Pardo JF, Miret i Estruch C, Verdasco Cebrián, CC (2019) Cordage, basketry and containers at the Pleistocene–Holocene boundary in southwest Europe. Evidence from Coves de Santa Maira (Valencian region, Spain). Veg Hist Archaeobot, 29, 581-594. https://doi.org/10.1007/s00334-019-00758-x.

Barber EW (1994) Women's Work: The First 20.000 Years. Women, Cloth and Society in Early Times. New York: W.W. Norton & Company.

Benahmed-bouhafsoun A, Cherifi F, Haili M, Bekhlifi Z, Maamar N, Kaid-Harche, M (2007) Anatomy, Histochimy and the Biometrics of Fibres of Chamaerops humilis L. Growing in Two Different Locality in Alegria. Asian J. Plant Sci. 6(2). DOI: 10.3923/ajps.2007.252.260.

Bergfjord C, Holst B (2010) A procedure for identifying textile bast fibres using microscopy: Flax, nettle/ramie, hemp and jute. Ultramicroscopy, 110(9):1192-1197. DOI: 10.1016/j.ultramic.2010.04.014.

Bodganovic I, Palomo A, Piqué R, Rosillo R, Terradas X (2017) Los últimos cazadores-recolectores en el NE de la Península Ibérica: evidencias de ocupaciones humanas durante el VI milenio cal BC. In: Iber-Crono. Actas del Congreso de cronometrías para la historia de la Península Ibérica: Universitat Autònoma de Barcelona, 35-45.

Borojevic K, Mountaing R (2013) Microscopic identification and sourcing of ancient Egyptian plant fibres using longitudinal thin sectioning. Archaeomet 55(1):81-112. DOI: 10.1111/j.1475-4754.2012.00673.x.

Bosch A, Chinchilla J, Tarrús J (2000) El poblat lacustre neolític de la Draga. Excavacions de 1990-1998. CASC-Museu d'Arqueologia de Catalunya, Girona.

Bosch A, Chinchilla J, Tarrús J (2006) Els objectes de fusta del poblat neolític de la Draga. Excavacions de 1995-2005. CASC-Museu d'Arqueologia de Catalunya, Girona.

Brinkkemper O, van der Heijden E (2012) Appendix A: Fibre identification criterio. In Wendrich W, The World Acconding to Basketry. An Ethno-archaeological Interpretation of Basketry Production in Egypt. Leiden University. Cotsen Institute of Archaeology Press.

Bús C, Tóth B, Stefkó D, Hohmann J, Vasas A (2018) Family Juncaceae: promising source of biologically active natural phenanthrenes. Phytochemi Rev: 17:833–851. DOI: 10.1007/s11101-018-9561-5.

Caruso-Fermé L, Piqué R (2014) Landscape and forest exploitation at the ancient Neolithic site of La Draga (Banyoles, Spain). Holocene, 24(3): 266-273. DOI: 10.1177/0959683613517400.

Clemente I, Cuenca D (2011) Instrumentos de trabajo de concha en el yacimiento neolítico de La Draga. In Bosch, A.; Chinchilla, J., Tarrús, J. (coords.): El poblat lacustre del neolític antic de La Draga. Les campanyes dels anys 2000-2005. Museu d'Arqueologia de Catalunya-CASC (Monografies del CASC, 9): 137-145. Girona.

Coles JM, Heal SVE, Orme BJ (1978) The Use and Character of Wood in Prehistoric Britain and Ireland. Proc Preh Soc, 44:1-45. DOI: 10.1017/S0079497X00009968.

Corrêa FF, Pereira MP, Madail RH, Santos BR, Barbosa D, Castro EM, Pereira FJ (2017) Anatomical traits related to stress in high density populations of Typha angustifolia L. (Typhaceae). Braz J Biol, 77(1): 52-59. DOI: 10.1590/1519-6984.09715.

Croes DR (1977) Basketry from the Ozette village archaeological site: a technological, functional and comparative stud. Dissertation. Washington Archaeological Research Center, Washington State University. Pullman, Washington.

Da Costa CR, Del Curto B, Ratti A (2014) Mechanical and chemical characteristics of vegetable fibers, and some applications. Conference: 7th International Textile, Clothing & design Conference, at Dubrovnik – Croatia. DOI: 10.13140/2.1.1046.8800.

Dahlgren RMT, Clifford HT, Yeo PF (1985) The families of the Monocotyledons. Structure, evolution and taxonomy. Springer – Verlag, Berlin, Heidelberg, New York, Tokyo. ISBN: 3-540-13655-X.

de Diego M, Piqué R, Palomo A, Terradas X, Clemente I, Mozota M (2017) Traces of textile technology in the Early Neolithic lakeside settlement of La Draga (Banyoles, Catalonia) from an experimental perspective. In Universidad Autónoma de Madrid (ed). Playing with the time. Experimental archaeology and the study of the past: 139-144.

de Diego M, Piqué R, Palomo A, Terradas X, Saña M, Clemente I, Mazota M (2018) Evidence of textile technology in the Early Neolithic site of La Draga (Banyoles, Spain). Some hypotheses. In First Textiles. The beginnings of textile manufacture in Europe and the Mediterranean: 69-80. ISBN: 978-1-78570-798-8.

Evert RF (2006) Esau's Plant Anatomy: Meristems, Cells and Tissues of the Plant Body. Their Structure, Function, and Development. 3rd edition. John Wiley and sons, Inc. ISBN: 978-84-282-1443-3.

Florian MLE (1990) Plant Anatomy: An illustrated aid to identification. In Florian MLE, Kronkright DP, Norton RE. The Conservation of Artifact Made from Plants Materials. Princeton University Press, 1-27.

Francheschi VR, Horner HT (1980) Calcium oxalate crystals in plants. Bot Rev, 46(4): 361-427.

Fumanal García MP, Badal García E (2009) In Bernabeu Aubán J, Molina Balaguer L (ed) La Cova de les Cendres (Moraira-Teulada, Alicante). Alicante: MARQ. Museo Arqueológico de Alicante. ISBN: 978-84-96979-44-4.

Gibaja JF (2011) La función de los instrumentos líticos tallados. In Bosch, A., Chinchilla, J. and Tarrús, J. (coord.). El poblat lacustre del neolític antic de La Draga: excavacions 2000-2005, Monografies del CASC, vol. 9, Girona, pp. 91-100.

Hardy K (2008) Prehistoric String Theory. How Twisted Fibers Helped to Shape the World. Antiquity 82 (316): 271–280. DOI: 10.1017/S0003598X00096794.

Harris S, Haigh S, Handley A, Sampson W (2016) Material choices for fibre in the Neolithic: an approach through the measurement of mechanical properties. Archaeometry, 59(3): 574-591. DOI: 10.1111/arcm.12267.

Haugan E, Holst B (2013) Determining the fibrillar orientation of bast fibres with polarized light microscopy: the modified Herzog test (red plate test) explained. J Microsc, 252(2): 159-168. DOI: 10.1111/jmi.12079.

Hurcombe LM (2007) Archaeological artefacts as material culture. Routledge, London.

Jingjing L, Zhang A, Zhenglei Z, Liang Y, Li X, Ren L (2017) The Structure and Flexural Properties of Typha Leaves. Appl Bionics Biomech. DOI: 10.1155/2017/1249870.

Jover FJ, López JA (2012) La producción textil durante la Edad del Bronce en el cuadrante suroriental de la Península Ibérica: materias primas, productos, instrumentos y procesos de trabajo. Zephyrus, LXXI, 149-171.

Jover FJ, López JA, Machado Yanes C, Herráez Martín MI, Rivera Núñez D, Precioso Arévalo ML, Llorach Asunción R (2001) La producción textil durante la Edad de Bronce: un conjunto de husos y bobinas de hilo del yacimiento de Terlinques (Villena, Alicante). Trabajos de Prehistoria, 58(1), 171-186.

Leuzinger U, Rast-Eicher A (2011) Flax processing in the Neolithic and Bronze Age pile-dwelling settlements of eastern Switzerland. Veget Hist Archaeobot. 20:535-543. DOI: 10.1007/s00334-011-0286-2.

Llamas F, Acedo C, Andrés J, Carbó R, Pérez MA, Penas Á (1993) Anatomy of the European species of Carex L. sect. Unciniiformes Kük (Cyperaceae). Anales Jard Bot Madrid 51(1): 97-109.

López i Bultó O (2015) Processos d'obtenció transformació i ús de la fusta en l'assentament neolític antic de La Draga (5320-4800 cal BC). Dissertation. Barcelona, Universitat Autònoma de Barcelona.

López-Bultó O, Piqué R (2018) Wood Procurement at the Early Neolithic site of La Draga (Banyoles, Barcelona). J Wet Archaeol. DOI: 10.1080/14732971.2018.1466415.

Lucas A (1948) Ancient Egyptian Materials and Industries, third ed. Edward Arnold.

Lukešová H, Salvador Palau A, Holst B (2017) Identifying plant fibre textiles from Norwegian Morevingian Perior and

Viking Age graves: The Late Iron Age Collection of the University Museum of Bergen. J Archaeol Sc Rep, 13:281-285. DOI: 10.1016/j.jasrep.2017.03.051.

Maier U, Schlichtherle H (2011) Flax cultivation and textile production in Neolithic wetland settlements on Lake Constance and in Upper Swabia (south-west Germany). Veget Hist Archaeobot, 20:567-578. DOI: 10.1007/s00334-011-0300-8.

Martínez-Segarra G, Abad P, Devesa JA (2017) Study of the leaf anatomy in cross-section in the Iberian species of Festuca L. (Poaceae) and its systematic significance. PhytoKeys 83: 43-74. DOI: 10.3897/phytokeys.83.13746

Martins S, Alves M (2009) Anatomical features of species of Cyperaceae from northeastern Brazil. Brittonia, 61(2): 189–200. DOI: 10.1007/s12228-009-9073-0.

Mavi DO, Dogan M, Cabi E (2011) Comparative leaf anatomy of the genus Hordeum L. (Poaceae). Turk J Bot, 35: 357-368. DOI: 10.3906/bot-1003-14.

McManus HA, Seago JL JR, Marsh LC (2002) Epifluorescent and Histochemical Aspects of Shoot Anatomy of Typha latifolia L., Typha angustifolia L. and Typha glauca Godr. Ann Bot, 90:489-493. DOI: 10.1093/mcf211.

Médard F (2003) Vestiges textiles et activités de filage sur le site néolithique d'Arbon-Bleiche 3 (TG Suisse), Bull Soc préhist fr, vol. 100, nº 2, pp. 375–391.

Médard F (2012) 18: Switzerland: Neolithic Period. In Gleba M, Mannering U (eds) Textiles and Textile Production in Europe from Prehistory to AD 400. Oxbow Books. Ancient textiles series, vol. 11: 367-377. ISBN: 978-1-84217-463-0.

Mellaart J (1967) Çatal Huyuk: A Neolithic Town in Anatolia, Editorial McGraw Hill.

Okagaki RJ, Haaning A, Bilgic H, Heinen S, Druka A, Bayer M, Waugh R, Muehlbauer GJ (2018) ELIGULUM-A Regulates Lateral Branch and Leaf Development in Barley. Plant Phys, 176: 2750-2760.

Palomo A, Piqué R, Terradas X, Bosch A, Buxó R, Chinchilla J, Saña M, Tarrús J (2014) Prehistoric occupation of Banyoles lakeshore: results of recent excavations at La Draga site, Girona, Spain. J Wetl. Archaeol, 14, 58-73.

Palomo A, Piqué R, Terradas X, López-Bultó O, Clemente I, Gibaja JF (2013) Woodworking technology in the Early Neolithic site of La Draga (Banyoles, Spain). In Anderson PC, Cheval C, Durand A. (eds.) Regards Croisés Sur Les Outils Liés Au Trevail Des Végétaux. An Interdisciplinary Focus on Plant-Working Tools. XXXIII Rencontres Internationales d'archéologie et d'histoire d'Antibes. APDCA, Antibes, pp. 383–396.

Palomo A, Terradas X, Piqué R, Rosillo R, Bodganovic I, Bosch A, Saña M, Alcolea M, Berihuete M, Revelles J (2018) Les Coves del Fem (Ulldemolins, Catalunya). Servei d'Arqueologia i Paleontologia – Tribuna d'Arqueologia 2015-2016. Departament de Cultura de la Generalitat de Catalunya. Direcció General del Patrimoni Cultural. Subdirecció General del Patrimoni Arquitectònic, Arqueològic i Paleontològic.

Panshin AJ, de Zeeuw C (1980) Textbook of Wood Technology: Structure, identification, properties, and uses of the commercial woods of the United States and Canada. 4th ed. McGraw-Hill Series in Forest Resources. New York, McGraw-Hill Book Co.

Piqué R, Berihuete M, Franch A, Gassman P, Girbal J, Herrero-Otal M, López-Bultó O, Palomo A, Rageot M, Revelles J, Romero-Brugués S, Terradas X (in press) Woody and non-woody forest raw material at the early Neolithic site of La Draga (Banyoles, Spain). In Berihuete M, De Force K, Martin M, López Bultó O, Piqué R. (eds.) The missing woodland resources: Archaeobotanical studies of the use of plant raw material. Barkhuis' series Advances in Archaeobotany.

Piqué R, Palomo A, Terradas X, Tarrús J, Buxó R, Bosch A, Chinchilla J, Bodganovic I, López-Bultó O, Saña M (2015) Characterizing prehistoric archery: technical and functional analyses of the Neolithic bows from La Draga (NE Iberian Peninsula). J. Archaeol. Sci. 55, 166–173.

Piqué R, Romero S, Palomo A, Tarrús J, Terradas X, Bogdanovic I (2018) The production and use of cordage at the early Neolithic site of La Draga (Banyoles, Spain), Quaternary International. http://dx.doi.org/10.1016/j.quaint.2016.05.024.

Raftery J (1970) Prehistoric Coiled Basketry Bags. J Roy Soc Antiq Ire, 100(2): 167-168.

Rast-Eicher A and Dietrich A (2015) Neolithische und bronzezeitliche Gewebe und Geflechte. Die Funde aus den Seeufersiedlungen im Kanton Zürich. Monographien der Kantonsarchäologie Zürich, 46. ISBN: 978-3-906299-00-6.

Revelles J, Antolín F, Berihuete M, Burjachs F, Buxó R, Caruso L, López O, Palomo A, Piqué R, Terradas X (2014) Landscape transformation and economic practices among the first farming societies in Lake Banyoles (Girona, Spain). Environ Archaeol, 19(3): 298-310. DOI: 10.1179/1749631414Y.0000000033.

Revelles J, Cho S, Eriarte E, Burjachs F, van Geel B, Palomo A, Piqué R, Peña-Chocarro L, Terradas X (2015) Mid-Holocene vegetation history and Neolithic land-use in the Lake Banyoles area (Girona, Spain). Palaeogeogr Palaeoclimatol Palaeoecol, 435: 70-85. DOI: https://doi.org/10.1016/j.palaeo.2015.06.002.

Revelles J, van Geel B (2016) Human impact and ecological changes in lakeshore environments. The contribution of non-pollen palynomorphs in Lake Banyoles (NE Iberia). Rev Palaeobot Palyno, 232: 81-97. DOI: https://doi.org/10.1016/j.revpalbo.2016.05.004.

Romero-Brugués S, Piqué Huerta R, Herrero-Otal M (2021) The basketry at the early neolithic site of La Draga (Banyoles). J Archaeol Sc Rep, 35. DOI: 10.1016/j.jasrep.2020.102692.

Rowell RM, Han JS, Rowell JS (2000) Characterization and Factors Effecting Fiber Properties. In Follini E, Leao AL, Mattoso, LHC (eds.). Natural Polymers and Agrofibers Composites. Embrapa Instrumentacao Agropecuaria, San Carlos, Brazil, 115-134.

Schick T (1988) Nahal Hemar Cave. Cordage, basketry and fabrics. Atiqot 18:31-43.

Schick T (2002) The early basketry and textiles from caves in the Northern Judean Desert. In Surveys and excavations of caves in the Northern Judean Desert. Antiqot XLI, Part 2, 223-239.

Schweingruber FH, Börner A, Schulze ED (2011) Atlas of Stem Anatomy in Herbs, Shrubs and Trees. Springer-Verlag Berlin Heidelberg.

Smith C, Lowe B, Blair K, Carr D, McNaughton A (2013) Identification of historical plant material using micro-computed tomography. Stud Conserv, 58(3): 256-268. DOI: 10.1179/2047058412Y.256 0000000043.

Soffer O (2004) Recovering Perishable Technologies Through Use Wear on Tools: Preliminary Evidence for Upper Paleolithic Weaving and Net Making. Current Anthropology 54(3): 407–413.

Suomela JA, Vajanto K, Räisänen R (2018) Seeking Neetle Textiles – Utilizing a Combination of Microscopic Methods for Fibre Identification. Stud Conserv, 67(7):412-422. DOI: 10.1080/00393630.2017.1410956.

Svedarsky D, Grosshans R, Venema H, Ellis-Felege S, Bruggman J, Ostlund A, Lewis J (2019) Integrated management of invasive cattails (Typha spp.) for wetland habitat and biofuel in the Northern Great Plains of the United States and Canada: A review. Mires and Peat, Volume 25, Article 09, 1–14. DOI: 10.19189/MaP.2018.APG.367.

Terradas X, Piqué R, Palomo A, Antolín F, López O, Revelles J, Buxó R (2017). Chapter 8: Farming Practices in the Early Neolithic According to Agricultural Tools: Evidence from La Draga Site (Northeastern Iberia). In García-Puchol O, Salazar-García DC (eds.). Times of Neolithic Transition along the Western Mediterranean, Fundamental Issues in Archaeology. DOI: 10.1007/978-3-319-52939-4_8.

Thomas R (2013) Anatomy of the endemic palms of the Near and Middle East: archaeobotanical perspectives. Rev d'ethnoécologie (online), 4. DOI: 10.4000/ethnoecologie.1366.

Thomas R, De Franceschi D (2013) Palm stem anatomy and computer-aided identification: the Coryphoideae (Arecaceae). Am J Bot 100(2): 289–313. DOI: 10.3732/ajb.1200242.

Wendrich W (1989) The World According to Basketry. An Ethnoarcheological Interpretation of Basketry Production in Egypt. Leiden. ISBN: 90-5789-035-6.

Wendrich W, Holdaway SJ (2018) Basket use, raw materials and arguments on early and Middle Holocene mobility in the Fayum, Egypt. Quater Int, 468. DOI: 10.1016/j.quaint.2017.01.010.

Wendrich W, Holdaway SJ, Phillips R, Emmitt JJ (2017) Chapter 5: The K basin archaeological record. In: Wendrich W, Holdaway SJ (eds.) The Desert Fayum reinvestigation: The early Mid-Holocene landscape archaeology of the Fatum north shore, Egypt. Monumenta archaeology, vol. 39. Cotsen Institute of Archaeology. Press at UCLA. DOI: 10.2307/j.ctvdjrq99.

Wendrich W, Ryan P (2012) Phytoliths and Basketry Materials at Çatalhöyük (Turkey): Timelines of growth, harvest and objects life histories. Paléorient, 38, n°1-2: 55-63. DOI: 10.3406/paleo.2012.5458.

6.2.5. The use of decalcifiers in the analysis of dental calculus and plant fibres: the case study of the Early Neolithic site of Cova del Pasteral (Girona, Spain).

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This paper addresses the need to search for evidence of plant fibres in non-perishable materials. In this context, the known use of teeth as tools for processing plant fibres in modern hunter-gatherer societies suggests that such fibres may be preserved in calcified bacterial plaque, known as dental calculus. A methodological approach commonly used in traditional dental calculus analysis was tested to assess its effect on plant fibres. Specifically, EDTA and HCl agents at concentrations of 0.2M and 0.5M were applied to six different types of modern plant fibres for 5, 30, 90 and 170 hours. The results showed that none of these treatments altered the appearance of the plant fibres. The methods were then applied to control samples of dental calculus from a medieval archaeological site. In all cases, the recovered fibres had a similar appearance, although the EDTA-treated samples showed a higher number of fibres. On the basis of these results, 0.5M EDTA was selected for the treatment of Early Neolithic samples from the Cova del Pasteral site (Girona).

The use of decalcifiers in the analysis of dental calculus and plant fibres: the case study of the Early Neolithic site of Cova del Pasteral (Girona, Spain).

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Abstract

Perishable organic raw materials such as plant fibres have been widely used since the time of the earliest human groups, although their poor preservation limits our knowledge of their use. Filling this gap requires a focused search for plant fibre evidence in non-perishable materials. Since teeth are sometime used in fibre-processing, evidence of fibres can be sought in mineralised bacterial plaque, and therefore its analysis can potentially be useful in the study of plant-human relationships. Experimental protocols have been tested to improve the recovery of microremains in dental calculus, although these are typically focused on microremains other than plant fibres. This paper investigates the possibility that plant fibres are identified less often in dental calculus because the corrosive agents used causes their disappearance. EDTA and HCl agents at 0.2M and 0.5M were applied for 5, 30, 90 and 170 hours to six different modern plant fibres considering their use in archaeological craft activities, and showed that none of the procedures affected their characteristics. After testing the same approach on medieval control dental calculus samples, a selected methodology (0.5M EDTA) was applied to ancient dental calculus from the Neolithic site of Cova del Pasteral (La Cellera de Ter, NE Spain) as a case study to identify the plant fibres present in it.

Keywords: plant fibres, dental calculus, indirect register, decalcification, methodology.

Introduction.

Plant fibres record in archaeology.

Perishable organic raw materials such as wood, plant fibres and skins have been widely used since the time of the earliest human groups. They are not commonly preserved in archaeological contexts, and consequently have not usually been studied in detail in archaeology, even though they are key to understanding human adaptations, past technological skills and ecological knowledge. The poor preservation of perishable material has limited our knowledge of past plant crafts, such as those made from plant fibres. Botanically, they are described as sclerenchyma cell bundles associated with vascular plant support and nutrient transport functions. However, in fibre crafts, the complete stem or leaves can also be used. Their composition is based on lignin and cellulose in varying concentrations, which gives durability, flexibility, and strength to the fibres (Evert 2006).

Although direct archaeological evidence is scarce (Hurcombe 2014), the use of this material has been well documented since Upper Pleistocene chronologies (Barber 1994; Soffer 2004; Hardy 2008; Kvavadze et al. 2009). Other indirect evidence can be obtained from the analysis of use-wear preserved on lithic and bone tools that attest work with plant materials. Current information about their use is usually provided by the analysis of fibre impressions on durable materials such as clay or pottery (Soffer et al. 2000; Wigforss 2014; Romero-Brugués et al. 2022; Guerra-Doce et al. 2024). Direct evidence of plant crafts becomes more frequent in early Holocene contexts (Aura Tortosa et al. 2019; Martínez Sevilla et al. 2023), although it remains limited to contexts with extraordinary preservation conditions. The environmental conditions in which organic materials can be preserved are unusual and limited to places where there is persistent waterlogging, aridity, or where the materials have been carbonised or mineralised.

The limited direct evidence for fibre-based materials in archaeology hinders our understanding of past craft activities, including variability in raw materials, technology, functionality, and distribution (Hurcombe 2014), and also their role in past societies, where they preceded other material cultures, such as pottery, but survived the introduction of new materials and are still part of a living material culture all around the world (Kuoni 1981). Filling this gap requires a focused search for evidence of the use of plant fibre in other non-perishable materials, like the tools used in plant fibre processing. In this sense, the use of teeth as a third hand in plant craft processing, which has been recorded in ethnographic and archaeological contexts (Schulz 1977; Milner and Larsen 1991; Bocquetin et al. 2005; Scott and Jolie 2008; Lozano et al. 2008), opens an opportunity to approach the fibres that can be potentially preserved in durable or mineralised materials such as bacterial plaque adhered to teeth. These studies are proving to be an effective method of gathering information without direct remains of fibre-based materials such as baskets or textiles.

Dental calculus and its research.

Dental calculus is the naturally mineralised bacterial plaque that adheres to the teeth and becomes calcified if not removed when it is soft. Dental calculus contains an organic fraction (amino acids, peptides, carbohydrates, and lipids) and an inorganic fraction composed mainly of calcium phosphate salts (Blatt et al. 2011; Lieverse 1999; Middleton 1994). It is associated with saliva production which is a guarantee against post-mortem inclusions. During its formation, particles of diverse nature can be trapped, including starch granules, phytoliths, fungal spores, plant fibres, animal hairs, and other lithological compounds such as pigments (Blondiaux and Charlier 2008; Power et al. 2018; Radini et al. 2019).

New insights into the palaeodiet and subsistence patterns of ancient populations have been provided by the identification of microremains entrapped in dental calculus matrix, demonstrating the consumption of inhaled or ingested materials during daily activities or the use of teeth as a third hand for extra-masticatory work (Masaubach 2012; Mickleburgh and Pagán-Jiménez 2012; Buckley et al. 2014; Warinner et al. 2014, Hardy et al. 2016; Radini 2016; Cristiani et al. 2018; Sperduti et al. 2018; among others). Molecular analyses have also been developed in relation to dental calculus to detect proteins, isotopes, DNA and associated metabolites (Preus et al. 2011; Adler et al. 2013; De La Fuente et al. 2013; Warinner et al. 2014; Hendy et al. 2018; Wright et al. 2021). In addition, particles within the dental calculus matrix provide an opportunity to infer past human life by combining physical anthropology, biomolecular analysis and archaeobotany.

Plant fibres and dental calculus.

Although the analysis of dental calculus microdebris is mainly focused on the presence of starch and phytoliths to explain dietary and medicinal practises (Fiorin et al. 2019; Hardy et al. 2012, 2016; Henry et al. 2012; Horrocks et al. 2014; Power et al. 2015, 2018; Tromp and Dudgeon 2015), plant fibres are also found. Debris of bast fibres such as hemp (Cannabis sp.), flax (Linum usitatissimum) and nettle (Urtica dioica), as well as cotton (Gossypium sp.) have been recorded by several researchers (Blatt et al. 2011; Warinner et al. 2014; Cristiani et al. 2016; Radini et al. 2016; MacKenzie 2022).

The presence of vegetal fibres can result from craft activities such as the production of textiles and baskets (Blatt et al. 2011; Radini et al. 2017), as well as from building or repair materials (Norström et al. 2019). Linking the presence of fibre debris in dental calculus to craft activities requires the consideration of other anthropological parameters, such as dental wear. This connection can be established when there is a significant concentration of debris and a large enough sample size of individuals for statistical analysis (Radini et al. 2019). This presence is justified by the use of dentition in extra-masticatory activities, which has been documented from an ethnographic and archaeological perspective (Schulz 1977; Milner and Larsen 1991; Bocquetin et al. 2005; Scott and Jolie 2008; Lozano et al. 2008)

As mentioned, dental calculus analyses can be potentially useful for studying plant-human relationships although limitations in interpretations should be considered (Hardy et al. 2018). It has been discussed how representative the results are of the role plants played in human activities and environment description (Radini and Nikita 2023), in both quality and quantity (Hardy et al. 2018; Power et al. 2021). Methodological issues may also be considered regarding the results of debris immersed in dental tartar deposits. Some chemical compounds usually used to disaggregate the matrix can be damaging to organic remains like plant debris (Le Moyne and Crowther 2021; Tromp et al. 2017). More research is now being carried out to improve methodologies for the extraction of remains (Hardy et al. 2018; Power et al. 2021; Radini et al. 2017).

The most common decalcification methodology uses hydrochloric acid (HCl) (Tromp et al. 2017; Mackie et al. 2017; Warinner et al. 2014; Gismondi et al. 2020; Fiorin et al. 2019; among others) and ethylenediaminetetraacetic acid (EDTA) (Modi et al. 2020; Mackie et al. 2017; Juhöla et al. 2019; Tromp et al. 2017; Fagernäs et al. 2020; Soto et al. 2019; among others), or even the non-chemical disintegration of calculus (Bucchi et al. 2019). Some authors recently recommended the use of EDTA instead of HCl based on the higher rates of microremain recovery (Tromp et al. 2017) and the null or minimal modification of the starch granules (Modi et al. 2020; Soto et al. 2019). Nonetheless, HCl is more commonly used in concentrations ranging from 0.05 to 9.5M. This is an aspect to be considered because of the important loss of information due to the chemical processes the material is submitted to. Decalcification processes including chemical concentrations and solvent exposure times may have a degradation effect on organic microremains, such as starch grains, pollen or even plant fibres (Le Moyne and Crowther 2020).

Experimental protocols to test the effectiveness of different concentrations of EDTA and HCl agents have also been performed and the use of EDTA has been proposed as a gentler decalcifier that increases the amount of microremains recovered from dental calculus samples (Tromp et al. 2017; Modi et al. 2020). Although other researchers documented that EDTA could cause alterations in starch granules (Soto et al. 2019), the latest experimental analysis proposed by Le Moyne and Crowther (2020) concluded that the use of low concentrations of HCl or EDTA is appropriate for dental calculus decalcification and recovery of starch grains.

Traditional focus on dental calculus research has been the analysis of starch granules preserved within dental calculus from early human diets (Hardy et al. 2012, 2016; Henry et al. 2011; Horrocks et al. 2014; Power et al. 2015, 2018; Tromp and Dudgeon 2015). However, more research should be performed to focus on plant fibres. The analysis of plant fibres immersed in a dental calculus matrix owing to fibre crafting is a promising line of research, but it has been underexplored in terms of both the methodological approach and the debris identification.

The aim of the present research is to propose a methodological procedure for the recovery of plant fibres embedded in calcified dental calculus samples, as this microdebris is often overlooked in dental calculus content analysis. The existing literature does not clarify whether this oversight is due to limitations in the recovery method, difficulties in identification, both factors, or other reasons. This paper addresses the question of whether plant fibres are under-represented in dental calculus analysis due to their potential destruction during the decalcification process.

Materials.

<u>Plant fibres for a methodological proposal.</u>

From this methodological perspective, three monocot species were selected: esparto grass (Stipa tenacissima), bulrush (Scirpus holoschoenus), and cattail (Typha sp.) (Table 1). Esparto grass is an endemic dry plant found in the central and southern parts of the Iberian Peninsula. Its use is documented from Mesolithic chronologies (Aura Tortosa et al. 2019; Martínez-Sevilla et al. 2023) to the present, and it is traditionally known as one of the most used plant fibres in Iberia. In addition, bulrush and cattails, both monocot hydroponic plants, were selected. Both have been traditionally used in basketry in different parts of the Iberian Peninsula, such as the northeast, since the establishment of the first farmers and herders in the Neolithic (Herrero Otal et al. 2021; Romero-Brugués et al. 2021). In order to study dicots, two different herbaceous plants were used: nettle (Urtica dioica) and flax (Linum usitatissimum), and the bast from an arboreal plant, the lime tree (Tilia sp.) (Table 1). In the first two cases, they are bast fibres, and in the case of the lime tree, the fibres are extracted from the secondary xylem. The use of these families of dicots has been very widespread since the Neolithic from northern to southern Europe (Gramsch 1992; Bender Jørgensen 1992; Altorfer and Médard 2000; Médard 2003; Miettinen et al. 2008; Wigforss 2014; Piqué et al. 2018; Herrero-Otal et al. 2023). The state of processing refers to the treatment the fibres need to be submitted to in order to make them malleable and usable for crafting. Although there is a wide diversity of ways to process this plant material, the most common ones are physical crushing or retting in water. In the present research, the processing of the plant fibres was chosen according to how they are normally used in traditional crafts. Thus, for the monocotyledonous families, esparto grass was used both raw and processed, and cattail and bulrush raw. The three dicots (flax, stinging nettle and lime tree) were used in their processed state.

Dental calculus samples.

Control sample: the Castell de Besora site (Santa Maria de Besora, Spain).

The Monumental Complex of the Castell de Besora is located on top of a hill, 1 km from the village of Santa Maria de Besora (Osona). On this summit, which is at 1025 m. a.s.l., lie the remains of the Castell de Besora, which was built in the 9th century, and the church of Santa Maria, constructed in the 11th century (Busquets and Fàbregas 2008). Besora was an important power centre during the medieval period until the castle's decline in the 14th century. The church of Santa Maria remained active until the 18th century, when a new church was built on the village plain. The land surrounding the church building was the necropolis for the local population, and a significant number of skeletons has been excavated.

Burial CB21-187 corresponds to an adult female individual buried in the parish necropolis surrounding the church, near the atrium arches. The anthropological field information records an adult female with a large amount of tartar deposits; these were sampled for the methodological approach of the present paper to test different procedures instead of using more ancient and valuable samples in order to prevent their loss. Dental calculus was collected from teeth 31, 32 and 33 (FDI System).

Neolithic case study: the Cova del Pasteral site (La Cellera de Ter, Spain).

The archaeological site of Cova del Pasteral refers to a set of naturally communicated caves nearly 300 m in length located in El Pasteral (La Cellera de Ter), in the northeast of the Iberian Peninsula 20 km west of Girona (Figure 1). The caves emerge in an outcrop of limestone on the northern side of a hill called Muntanya de Canet or Puig de Gria. This burial cave with Neolithic archaeological materials was found at the end of the 20th century when the area was exploited as a marble quarry.

Figure 1. Location of Cova del Pasteral and Entrance-1 between the marble outcrops.

The site was visited numerous times by residents in the area who recovered archaeological materials from the site. Riuró (1942) published the first description of the cave and the materials recovered are currently stored in the Museu d'Arqueologia de Catalunya (MAC). In the 1980s, speleologists made some interesting new finds on the cave, and the first archaeological analysis of the materials was published. Bosch (1985) carried out a study of the materials recovered from the site and dated them in a wide chronocultural period: from the Early to the Late Neolithic/Chalcolithic. Furthermore, the anthropological analysis of the human remains identified at least 23 individuals (nine from the early phase of the site, and 14 from the latest) (Campillo and Vives 1985). Since the discovery of a possible natural entrance to the cave (Entrance-1) in the 2020 archaeological field season (García 2020), the annual fieldwork from 2021 to 2023 confirmed the existence of this access as well as its richness in prehistoric remains. The pottery record from the excavations has confirmed the chronocultural adscriptions made by Bosch (1985). Together with the first radiocarbon results, this dates the use of Cova del Pasteral in ca. 5000-3000 BC.

The material from the site studied in this research was recovered in the Early Epicardial Neolithic layer (UE1008). It is characterized by the high concentration of pottery fragments chronologically ascribed to this chronological phase and dispersed human remains (Rosillo et al. 2022). Anthropological studies have found that at least twelve individuals from all age groups were buried in the cave during this period. In addition, the analysis of the bone remains have identified degenerative osteoarthritis in vertebrae, calcification of the anterior ligament of the joints, and infectious pathologies in the mouth, such as caries (Agustí Farjas 2022).

Figure 2. In situ tartar deposits from the Cova del Pasteral site: isolated Tooth 14 (left) and Tooth 22 (right).

Dental calculus analysed in the current paper was collected from two isolated teeth from the Epicardial Neolithic layer. As both teeth were isolated, no further information about the individuals is available, besides them being adult teeth with different wear patterns but no other pathologies. Supragingival tartar deposits from buccal surfaces were extracted from a maxillary right first premolar (Tooth 14) and from a maxillary lateral incisor (Tooth 22) (Figure 2).

Methods.

In order to establish the appropriate methodological approach, a bibliographic review of dental calculus analysis was carried out in order to select different solvents, concentrations and reaction times to test their effect on plant fibres. EDTA and HCl solvents were selected and applied at 0.2M and 0.5M for 5, 30, 90 and 170 hours to both the plant fibres and the dental calculus samples, as explained below.

<u>Selection of vegetal species and testing protocol.</u>

Plants documented for craft purposes at different times in prehistory and history, as well as those that are still being used, were selected. This selection aimed to be representative of the different types of plant fibres that are and have been traditionally used basketry and textile production. Differences in the way they are normally physically processed were also taken into account.

The samples of plant species were washed to remove any residual sediment using a Bransonic® 5510EDTH ultrasound machine in the Anthropology Unit of the Department of Animal Biology, Plant Biology and Ecology (BABVE) at the Autonomous University of Barcelona (UAB). The washing procedure consisted of immersing the fibres in ultrapure Mili-Q water in the ultrasonic machine for 15 minutes. This process was repeated three times, changing the ultrapure water between each bath. The samples were then dried in a laboratory oven for approximately 48 hours or until completely dry.

Two different decalcification procedures were used in the current methodological approach, taking into account previous analyses on dental calculus samples. Following this, EDTA and HCl were used in two different concentrations (0.2M and 0.5M) for four different reaction times (5, 30, 90 and 170 hours). The procedure consisted of immersing the fibres in the different solvents during different periods. The samples were then transferred into 1.5 ml Eppendorf tubs and washed with ultrapure Mili-Q water. Washing involved shaking the samples manually and with a vortex, and centrifuging them using a microcentrifuge machine for 5 minutes at 3,000 RPM. This procedure was repeated three times to remove any residual solvent. The samples were then mounted for optical microscopy using Euromex PB5265 Entellan permanent mounting medium. Both transverse and epidermal sections were prepared from the raw fibres, while the processed fibres were mounted directly, corresponding to longitudinal views. The samples were examined using an Olympus BX43 optical microscope with a polarizing filter coupled with an Olympus DP26 camera linked to Olympus cellSens software. The observation was performed in the Archaeobotany Laboratory of the Prehistory Department at the Autonomous University of Barcelona (UAB).

<u>Dental calculus analysis.</u>

The same methodological approach carried out on the modern plant fibres was then performed on control samples from the Castell de Besora site to test the decalcification process and to demonstrate the effect of the solvents used on plant fibres immersed in dental calculus samples, prior to the analysis of Neolithic dental calculus. Finally, the tested methodology was applied to ancient dental calculus material from the Neolithic site of Cova del Pasteral as a case study to identify the fibres in the calculus.

Sampling and decontamination.

A published protocol for the extraction of microremains from archaeological human dental calculus was followed for the initial steps of selection, documentation, removal, storage, weighing and decontamination (Fiorin and Cristiani 2024), although some steps were adapted to the laboratory facilities. Following this protocol, dental calculus samples were selected according to their size and origin, quantity, colour and texture. The teeth were photographed before and after removing the tartar. The whole process was carried out in the Anthropology Unit of the Department of Animal Biology, Plant Biology and Ecology (BABVE) at the Autonomous University of Barcelona (UAB).

The teeth were then cleaned mechanically with distilled water using a new soft toothbrush. Tartar was removed from each side of the tooth using a dental scaler. In addition, tartar was extracted separately according to the part of the tooth from which it originated (lingual, buccal, distal, medial or occlusal). The samples were weighed and transferred into 1.5 ml Eppendorf plastic tubes.

Decontamination of the samples consisted of removing any residual soil adhering to their outer surface. Contaminants were extracted from the sediments using ultrapure water and shaken manually several times at minimum speed in a vortex. The deposits were then cleaned manually under a stereomicroscope using a nylon brush soaked in drops of 0.5M HCl. At this point the samples were rinsed with ultrapure water and centrifuged up to three times to remove any residual sediment or HCl. The samples were then transferred to new sterile 1.5 ml Eppendorf tubes and dried until processed for calculus disaggregation.

Disaggregation, microscopical observation and identification.

Although there is no standardisation of the methods used to decalcify dental calculus, the literature has grown in recent years. Authors have tried different methods such as no chemical treatment (Power et al. 2018), while other chemical methods using different solvents such as ethylenediaminetetraacetic acid (EDTA) or acetic acid (HCl) have been tested (Boyadjian 2018; D'Agostino et al. 2019; Hardy et al. 2016; Tromp et al. 2017). The choice of decalcification method is very important, as it may affect the number and identification of microremains (Bucchi et al. 2019).

With regard to the tartar used in the methodological approach, from the Castell de Besora site, the same solvents and times as in the plant fibre methodological approach were used. Thus, EDTA and HCl at 0.2M and 0.5M were used for 5, 30, 90 and 170 hours. Dental calculus samples were transferred to 1.5 ml Eppendorf tubes and washed with ultrapure Mili-Q water. Washing consisted of manual and vortex shaking and centrifugation in a microcentrifuge for 5 minutes at 5,000 rpm. The samples were then immersed in the different solvents and mixed manually and by vortexing several times during the different decalcification times. When the samples were disaggregated, they were centrifuged at 5,000 rpm for 5 minutes and the supernatant was removed. The pellet was rinsed with ultrapure Mili-Q water and centrifuged again to remove any residual acid. It should be noted that in some cases the time and speed of centrifugation was modified to achieve pellet deposition. This procedure was repeated three times for each sample to remove any residual solvent.

For the case study samples, from the Cova del Pasteral site, following the results obtained from the methodological approach with the modern plant fibres and the test with control medieval dental calculus, 0.5M EDTA was chosen to disaggregate them. In this case, the exposure time was until the sample was completely disaggregated, but in no case more than 170 hours. The rest of the procedure was the same as for the control samples.

Dental calculus samples were then mounted on optical microscope slides with pure glycerine and sealed with transparent nail polish. The samples were examined with the same optical microscope as used for the plant fibres in the same laboratory facilities. Finally, the microremains were photographed, measured, described, and compared with modern reference materials. It should be noted that greater attention was paid to microremains found embedded in the dental calculus matrix and those situated in the centre of the samples, which supports the absence of contamination.

Results.

<u>Methodological approach.</u>

Plant fibre materials.

Each of the plant fibres was observed in detail in order to identify any changes in their appearance due to the use of 0.2M and 0.5M EDTA and HCl. In the case of the raw fibres, both the transverse section and the epidermis were observed. In the case of processed fibres, it is difficult to observe both the transversal section and the epidermis (because processing usually involves physical damage), so in this case the longitudinal characteristics were considered.

Stipa tenacissima (raw). Raw esparto grass leaves are naturally flat, but in arid environments they convolute to reduce their size and limit water transpiration. This folding is clearly visible in the transverse section views as protuberances on the abaxial surface containing isolated vascular bundles surrounded by a thick sclerenchyma tissue. Adaxial and abaxial epidermis are different in appearance as the former is smooth with short and long cells alternation, while abaxial epidermis is characterised by a high concentration of silica hairs and stomata in the inner part of the protuberances (Figure SM1-4).

Stipa tenacissima (processed). The previous characteristics of raw esparto grass are mostly lost when it is physically processed. The transversal section becomes difficult to observe, although in both adaxial and abaxial surfaces some of the cells are visible in some scattered parts. Otherwise, inner structures like parenchyma and sclerenchyma tissue are visible longitudinally. In both cases, they correspond to histological structures very similar to other plant families and species and they are not characteristic enough for raw material determination (Figure SM5-8).

Scirpus holoschoenus (raw). Bulrush stems are characterized by a rounded or oval cross section in which the inner part can be full of parenchyma/aerenchyma tissue depending on the species and the age on the stem. In the case of Scirpus holoschoenus this medulla part is empty. Even so, the isolated vascular bundles are arranged in different rows along the tissue with the large ones in the outer part, surrounded by sclerenchyma tissue. Collenchyma is also clearly visible in the transversal section. As it is an aquatic plant, the epidermis is characterized by a high number of stomatal cells arranged in longitudinal lines along the tissue and separated by two or three lines of epidermal cells (Figure SM9-12).

Typha sp. (raw). Cattail leaves differ in the appearance of their vascular bundles from the monocot species described above. Small ones are near the epidermis and large ones in the columns of parenchyma along the aerenchyma chambers. Epidermis, both adaxial and abaxial, displays a high number of stomata dispersed along the surfaces (Figure SM13-16).

Linum usitatissimum (processed). Flax fibres are similar to nettle fibres and also correspond to sclerenchyma fibres. The surface of flax fibres appears smooth and has characteristic knots or cross-marks at regular intervals. In cross-section, flax fibres are polygonal or irregular in shape although they are not visible in our samples as only longitudinal views are present (Figure SM17-20).

Urtica dioica (processed). Stinging nettle fibres are visible when the stem of the plant is processed and retted in water and correspond to the sclerenchyma tissue of the plant which surrounds the vascular system of secondary phloem. They have a central lumen running the length of the fibre. The surface appears slightly rough or striated due to the orientation of the cellulose microfibrils that provide structural support and are used in determination (Figure SM21-24).

Tilia sp. (processed). What is microscopically visible in the cross-section of the lime tree bast is the secondary phloem. It derives from the vascular cambium. In this research what is visible in the images is the longitudinal view where rays appear empty as they were previously retted in water (Figure SM25-28).

Table 1. Classification of the plant fibre species used in the methodological approach.

Division	Class	Order	Family	Genus	Specie	Plant part	Processing state
Angiospermae	Monocotyledoneae	Poales	Poaceae	*Stipa*	*S. tenacissima*	Leaf	Raw Processed
Angiospermae	Monocotyledoneae	Poales	Cyperaceae	*Scirpus*	*S. holoschoenus*	Stem	Raw
Angiospermae	Monocotyledoneae	Poales	Typhaceae	*Typha*	*Typha sp.*	Leaf	Raw
Angiospermae	Dicotyledoneae	Malpighiales	Linaceae	*Linum*	*L. usitatissimum*	Stem bast	Processed
Angiospermae	Dicotyledoneae	Rosales	Urticaceae	*Urtica*	*U. dioica*	Stem bast	Processed
Angiospermae	Dicotyledoneae	Malvales	Malvaceae	*Tilia*	*Tilia* sp.	Bast	Processed

These characteristics explained for each of the plant families are the ones used in their identification. Moreover, in all the cases, they are visible in all the solvent concentrations and timings used in this study and no major alterations were observed.

Plant fibres in the dental calculus control sample: the Castell de Besora site.

Several plant fibres were found in the dental calculus of individual CB21-187 from the Castell de Besora site. Methodologically, no qualitative differences were found between the fibres recovered from this individual when treated with 0.2M and 0.5M EDTA for 5, 30, 90 and 170 hours (Figure 3). Although EDTA is a chelating agent known for its decalcifying properties, enabling it to dissolve calcium carbonate deposits and other forms of precipitated calcium, its use in dental calculus does not appear to affect the identification characteristics of plant fibres at these concentrations for periods up to 170 hours (Figure 3a-h). Very similar results were obtained using HCl at different concentrations (0.2M and 0.5M) and timings. Even with these concentrations and times of HCl, no qualitative changes were observed in the current study protocol (Figure 3i-p). It should be noted that the tartar in the material studied was not completely decalcified, as seen in Figures 3, although microremains were visible with this protocol. From a quantitative point of view and in a general overview, more fibres have been recovered in the samples treated with EDTA than the ones decalcified with HCl (Table 2). The samples were obtained from three different teeth (Teeth 31, 32 and 33).

Some of those fibres present a rounded section with frayed edges and an internal striated texture, as well as being colourless. Under polarized light, many of these fibres appear brownish, and transversal lines appear corresponding to the cross-section marks. These transversal lines are consistent with those that appear in the commonly known bast fibres, but they differ in some specific features. The cross-section is not visible, although from their sizes, the identification is consistent with flax, hemp, and nettle, which are the plant fibres most often used in textile production in this chronological context (Bergfjord and Holst 2010; Andersson Strand 2012; Haugan and Holst 2014; Sperduti et al. 2018). Although the present research is focused on the recovery and identification of plant fibres, the presence of other microremains such as starch grains, phytoliths, fungal spores and indeterminate remains was also recorded.

Microremains in the Neolithic case study: the Cova del Pasteral site.

The results obtained from the decalcification of Neolithic dental calculus indicate the recovery of such microremains as plant fibres, multicellular plant tissues, starch grains, minerals, fungi, animal hair and unidentified materials. Although this research is focused on the identification of plant fibres, attempts have also been made to identify the plant tissue remains.

Plant fibres in dental calculus are often difficult to identify as they usually display no identifiable characteristics. In the case of the plant fibres found in the dental calculus samples from the Cova del Pasteral site, they generally presented a round section with a smooth surface (Figure 4a-f). These characteristics are not sufficiently reliable for identification, so no determination could be made. However, their appearance is similar to that of cellulose fibres, which can be obtained from bark, wood or leaves and stems of plants. In addition, cellulose fibres may contain other organic compounds such as hemicellulose and lignin, which are also present in other structural parts of plants with different mechanical properties, such as sclerenchyma tissue.

Vegetal tissue remains were considered to be multicellular structures. Although it was not possible to identify all of them, two showed clearly recognisable features. The first could correspond to a fragment of a Poaceae/Gramineae, as long dendritic cells are visible (Figure 4g,h), even though the part of the plant could not be identified. In two more multicellular tissue remains, parenchyma cells consistent with non-defined monocots are visible (Figure 4i-j), although the genus, or even the family, could not be identified.

Several microremains corresponding to other categories were also identified in the dental calculus from the case study in this paper, although from a quantitative perspective the most common microremain typology found in the Neolithic dental calculus samples are plant fibres followed by the indeterminate plant tissue (Table 3). Some of the other recognised categories correspond to starch grains, fungal spores (Figure 4m,n), an animal hair (Figure 4o), unidentified microremains (Figure 4p,q) and coloured minerals (Figure 4r).

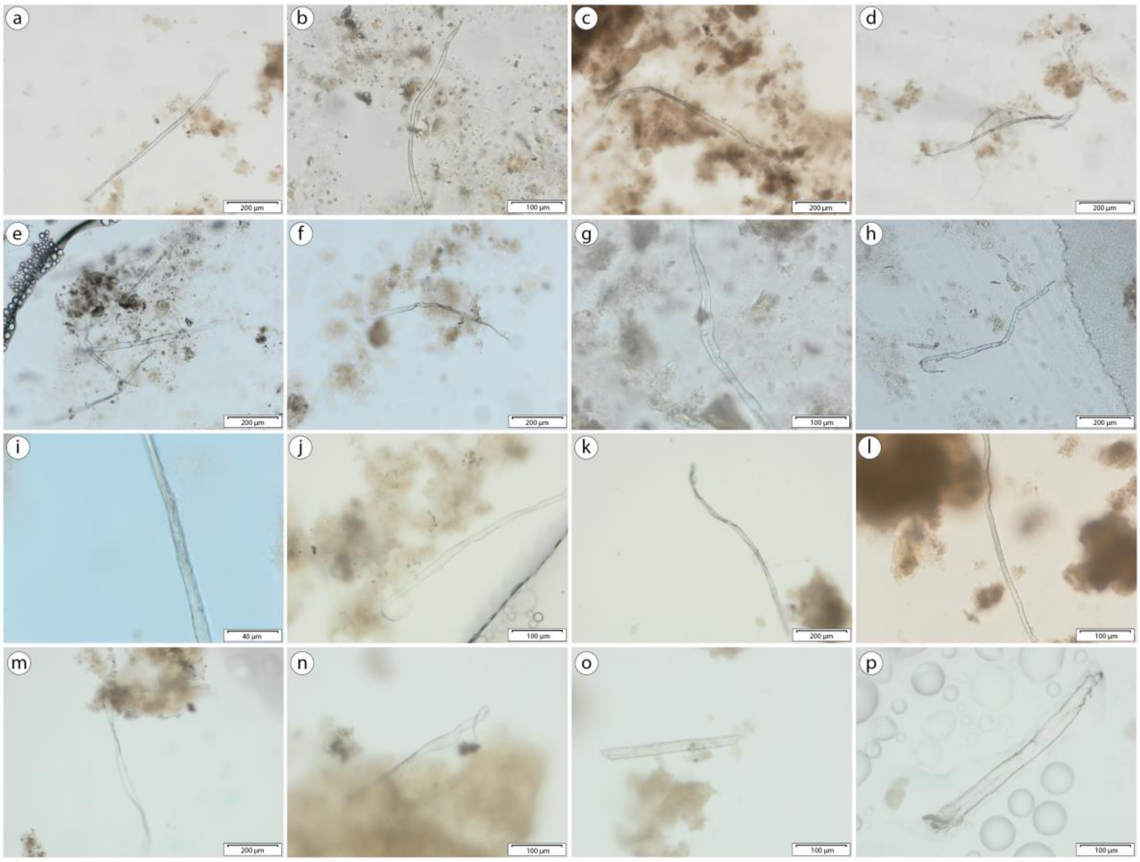

Figure 3. Plant fibres recovered from dental calculus from the Castell de Besora Site: a) 0.2M EDTA -5h, b) 0.2M EDTA-30h, c) 0.2M EDTA-90h, d) 0.2M EDTA-170h, e) 0.5M EDTA-5h, f) 0.5M EDTA-30h, g) 0.5M EDTA-90h, h) 0.5M EDTA-170h. a) 0.2M HCl-5h, b) 0.2M HCl-30h, c) 0.2M HCl-90h, d) 0.2M HCl-170h, e) 0.5M HCl-5h, f) 0.5M HCl-30h, g) 0.5M HCl-90h, h) 0.5M HCl-170h.

Table 2. Number of plant fibres recovered in each protocol of the medieval control samples from Castell de Besora.

			5h	30h	90h	170h
EDTA	Tooth 31	0.2M	10	7	5	13
EDTA	Tooth 31	0.5M	1	12	7	16
HCl	Tooth 32	0.2M	1	4	6	9
HCl	Tooth 33	0.5M	2	2	1	2

Table 3. Microremains found in the Neolithic case study samples from Cova del Pasteral.

	Plant fibres	Plant tissue	Starch grains	Animal hairs	Coloured minerals	Others/Non-identified
Tooth 14	18	12	5	1	1	7
Tooth 22	13	15	0	0	2	4

Figure 4. Microremains found in dental calculus from the Neolithic case study samples from the Cova del Pasteral site: a-f) plant fibres; g, h) Poaceae/Gramineae tissue; i-j) non-identified monocot plant tissue; k-l) non-identified monocot plant tissue; m, n) fungal spores; o) animal hair; p, q) unidentified microremains, r) coloured mineral.

Discussion.

The use of EDTA and HCl in modern plant fibres and dental calculus control samples.

Decalcification is the process of removing inorganic calcium. It is used in various medical, research and industrial processes and is essential for studying the organic components of materials. Decalcification can be carried out using different methods such as heat, electricity and chemical agents. The latter are divided into strong (inorganic) acids such as nitric acid (HNO_3) and hydrochloric acid (HCl), weak (organic) acids such as acetic acid (AcOH) and chelating agents such as EDTA (Gupta et al. 2014). The action of these compounds is based on the chemical reaction with the calcium present in the material in order to dissolve it into salts forming compounds. Factors such as concentration, exposure time, temperature and agitation also play an important role in the action of these agents (Gupta et al. 2014; Sheehan and Hrapchak 1980). The aggressiveness of strong inorganic acids like HCl can damage soft-tissue structures and negatively affect cellular integrity. However, they usually take less time to complete decalcification procedures, making them suitable for highly mineralized specimens. On the other hand, weak organic acids take longer to complete decalcification and are used for hard materials such as dense cortical or large bones. Chelating agents, like EDTA, do not behave like inorganic or organic acids, but bind to metal ions, predominantly calcium and magnesium and are therefore more respectful of organic matter, and do not damage tissue or affect their stainability (Hendy et al. 2018; Gismondi et al. 2018).

Some authors suggest that the selection of decalcifiers depends on such variables as the urgency of the study, the degree of mineralisation of the samples and the objective of the research. Numerous studies have been carried out to develop new decalcifiers and improve existing ones to meet the criteria for the most efficient decalcifier. The current research has sought the best decalcifying agent for archaeological dental calculus samples, in order to prevent the loss of the organic record inside, such as plant fibres. The ideal agent removes calcium completely without damaging tissue morphology. The results of the methodological approach of this research on different vegetable species used for the extraction of plant fibres showed that the use of chelating agents such as EDTA or strong acids such as HCl, do not affect the histological structure of plant fibres at 0.2M and 0.5M, at least for the first 170 h. Their subsequent use on control samples of dental calculus from individual CB21-187 showed that they complete decalcify without affecting the structural characteristics of plant fibres.

Therefore, in the current study, we focused on the characteristics of the microremains, specifically the plant fibres and not on their quantitative presence. However, the fact that more plant fibres were recovered in the samples treated with EDTA in the protocol sample should be mentioned. It should also be noted that the presence of microremains in dental calculus samples is not homogeneous, making quantitative results difficult to interpret as the samples also came from three different teeth (although they are anatomically close to one another and the components should be very similar) We cannot discard that the recurrent lower presence of plant fibres in the samples treated with HCl (both 0.2 and 0.5M) could be related to a greater impact of HCl, but the fact that no other evidence of degradation has been observed on the surface of the fibres suggests that there is no relation.

Similar studies have been carried out on the recovery of other organic materials from dental calculus. Le Moyne and Crowther (2021) analysed the recovery of starch granules and suggested that the use of 0.5M HCl for prolonged periods did not cause significant morphological changes or complete dissolution of different starch granules. However, they suggest that chemical interactions between HCl and the calcium phosphate of the dental calculus matrix may affect starch recovery during decalcification as the reaction between HCl and the calcium phosphate is exothermic and this increase in heat may cause starch granule degradation. Other authors suggest that phosphated starch in dental calculus may be more susceptible to disruption by calcium ions released during HCl decalcification (Mercader et al. 2018; Tromp et al. 2017). On the other hand, Tromp et al. (2017) argued that the use of EDTA reduces the calcium ions they sequester, reducing their reactivity and potentionality. An advantage of the use of EDTA is related to DNA and protein analysis, providing greater opportunities to study the materials, considering that this type of analysis is destructive. Although some researchers reported no morphological changes on starch granules, others found morphological changes on the surface of starch granules (Soto et al. 2019; Le Moyne and Crowther 2021). Le Moyne and Crowther (2021) conclude that the minor alterations they report are negligible and do not affect starch recovery and identification, although they recommend further research. They, like Tromp et al. (2017), also state that 0.5M EDTA (pH: 8) is a more suitable decalcifying agent than corrosive HCl for the recovery of microremains from dental calculus.

<u>Plant fibres from the Cova del Pasteral site.</u>

Although our results showed that the use of EDTA and HCl for the demineralisation of archaeological dental calculus for plant fibre recovery at 0.2M and 0.5M for a maximum of 170 hours did not affect the appearance of plant fibres, we prioritised the use of the EDTA chelating agent due to its chemical properties of sequestering calcium ions in the Neolithic samples. Its use also allows more opportunities to study the materials, if we bear in mind that this type of analysis is destructive as regards DNA and protein analysis, as other researchers have suggested (Soto et al. 2019; Le Moyne and Crowther 2021, Tromp et al. 2017). We also observed a higher number or plant fibres recovery in the control samples treated with EDTA (although this might be related to a non-homogeneous presence of microremains in different dental tartar). The concentration was chosen to accelerate the process so that the time to complete calculus disaggregation was 70h.

The identification of plant fibres through the study of indirect evidence is particularly challenging due to the low resolution of some of the documented diagnostic plant features and the lack of comprehensive reference materials. This makes accurate identification and analysis difficult for researchers. In addition, similarities between different plants often prevent specific differentiation.

Dental calculus can be studied because it is a mineralised material, and the presence of plant fibres can be explained by the use of teeth for extramasticatory activities. Although linking the presence of fibre debris on dental calculus to craft activities requires the consideration of additional anthropological parameters, such as dental wear, this link is feasible when there is a high concentration of debris and a sufficient number of individuals to allow for robust statistical analysis (Radini et al. 2019).

This method is particularly effective when the sample size is large enough to provide meaningful data, allowing researchers to draw more accurate conclusions about past human activity and behaviour. The identified microremains revealed the presence of plants in the analysed dental calculus in the form of both plant fibres and plant tissues. Although the plant fibres could not be determined due to the absence of diagnostic features, they are very similar to cellulose fibres. These fibres appear in a wide range of sizes and appearance, as cellulose is present in all plants, both monocots and dicots (Vanderghem et al. 2012). As regards the presence of cellulose fibres, this cannot be a definitive sign that this is due to the use of plant fibres, since they are present in a great variety of structures and elements of plants. Thus, their origin might be inferred from the consumption of plant leaves and stems, but also from seeds and fruits for nutritional purposes. More hypotheses could be made if more contextual information about the individual, the site and the environment could be obtained through anthropological and archaeobotanical studies, but in the case study of this research this information is not available, so no further information can be extracted. The same conclusion can be drawn from the presence of plant tissues, which will be discussed below.

In the case of plant tissues, different cell types have been identified, such as those from the epidermis, sclerenchyma and parenchyma tissues of stems and leaves of monocots. However, the characteristics did not allow the identification of specific families or genera, except for an indeterminate Poaceae/Gramineae. The presence of monocots in general and cereals in particular in the Early Neolithic in the study area is chronologically proven by the appearance of agricultural practices in the area. Moreover, several archaeobotanical studies from relatively proximate archaeological sites, such as the settlement of La Draga (5292-4713 cal BC; Banyoles, Girona), have revealed the presence of different species of monocots, such as Triticum durum/turgidum type, Hordeum distichum, Triticum dicoccum, Triticum monococcum, and Triticum timopheevi (Antolín 2013; Piqué et al. 2021). Other monocots identified at the site include Cladium mariscus, Cyperus fuscus, Phragmites australis, Typha angustifolia, and Typha latifolia (Antolín and Buxó 2011) through carpological analysis, and a Cyperus sp. as an underground storage organ (USO) (Berihuete-Azorín et al. 2018). The use of monocotyledonous families in the production of handicrafts such as plant fibre cords and baskets at the site must also be considered, as three different Poaceae/Gramineae, one Cyperaceae and one Typhaceae family were used (Herrero-Otal et al. 2021). The use of Cyperaceae is also recorded in other archaeological sites in northeastern Iberia, such as the Coves del Fem site (ca. 6065-4545 cal BC; Ulldemolins, Tarragona), where fragments of baskets and a single small piece of cord made from sedges and Juncaceae were found (Romero-Brugués et al. 2021).

The presence of various plant tissues such as plant fibres and other histological parts in the samples of this study cannot be directly related to the use of teeth as a third hand or tool because no contextual knowledge is available such as individual biological information about the individuals, oral pathologies and/or characteristics and other osteological details or even the associated burial goods. However, this study demonstrates the possibilities of fibre survival in dental calculus, which can be a powerful tool to complement other approaches such as the use of wear traces or Activity Induced Dental Modification (AIDM), as it has been called by some authors (Lozano et al. 2021). It should also be noted that the use of teeth as a tool or as a third hand can imply a wide variety of actions, such as the processing of plant fibres, such as softening or spinning, but also the processing of seeds with a more alimentary objective. More detailed experimental or anthropological work is recommended in order to identify differences in the microwear patterns produced by different types of processing of plants associated with different activities (Emperaire 2002).

Conclusions.

The present study aimed to find a non-aggressive decalcification method for the extraction of plant fibres that can become embedded in the dental calculus matrix. To this end, seven different plant fibres, traditionally used in handicrafts, were exposed to two different concentrations of EDTA and HCl, the most commonly used decalcifiers in dental calculus analysis, for different periods of time up to 170 h. The results of this methodological approach showed that none of the treatments affect the quality appearance of the plant fibres, preserving their identifying characteristics. These steps were then repeated on control samples of tartar, with the same results, although quantitatively more plant fibres were recovered in the samples treated with EDTA. Based on these results, other references and the chelating properties of EDTA, it was decided to use that decalcifier for the disaggregation of Early Neolithic samples from the Cova del Pasteral site. The identified microremains revealed the presence of plants in the analysed dental calculus in the form of both plant fibres and plant tissues, in agreement with previous archaeobotanical studies for other archaeological sites in the surroundings. However, a direct relationship between the use of teeth and the treatment of plant fibres cannot be reported due to the lack of further anthropological information on the individuals from whom the samples were taken. We conclude, as have other authors, that future studies of archaeological dental calculus should use EDTA for decalcification, as this chelating agent reduces the reactivity of metal ions, it is gentler on microbotanical remains, and it also allows other analytical procedures such as DNA or protein extraction to be carried out. In sum, this study has successfully demonstrated the survival of plant fibres in dental calculus samples, employing a methodology that can be explored and complemented with other approaches - biological, anthropological and archaeological - to infer the use of teeth as a third hand for multiple purposes.

Author's Statements

Author contributions: M.H.-O.: excavation and field collection, laboratory sampling, analysis, interpretation of data, writing the paper, revision and decision to submit it for publication; L.C.: excavation collection, analysis, writing the paper, revision and decision to submit it for publication; B.A., R.R., À.B., A.B., A.P.: excavation collection, analysis, revision and decision to submit it for publication; R.P., X.T., A.M.-M.: revision and decision to submit it for publication.

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References

Adler, CJ., Dobney, K., Weyrich, LS., Kaidonis, J., Walker, AW., Haak, W., Bradshaw, CJA., Townsend, G., Sołtysiak, A., Alt, KW., Parkhill, J., Cooper, A. (2013) Sequencing ancient calcified dental plaque shows changes in oral microbiota with dietary shifts of the Neolithic and Industrial revolutions. Nat Genet, 45: 450-455. DOI: 10.1038/ng.2536.

Agustí Farjas, B. (2022) Informe de l'estudi antropològic: Cova del Pasteral (La Cellera de Ter). Sector 1. Anthropological report.

Altorfer, K., Médard, F. (2000) Nouvelles découvertes textiles sur le site de Wetzickon-Robenhausen (Zürich, Suisse). Sondages 1999. Montagnac. Mergoil, 35-75.

Andersson Strand, E. (2012) The textile chaîne opératoire: Using a multidisciplinary approach to textile archaeology with a focus on the Ancient Near East. Paléorient, 38-1-1: 21-40. DOI: 10.3406/paleo.2012.5456

Antolín, F. (2013) Of cereals, poppy, acorns and hazelnuts. Plant economy among early farmers (5500-2300 cal BC) in the NE of the Iberian Peninsula. An archaeobotanical approach. PhD Dissertation. Barcelona, Universitat Autònoma de Barcelona.

Antolín, F., Buxó, R. (2011) L'explotació de les plantes al jaciment de La Draga: contribució a la historia de l'agricultura i de l'alimentació de l'agricultura i de l'alimentació vegetal del Neolític a Catalunya. In: Bosch A, Chinchilla J, Tarrús J (eds) El poblat lacustre del Neolític Antic de La Draga: Excavacions de 2005-2005. CASCMuseu d'Arqueologia de Catalunya, Girona, pp 147-174.

Aura Tortosa, JE., Pérez-Jordà, G., Carrión Micó, Y., Seguí Seguí, JR., Jordá Pardo, JF., Miret i Estruch, C., Verdasco Cebrián, CC. (2019) Cordage, basketry and containers at the Pleistocene–Holocene boundary in southwest Europe. Evidence from Coves de Santa Maira (Valencian region, Spain). Veg Hist Archaeobot, 29, 581-594. DOI: 10.1007/s00334-019-00758-x.

Barber, EW. (1994) Women's work: the first 20.000 years. Women, cloth and society in early times. Norton & Company, New York.

Bender Jørgensen, L. (1992) North European textiles until AD 1000. Aarhus: Aarhus University Press. ISBN: 87-72888-416-9.

Bergfjord, C., Holst, B. (2010) A procedure for identifying textile bast fibres using microscopy: Flax, nettle/ramie, hemp and jute. Ultramicroscopy, 110(9): 1192-1197. DOI: 10.1016/j.ultramic.2010.04.014.

Berihuete-Azorín, M., Arranz Otaegui, A., López-Doriga IL. (2018) Prehistoric plant underground storage structures in Europe. Conference: Subsistence strategies in the Stone Age, direct and indirect evidence of fishing and gathering, Saint Petersburg. DOI: 10.31600/978-5-907053-00-7-2018-198-199.

Blatt, SH., Redmond, BG., Cassman, V., Sciulli, PW. (2011) Dirty teeth and ancient trade: Evidence of cotton fibres in human dental calculus from Late Woodland, Ohio. International Journal of Osteoarchaeology, 21(6): 669–678.

Blondiaux, J. Charlier, P. (2008) Palaeocytology in skeletal remains: microscopic examination of putrefaction fluid deposits and dental calculus of skeletal remains from French archaeological sites. International Journal of Osteoarchaeology, 18: 1–10. DOI: 10.1002/oa.931.

Bocquentin, F., Sellier, P., Murail, P., (2005) Tooth abrasion and task activity in the Natufian population of Mallaha (Israel). Comptes Rendus Palevol, 4, 351–357. DOI: 10.1016/j.crpv.2005.01.002.

Bosch Lloret, A. (1985) La Cova d'el Pasteral (La Cellera de Ter, La Selva): un jaciment neolític sobre la vall mitja del Ter. Quaderns del Centre d'Estudis Comarcals de Banyoles. Número Homenatge al Dr. Josep Maria Corominas, vol II. Banyoles.

Boyadjian, C. (2018) Plant Micro-remains in Dental Calculus. In Smith, C. Encyclopedia of Global Archaeology, 1-16. DOI: 10.1007/978-3-319-51726-1_3200-1.

Bucchi, A., Burguet-Coca, A., Expósito, I., Bocanera, FJA., Lozano, M. (2019) Comparisons between methods for analysing dental calculus samples from El Mirador cave (Sierra de Atapuerca, Spain). Archaeol Anthropol Sci, 11: 6305–6314. DOI: 10.1007/s12520-019-00919-z.

Buckley, S., Usai, D., Jakob, T., Radini, A., Hardy, K. (2014) Dental calculus reveals unique insights into food items, cooking and plant processing in prehistoric central Sudan. Public Library of Science ONE, 9(7).

Busquets, F., Fàbregas, M. (2008) Memòria de la intervenció arqueològica al Castell de Besora (Santa Maria de Besora, Osona). Mataró: Direcció General de Patrimoni Cultural. Excavation report.

Campillo, D., Vives, E. (1985) Estudi de les restes humanes de la cova d'El Pasteral. Quaderns del Centre d'Estudis Comarcals de Banyoles. Número Homenatge al Dr. Josep Maria Corominas, vol II. Banyoles.

Cristiani, E., Radini, A., Borić, D., Robson, HK., Caricola, I., Carra, M., Mutri, G., Oxilia, G., Zupancich, A., Šlaus, M., Vujević, D., (2018) Dental calculus and isotopes provide direct evidence of fish and plant consumption in Mesolithic Mediterranean. Sci Rep, 8: 8147. DOI: 10.1038/s41598-018-26045-9.

Cristiani, E., Radini, A., Edinborough, M., Borić, D. (2016) Dental calculus reveals Mesolithic foragers in the Balkans consumed domesticated plant foods. P Natl Acad Sci, 113: 10298-10303. DOI: 10.1073/pnas.1603477113.

D'Agostino, A., Gismondi, A., Di Marco, G., Lo Castro, M., Olevano, R., Cinti, T., Leonardi, D., Canini, A. (2019) Lifestyle of a Roman Imperial community: ethnobotanical evidence from dental calculus of the Ager Curensis inhabitants. Journal of Ethnobiology and Ethnomedicine, 15: 62. DOI: 10.1186/s13002-019-0334-z.

De La Fuente, C., Flores, S., Moraga, M. (2013) DNA from human ancient bacteria: a novel source of genetic evidence from archaeological dental calculus. Archaeometry, 55: 767-778. DOI: 10.1111/j.1475-4754.2012.00707.x

Emperaire, J. (2002) Los Nomades del Mar. Libros Arces-LOM. ISBN: 9789562824293.

Evert RF. (2006) Esau's Plant Anatomy: Meristems, Cells and Tissues of the Plant Body. Their Structure, Function, and Development. 3rd edition. John Wiley and sons, Inc. ISBN: 978-84-282-1443-3.

Fagernäs, Z., García-Collado, MI., Hendy, J., Hofman, CA., Speller, C., Velsko, I., Warinner, C., (2020) A unified protocol for simultaneous extraction of DNA and proteins from archaeological dental calculus. J. Archaeol. Sci., 118: 105135. DOI: 10.1016/j.jas.2020.105135.

Fiorin, E., Cristiani, E. (2024) A protocol for the extraction of microremains from archaeological human dental calculus. DOI: 10.17504/protocols.io.3byl4q6r8vo5/v1.

Fiorin, E., Sáez, L., Malgosa, A. (2019) Ferns as healing plants in medieval Mallorca, Spain? Evidence from human dental calculus. Int J Osteoarchaeol, 29: 82-90. DOI: 10.1002/oa.2718.

García, A. (2020) Memòria de la intervenció arqueològica a la Cova del Pasteral (La Cellera de Ter, la Selva). Excavation report.

Gismondi, A., D'Agostino, A., Canuti, L., Di Marco, G., Martínez-Labarga, C., Angle, M., Rickards, O., Canini, A. (2018) Dental calculus reveals diet habits and medicinal plant use in the Early Medieval Italian population of Colonna. J. Archaeol. Sci. Rep., 20: 556–564.

Gramsch, B. (1992) Friesack Mesolithic wetlands. In Coles, B. (Ed.) The wetland revolution in prehistory: 65–72. Exeter: WARP and The Prehistoric Society.

Gupta, S., Jawanda, MK., Sm, M., Bharti. A. (2014) Qualitative histological evaluation of hard and soft tissue components of human permanent teeth using various decalcifying agents – A comparative study. J. Clin. Diagn. Res., 8: 69-72. DOI: 10.7860/JCDR/2014/10195.4874

Hardy, K. (2008) Prehistoric string theory. How twisted fibers helped to shape the world. Antiquity 82(316): 271–280. DOI: 10.1017/S0003 598X0 00967 94.

Hardy, K., Buckley, S., Collins, MJ., Estalrrich, A., Brothwell, D., Copeland, L., García-Tabernero, A., García-Vargas, S., de la Rasilla, M., Lalueza-Fox, C., Huguet, R., Bastir, M., Santamaría, D., Madella, M., Wilson, J., Fernández Cortés, Á., Rosas, A. (2012) Neanderthal medics? Evidence for food, cooking, and medicinal plants entrapped in dental calculus. Naturwissenschaften, 99: 617-626. DOI: 10.1007/s00114-012-0942-0.

Hardy, K., Buckley, S., Copeland, L. (2018) Pleistocene dental calculus: recovering information on Paleolithic food items, medicines, paleoenvironment and microbes. Evol. Anthropol., 27: 234-246. DOI: 10.1002/evan.21718.

Hardy, K., Radini, A., Buckley, S., Sarig, R., Copeland, L., Gopher, A., Barkai, R. (2016) Dental calculus reveals potential respiratory irritants and ingestion of essential plant-based nutrients at Lower Palaeolithic Qesem Cave Israel. Quat. Int., 398: 129-135. DOI: 10.1016/j.quaint.2015.04.033.

Haugan, E., Holst, B. (2014) Flax look-alikes: pitfalls of ancient plant fibre identification. Archaeometry, 56(6):951-960. DOI: 10.1111/arcm.12054

Hendy, J., Warinner, C., Bouwman, A., Collins, M.J., Fiddyment, S., Fischer, R., Hagan, R., Hofman, C.A., Holst, M., Chaves, E. et al. (2018) Proteomic evidence of dietary sources in ancient dental calculus. Proc. R. Soc. B Boil. Sci., 285: 20180977.

Henry, AG., Ungar, PS., Passey, BH., Sponheimer, M., Rossouw, L., Bamford, M., Sandberg, P., de Ruiter, DJ., Berger, L. (2012) The diet of Australopithecus sediba. Nature, 487: 90-93. DOI: 10.1038/nature11185.

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R. (2021) Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula. Vegetation History and Archaeobotany. DOI: https://doi.org/10.1007/s00334-021-00826-1

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R., Homs, A., De Diego, M., Palomo, A. (2023) “Describing neolithic cord production process: raw materials, techniques and experimental archaeology in La Draga (Girona, Spain; 5207-4862 cal BC). Journal of Archaeological Sciences: Reports, 50: 104092. DOI: 10.1016/j.jasrep.2023.104092.

Horrocks, M., Nieuwoudt, MK., Kinaston, R., Buckley, H., Bedford, S. (2014) Microfossil and fourier transform InfraRed analyses of lapita and post-lapita human dental calculus from Vanuatu, southwest pacific. J. Roy. Soc. N. Z., 44: 17-33. DOI: 10.1080/03036758.2013.842177.

Hurcombe, L. (2014) Perishable Material Culture in Prehistory: Investigating the Missing Majority (Routledge). ISBN: 0415537932.

Juhola, T., Henry, A.G., Kirkinen, T., Laakkonen, J., Väliranta, M. (2019) Phytoliths, parasites, fibers, and feathers from dental calculus and sediment from Iron Age Luistari cemetery, Finland. Q. Sci. Rev., 222: 10588–105896. DOI: 10.1016/j.quascirev.2019.105888.

Kuoni, B. (1981) Cestería tradicional ibérica. Ediciones del Serbal, Barcelona. ISBN: 8485800117.

Kvavadze, E., Narimanishvili, G., Bitadze, L. (2010) Fibres of Linum (flax), Gossypium (cotton) and animal wool as non-pollen palynomorphs in the late Bronze Age burials of Saphar-Kharaba, southern Georgia. Vegetal History and Archaeobotany, 19: 479-494.

Le Moyne, C., Crowther, A. (2021) Effects of chemical pre-treatments on modified starch granules: recommendations for dental calculus decalcification for ancient starch research. J Archaeol Sci: Reports, 35: 102762. DOI: 10.1016/j.jasrep.2020.102762.

Lieverse, AR. (1999) Diet and the Aetiology of Dental Calculus. International Journal of Osteoarchaeology, 232: 219–232.

Lozano, M., de Castro, JMB., Carbonell, E., Arsuaga, JL. (2008) Non-masticatory uses of anterior teeth of Sima de los Huesos individuals (Sierra de Atapuerca, Spain). J. Hum. Evol., 55: 713–728. DOI: 10.1016/j.jhevol.2008.04.007.

Lozano, M., Jiménez-Brobeil, SA., Willman, JC., Sánchez-Barba, LP., Molina, F., Rubio, A. (2021) Argaric craftswomen: Sex-based division of labor in the Bronze Age southeastern Iberia. J. of Arch. Sci.: 105236. DOI: 10.1016/j.jas.2020.105239.

MacKenzie, L., Speller, CF., Holst, A., Keefe, K., Radini, A. (2022) Dental calculus in the industrial age: human dental calculus in the Post-Medieval period, a case study from industrial Manchester. Quat. Int. DOI: 10.1016/j.quaint.2021.09.020.

Mackie, M., Radini, A., Speller, CF. (2017) The sustainability of dental calculus for archaeological research. In Favreau, J., Patalano, R. (Eds.) Shallow Pasts, Endless Horizons: Sustainability & Archaeology: Proceedings of the 48th Annual Chacmool Archaeology Conference, Chacmool Archaeological Association, University of Calgary, 74-81.

Martínez-Sevilla, F.*, Herrero-Otal, M.*, Martín-Seijo, M., Jonathan Santana, Lozano Rodríguez, J.A., Maicas Ramos, R., Cubas, M., Homs, A., Martínez Sánchez, R.M., Bertin, I., Barroso Bermejo, R., Bueno Ramírez, P., de Balbín Behrmann, R., Palomo Pérez, A., Álvarez-Valero, A.M., Peña-Chocarro, L., Murillo-Barroso, M., Fernández-Domínguez, E., Altamirano-García, M., Pardo-Martínez, R., Iriarte-Cela, M., Carrasco Rus, J.L., Alfaro Giner, C., Piqué Huerta, R. (2023) The earliest basketry in Southern Europe: hunter-gatherer and first farmers plant-based technology preserved in the Cueva de los Murciélagos (Albuñol, Spain)". Science Advances, 9:eadi3055. DOI: 10.1126/sciadv.adi3055.

Médard, F. (2003) Vestiges textiles et activités de filage sur le site néolithique d'Arbon-Bleiche 3 (TG Suisse), Bull Soc préhist fr, vol. 100, nº 2, pp. 375-391.

Mercader, J., Akeju, T., Brown, M., Bundala, M., Collins, MJ., Copeland, L., Crowther, A., Dunfield, P., Henry, A., Inwood, J., Itambu, M., Kim, JJ., Larter, S., Longo, L., Oldenburg, T., Patalano, R., Sammynaiken, R., Soto, M., Tyler, R., Xhauflair, H., Al, TA., (2018) Exaggerated expectations in ancient starch research and the need for new taphonomic and authenticity criteria. FACETS, 3: 777–798. DOI: 10.1139/facets-2017-0126.

Mickleburgh, HL., Pagán-Jiménez, JR. (2012) New insights into the consumption of maize and other food plants in the pre-Columbian Caribbean from starch grains trapped in human dental calculus. Journal of Archaeological Science, 39(7): 2468–2478.

Middleton, WD. (1994) Extraction of Opal Phytoliths from Herbivore Dental Calculus. Journal of Archaeological Science, 21: 469-473.

Miettinen, A., Sarmaja-Korjonen, K., Sonninen, E., Junger, H., Lempiäinen, T., Ylikoski, K., Mäkiaho, JP., Carpelan, C., Jungner, H. (2008) The palaeoenvironment of the Antrea Net Find. A: Karelian Isthmus. Finnish Antiquarian Society, 16: 71-87.

Milner GR., Larsen, CS. (1991). Teeth as artifacts of human behavior: Intentional mutilation and accidental modification. In Kelley, MA., Larsen, CS. (Eds.) Advances in Dental Anthropology. Wiley-Liss, New York: 357–378.

Modi, A., Pisaneschi, L., Zaro, V., Vai, S., Vergata, C., Casalone, E., Caramelli, D., Moggi-Cecchi, J., Mariotti Lippi, M., Lari, M., (2020) Combined methodologies for gaining much information from ancient dental calculus: testing experimental strategies for simultaneously analysing DNA and food residues. Archaeol. Anthropol. Sci., 12: 10. DOI: 10.1007/s12520-019-00983-5.

Musaubach, M. (2012) Potencialidad de estudios arqueobotánicos sobre tártaro dental de cazadores-recolectores de la provincia de La Pampa, Argentina. Revista Argentina de Antropología Biológica, 14: 105–113.

Norström, E., Gustavsson, E., Molin, F., Gummesson, S. (2019) Micro-fossil analysis of Mesolithic human dental calculus, Motala, Sweden-Indications of health status and paleo-diet J. Archaeol. Sci.: Reports, 26: 101866. DOI: 10.1016/j.jasrep.2019.05.031.

Piqué, R., Alcolea, M., Antolín, F., Berihuete-Azorín, M., Berrocal, A., Rodríguez-Antón, D., Herrero-Otal, M., López-Bultó, O., Obea, L., Revelles, J. (2021) Mid-Holocene Palaeoenvironment, Plant Resources and Human Interaction in Northeast Iberia: An Archaeobotanical Approach. Appl. Sci., 11: 5056. DOI: 10.3390/app11115056

Piqué, R., Romero, S., Palomo, A., Tarrús, J., Terradas, X., Bogdanovic, I. (2018) The production and use of cordage at the early Neolithic site of La Draga (Banyoles, Spain). Quat. Int. 468: 262-270. DOI: 10.1016/j.quain t.2016.05.024

Power, RC., Salazar-García, DC., Rubini, M., Darlas, A., Harvati, K., Walker, M., Hublin, JJ., Henry, AG. (2018) Dental calculus indicates widespread plant use within the stable Neanderthal dietary niche J. Hum. Evol., 119: 27-41. DOI: 10.1016/j.jhevol.2018.02.009.

Power, RC., Salazar-García, DC., Straus, LG., Morales, MRG, Henry, AG. (2015) Microremains from El Mirón Cave human dental calculus suggest a mixed plant–animal subsistence economy during the Magdalenian in Northern Iberia. J. Archaeol. Sci., 60: 39-46. DOI: 10.1016/j.jas.2015.04.003.

Power, RC., Wittig, RM., Stone, JR., Kupczik, K., Schulz-Kornas, E. (2021) The representativeness of the dental calculus dietary record: insights from Taï chimpanzee faecal phytoliths. Archaeol. Anthropol. Sci., 13: 1-11. DOI: 10.1007/s12520-021-01342-z.

Preus, HR., Marvik, OJ., Selvig, KA., Bennike, P. (2011) Ancient bacterial DNA (aDNA) in dental calculus from archaeological human remains. J. Archaeol. Sci., 38: 1827-1831. DOI: 10.1016/j.jas.2011.03.020.

Radini, A. (2016) Particles of Everyday Life: Past Diet and Living Conditions as Evidenced by Microdebris Entrapped in Human Dental Calculus: A Case Study from Medieval Leicester and Surrounding. PhD thesis, University of York.

Radini, A., Buckley, S., Rosas, A., Estalrrich, A., De La Rasilla, M., Hardy K. (2016) Neanderthals, trees and dental calculus: new evidence from El Sidrón. Antiquity, 90: 290-301. DOI: 10.15184/aqy.2016.21

Radini, A., Nikita, E. (2023) Beyond dirty teeth: Integrating dental calculus studies with osteoarchaeological parameters. Quaternary International. Volumes 653-654: 3-18. DOI: 10.1016/j.quaint.2022.03.003.

Radini, A., Nikita, E., Buckley, S., Copeland, L., Hardy, K. (2017) Beyond food: the multiple pathways for inclusion of materials into ancient dental calculus.

Am J Phys Anthropol, 162: 71-83. DOI: 10.1002/ajpa.23147.

Radini, A., Tromp, M. Beach, A., Tong, E., Speller, C., McCormick, M., Dudgeon, JV., Collins, MJ., Rühli, F., Kröger, R., Warinner, C. (2019) Medieval women's early involvement in manuscript production suggested by lapis lazuli identification in dental calculus, SciAdv, 5. DOI: 10.1126/sciadv.aau7126.

Riuró, F. (1942) La cueva de El Pasteral. Ampurias IV, 189-204.

Romero-Brugués, S. (2022) Cordes i cistells elaboratos amb fibres vegetals entre el 2300-800 cal BC al Nord-Est peninsular i Balears: Tecnología, materia prima i funció. PhD Dissertation. Barcelona, Universitat Autònoma de Barcelona.

Romero-Brugués, S., Piqué Huerta, R., Herrero-Otal, M. (2021) The basketry at the early neolithic site of La Draga (Banyoles). Journal of Archaeological Sciences: Reports, 35(102692). DOI: doi.org/10.1016/j.jasrep.2020.102692

Romero-Brugués, S., Tzerpou, E., Herrero-Otal, M., Homs, A., López Bultó, O., Bogdanovic, I., Fanlo, J., Palomo, A., Piqué, R. (2022) Approach to plant craft techniques from the mat impressions on the bases of Early Bronze Age ceramic vessels: the case of Cova Fonda (Spain). Journal of Archaeological Sciences: Reports. 103472. DOI: 10.1016/j.jasrep.2022.103472

Rosillo, R., Herrero, M., Agustí, B., Palomo, A., Berrocal, A. (2022) Intervenció arqueológica en el complex arqueològic de la Cova del Pasteral. Excavation report.

Schulz, PD. (1977) Task activity and anterior tooth grooving in Prehistoric California Indians. Am. J. Anthropol., 46: 87–92. DOI: 10.1002/ajpa.1330460112.

Scott, GR., Jolie, RB. (2008) Tooth-tool use and yarn production in Norse Greenland. Alsk. J. Anthtopol. 6: 253–264.

Sheehan, DC., Hrapchak, BB. (1980) Bone. In Theory and Practice of Histotechnology. 2nd ed. Columbus: Battelle Press; 89-117.

Soffer, O. (2004) Recovering perishable technologies through use wear on tools: preliminary evidence for upper paleolithic weaving and net making. Curr Anthropol, 45: 407–413.

Soffer, O., Adovasio, JM., Hyland, DC. (2000) The “Venus” figurines: textiles, basketry, gender and status in the Upper Paleolithic. Current Anthropology, 41(4): 511-537.

Soto, M., Inwood, J., Clarke, S., Crowther, A., Covelli, D., Favreau, J., Itambu, M., Larter, S., Lee, P., Lozano, M., Maley, J., Mwambwiga, A., Patalano, R., Sammynaiken, R., Verg`es, J.M., Zhu, J., Mercader, J. (2019) Structural characterization and decontamination of dental calculus for ancient starch research. Archaeol. Anthropol. Sci., 11: 4847–4872. DOI: 10.1007/s12520-019-00830-7.

Sperduti, A., Giuliani, M.R., Guida, G., Petrone, P.P., Rossi, P.F., Vaccaro, S., Frayer, D.W., Bondioli, L. (2018) Tooth grooves, occlusal striations, dental calculus, and evidence for fiber processing in an Italian eneolithic/bronze age cemetery. Am. J. Phys. Anthropol. 167, 234–243. DOI: 10.1002/ajpa.23619.

Tromp, M., Buckley, H., Geber, J., Matisoo-Smith, E. (2017) EDTA decalcification of dental calculus as an alternate means of microparticle extraction from archaeological samples. J. Archaeol. Sci.: Reports, 14: 461-466. DOI: 10.1016/j.jasrep.2017.06.035.

Tromp, M., Dudgeon, JV. (2015) Differentiating dietary and non-dietary microfossils extracted from human dental calculus: the importance of sweet potato to ancient diet on Rapa Nui. J.

Archaeol. Sci., 54: 54-63. DOI: 10.1016/j.jas.2014.11.024.

Vanderghem, C., Jacquet, N., Danthine, S., Blecker, C., Paquot, M. (2012) Effect of Physicochemical Characteristics of Cellulosic Substrates on Enzymatic Hydrolysis by Means of a Multi-Stage Process for Cellobiose Production. Appl. Biochem. Biotechnol., 166: 1423–1432. DOI: 10.1007/s12010-011-9535-1.

Warinner, C., Hendy, J., Speller, C., Cappellini, E., Fischer, R., Trachsel, C., Arneborg, L., Lynnerup, N., Craig, OG., Swallow, DM., Fotakis, A., Christensen, RJ., Olsen, JV., Liebert, A., Montalva, N., Fiddyment, S., Charlton, S., Mackie, M., Canci, A., Bouwman, A., Rühli, F., Gilbert, MTP., Collins, MJ. (2014) Direct evidence of milk consumption from ancient human dental calculus. Sci Rep, 4: 1-6. DOI: 10.1038/srep07104.

Warinner, C., Rodrigues, JF., Vyas, R., Trachsel, C., Shved, N., Grossmann, J., Radini, A., Hancock, Y., Tito, RY., Fiddyment, S., Speller, C., Hendy, J., Charlton, S., Luder, HU., Salazar-García, DC., Eppler, E., Seiler, R., Hansen, LH., Castruita, JA., Barkow-Oesterreicher, S., Teoh, KY., Kelstrup, CD., Olsen, JV., Nanni, P., Kawai, T., Willerslev, E., von Mering, C., Lewis, CM. Jr., Collins, MJ., Gilbert, MT., Rühli, F., Cappellini, E. (2014) Pathogens and host immunity in the ancient human oral cavity. Nat Genet., 46(4): 336-44. DOI: 10.1038/ng.2906.

Wigforss, E. (2014) Perished material – vanished people. Understanding variation in Upper Paleolithic/Mesolithic textiles technologies, Department of Archaeology and Ancient History, Lund Universitet.

Wigforss, E. 2014. Perished material – vanished people. Understanding variation in Upper Palaeolithic/Mesolithic textile technologies. Lunds Universitet. Department of Archaeology and Ancient History.

Wright, SL., Dobney, K., Weyrich, LS. (2021) Advancing and refining archaeological dental calculus research using multiomic frameworks. Science and Technology of Archaeological Research, 7: 13-30. DOI: 10.1080/20548923.2021.1882122.

CHAPTER VII – DISCUSSION

7. Discussion.

7.1. Methodological questions.

7.1.1. Contributions and limitations of modern reference collections for plant fibres.

Reference collections are essential for archaeobotanical studies, and the creation of a specific one was the basis for the research in this thesis. The value of reference collections lies in their ability to provide a comparative framework for identifying plant species in archaeological artefacts, allowing researchers to accurately reconstruct past human practices and the environments in which those activities took place. Collections for plant fibre use research include such species as rushes, cattails, esparto grass and other monocotyledons, as well as dicotyledons like lime bark and bast fibres such as nettle, flax and hemp, as they may all have been used in prehistoric times for fibre-based productions. Including those species in the reference collection is supported by their presence at sites recorded by other archaeobotanical analyses, and by traditional and ethnographic documentation recording their use for these purposes. This reference material should be specific to the chronology, environment and location of the case under study. Although some online reference collections are freely available, it is beneficial for each researcher or laboratory to develop their own reference collection. This personalised approach helps researchers to familiarise themselves with the characteristics or key features required to identify different species.

Optical microscopy and scanning electron microscopy have been the most commonly used methods for the identification of plant fibres, and have been the methods utilised in the identification of raw materials in this thesis. As mentioned in Chapters II and VI, transversal sections and epidermis of both stems and leaves of monocotyledonous plants, as well as longitudinal sections of bast fibres and bark strips of some dicotyledonous families and species were used for the taxonomic determination of the materials. However, the use of microscopy has certain limitations, since in many cases the overlapping of anatomical features between species of the same family or genus, or even the absence of key features in the sampled specimens, make identification difficult in both monocotyledonous and dicotyledonous plants. Further difficulties may be caused by sampling problems or the preservation conditions and state of the archaeological remains.

Overlapping features have been worked on in the current thesis, which focuses most on monocotyledonous plants used as raw materials, as they were the most common types in the archaeological plant remains analysed here. The problem of common features has been tried to be solved by the formation of an ample modern reference collection, considering different families, genera and species. Nevertheless, more research can be done on this reference collection, including some metric analyses such as cell measurements or stomatal density (Castells et al. 2020). To achieve this, greater attention was paid to the epidermal structures of the monocotyledonous species included in the reference collection for this thesis, focusing on the shape of epidermal cells, stomata and appendages such as trichomes. In addition, elements visible in cross-sectional views were considered to define the key features for fibre identification, including the number of cells in the epidermis, the distribution of vascular bundles (both xylem and phloem) and the arrangement of sclerenchyma tissue in the plants. Although further research could be conducted on cell measurements, it is important to note that other variables should also be explored.

It is relatively easy to distinguish between taxonomical families because anatomical and histological features are directly related to the environment in which the plants live, so it is easy to distinguish, for example, between dry land plants and hydrophytes. It is also possible to distinguish between genera within the same family. It becomes more difficult to distinguish between species in the same genus by microscopic analysis. The analysis of the reference collection in the current thesis has succeeded in determining identification criteria for the main taxa in both monocotyledonous and dicotyledonous families.

In the case of the monocots, the epidermal characteristics regarding different cellular types, in adaxial and abaxial surfaces, has been considered to discriminate different families, but also other features visible in cross-sections. While parenchymatic cells are usually very similar between families, the disposal of vascular tissues, both xylem and phloem, together with their associated sclerenchyma fibres are the characteristics considered for identification.

In monocotyledons, epidermal features, such as the different types of cells found on the adaxial (upper) and abaxial (lower) surfaces, together with the presence and shape of stomatal structures, and the presence and type of trichomes, have been used to distinguish different plant families. However, additional anatomical features visible in cross-sections are also important in making these distinctions. Although parenchyma cells tend to be quite similar in different monocotyledonous families, the arrangements of vascular bundles, including both xylem and phloem tissues, possess valuable distinguishing features. The presence and organisation of associated sclerenchyma fibres, which provide structural support, are also key features to be considered in the identification process. These anatomical details help to accurately identify and differentiate between monocotyledonous families. For example, the vascular bundles (xylem, phloem and sclerenchyma fibres) present a very different structure in Typhaceae families from in

Cyperaceae, Juncaceae and Poaceae, although in the case of particular species of Cyperaceae (e.g. *Scirpus holoschoenus*) and Juncaceae (e.g. *Juncus* sp.) rather similar features are visible.

Furthermore, it is also possible to distinguish which part of the plant a sample corresponds to, specifically between leaves and stems; for example, based on the presence and density of stomata, as leaves generally have a higher stomatal density than stems (Evert 2006). This characteristic was observed in the archaeological material studied here and was used to classify leaves and stems. In addition, the general morphology of the element should be considered to determine which part of the plant was used. Leaves are typically flat and very thin, while stems are in most cases round or oval in cross-section (although some Cyperaceae are triangular in shape). This also leads to differences in the localisation of vascular bundles between leaves and stems. In stems, for example, the vascular bundles are often located around the periphery, forming a sort of ring, although they are isolated from each other. In some Cyperaceae, additional small vascular bundles appear throughout the element. In Poaceae stems, which have a hollow medulla, these small vascular bundles are absent.

Research into the differentiation of dicotyledonous families on the basis of bark characteristics is mainly carried out at research centres in Central Europe (Banck-Burgess 2018; Böhm et al. 2023). This specific area of study has not been extensively explored in the current work. The bark stripes identified in this thesis have been attributed to the lime tree (*Tilia* sp.), which has distinctive anatomical features. In cross-section, the bark of the lime tree is characterised by sieve tubes arranged in layers. In longitudinal sections, rays are also visible, and it is possible to determine whether the fibres have undergone retting by observing whether these rays appear empty (Banck-Burgess 2018; Böhm et al. 2023). However, such observations could not be confirmed for the lime bark from the La Draga site.

Research on bast fibres from dicotyledonous families is better developed due to a stronger research tradition. In order to overcome the challenges of identification, several tests have been described in bast fibre research for more precise identification. For example, some analyses focus on metric definitions of bast fibre cross-sections, while others empirically assess the microfibrillar orientation of their internal structure using polarised light microscopy, applying techniques such as the Herzog test or the Red Plate test. However, none of these methods alone is considered sufficient for definitive identification of bast fibres (Lukesová and Holst 2021, 2024). Indeed, recent studies emphasise the need to combine several techniques or tests to improve the accuracy of bast fibre identification (Bergfjord and Holst 2010; Haugan and Holst 2013, 2014; Suomela et al. 2018). This approach could also be useful for plant fibre identification in general, not only for bast fibres. In the present study, these research methods were applied to identify cf. Urtica fibres in cords recovered from the La Draga site.

Another limitation in the study of plant fibres is the effect that processing methods have on the integrity of their anatomical features, making them difficult to observe and analyse. As mentioned above, plant fibres are often subjected to processing techniques such as physical comminution or retting. Physical comminution involves mechanical breaking of the fibres, which can cause significant deformation or damage to the cell structures. Retting, on the other hand, is a process that uses microbial activity to break down the pectin that binds the fibres together, effectively separating them but potentially altering their microstructural characteristics. These processing methods can significantly affect the diagnostic characteristics of plant fibres, such as the arrangement and visibility of vascular bundles, the presence of specific cell types such as parenchyma or sclerenchyma, and the overall pattern of the fibres. For example, retting may result in the partial or complete removal of certain cellular components, while crushing may result in the collapse or fragmentation of fibres. As a result, identification of the plant species, or even the specific part of the plant, from processed fibres becomes challenging, as the characteristics typically used for identification may be altered or even lost.

This loss or alteration of diagnostic features is a significant challenge in the analysis of archaeological plant material, where fibres have often undergone extensive processing and use. It requires the development and use of more advanced analytical techniques and approaches that can account for these changes, such as combining microscopic examination with chemical analysis, or using modern imaging techniques. Understanding the extent and nature of these changes is crucial to improve the accuracy of plant fibre identification in both archaeological and botanical studies. In the case of the fibres analysed in the current thesis, this loss of diagnostic features was evidenced mainly in the Neolithic assemblage from Cueva de los Murciélagos, since in the case of the Mesolithic objects the esparto does not appear to have been physically processed, as in the case of both Les Coves del Fem and La Draga.

In addition, another significant limitation is the state of preservation of archaeological materials at the time of their recovery during excavations, as well as the effects of conservation measures applied after excavation. These factors can greatly affect the integrity and legibility of plant fibres, further complicating their analysis. In addition, post-excavation conservation treatments designed to stabilise materials and prevent further deterioration may also affect the fibres. For example, treatments involving chemical consolidants or desiccation can alter the appearance and structural integrity of the fibres, making it difficult to accurately observe their original characteristics. Such treatments can obscure or even destroy delicate anatomical details, making diagnostic analysis of the fibres difficult, as will be explained in the following section.

7.1.2. Types of conservation and sampling.

7.1.2.1. Conservation practises and their effect on identification processes.

Archaeological organic materials are quite rare at most archaeological sites and are only preserved under specific conditions. When these materials are found, specific conservation measures are required to ensure their integrity. These actions include specific procedures at the site immediately after the objects have been recovered, as well as various processes carried out in specialised laboratories. Ideally, professional and specialised curators should oversee these conservation actions, but this is not always possible. In such cases, a number of publications provide guidance on initial first-aid measures during the excavation of archaeological textiles (which can also be adapted to such materials as cords and baskets). A notable example is the publication edited by Gillis and Nosch (2007), which provides guidelines for the excavation of these types of materials from the very beginning of the excavation process, covering aspects such as documentation, cleaning, analysis, and storage. If the materials are preserved by mineralisation, the organic components have been replaced by inorganic components as mineral elements, creating durable materials that do not require specific storage recipients to be preserved. Preservation by dehydration and/or carbonisation makes the conservation processes somewhat more delicate, although the processes are not much more complex than creating specific storage structures that protect them and prevent their degradation as much as possible, taking into account the fragmentation and state of conservation of each specimen. In this case, consolidating resins can be used in various concentrations - determined by a specialist curator - to maintain and guarantee their structure and stability, such as polyethylene glycol (PEG) or Paraloid® (Chinchilla et al. 2017).

With regard to the organic materials analysed in this thesis, those from the Cueva de los Murciélagos have been cleaned and conserved by different curators since they were deposited in the museums (MAN and MAEG), although there are no systematic reports on conservation measures. Those that are available correspond to eleven registers (MAN584, MAN588, MAN592, MAN594, MAN595, MAN596, MAN602, MAN605, MAN606, MAN614, MAN626). These documents describe the following measures: mechanical cleaning with nylon brushes and micro-suction, chemical cleaning with solvents of different polarity and distilled water, pest control with C-55 Argon, consolidation with hydroxypropyl cellulose (Klulel 6) in ethyl alcohol with PEG 400 and the creation of specific stable storage supports made of polycarbonate, cotton and linen fabrics. These conservation measures are visible in some of the materials, as some of them show clear traces of conservation practices, such as the use of modern threads for sewing some parts, or an unidentified light layer of glue on the surface as a varnish (Figure 117). In addition, pictures of old museum displays show clear differences in shape from their current appearance.

Figure 117. Conservation practices remains visible on Cueva de los Murciélagos materials.

The materials from the Coves del Fem site were mechanically cleaned with nylon brushes and micro-suction, and no other conservation measures were taken except for the creation of a stable storage support.

When materials are preserved by waterlogging, the conservation process becomes more complex. Although they often appear well preserved and retain their original shape because the water fills the intercellular spaces, keeping the structure turgid and relatively stable, this initial impression is misleading. In reality, these materials have undergone significant changes due to physical and chemical processes. As a result, they have become soft, lacking in mechanical strength and extremely fragile when dried. In addition, uncontrolled evaporation of water can cause the structure to lose a considerable amount of volume, which is more evident in wooden materials. Therefore, the initial conservation measures, from the moment organic objects are recovered from the site, are crucial to prevent deterioration. This applies not only to wooden materials, but also to plant fibres, which are subject to similar degradation processes. Wet remains, which have remained stable as long as their depositional environment has not been disturbed, are subject to multiple stresses as soon as they are recovered. The first interventions at the site should focus on preventing the evaporation of structural water within the objects, as this is the key element that has ensured their preservation.

In the case of La Draga, there exists a long tradition of conservation practises by specialized curators since the beginning of the excavations in 1993 (Chinchilla 2000; Aguer 2006;

Piqué et al. 2013; Chinchilla et al. 2017). The plant remains have only been preserved in sectors where water is present (sectors B, C, D). In sector C - inside the lake - the materials present small holes caused by the roots of aquatic plants, and they are recovered with extreme care and stored in water, in trays or polyethylene bags. In addition, they are sometimes recovered in a block with the sediment enclosed in a rigid plastic structure to ensure the integrity of the object (Figure 118). Carbonised objects are allowed to dry, a slow process, and are later consolidated with acrylic resin (PEG or Paraloid®). For extremely fragile pieces, such as fibre-based objects and wooden bowls, moulds are made to support them and facilitate cleaning and study. They are then conserved in a refrigerator to minimise the development of micro-organisms. In the case of non-charred objects, dehydration is carried out using the freeze-drying method. The process begins in the laboratory with water cleaning, and then the objects are studied, with preliminary photographs and drawings showing the pathologies and the contractions and changes in size that can occur during the drying process. In the case of basketry and rope fragments, the main problem is the fragility and loss of their fibres. Freeze-drying is a process based on the combined action of cold and a vacuum. Water is first transformed into ice and then sublimated by direct conversion from solid to gas in a vacuum chamber, which allows the pressure inside to be regulated. Before being frozen, the objects are immersed in a water-soluble wax (PEG), which acts as a cryoprotectant and consolidant. The drying phase takes place in the lyophilisation chamber and is considered complete when the pressure reading remains stable.

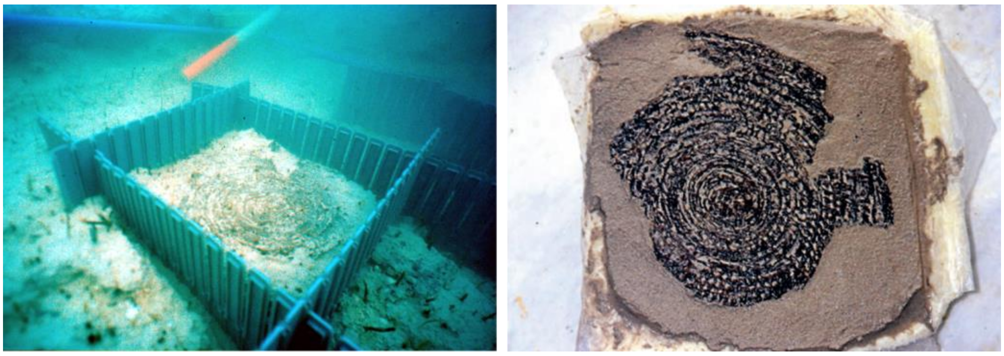

Figure 118. Recovery of basket D97 FF96-1 from Sector-C in a block with the sediment enclosed in a rigid plastic structure to ensure its integrity (Centre d'Arqueologia Subaquàtica de Catalunya, CASC).

7.1.2.2. The importance of sampling fibre-based objects prior to conservation practice and self-sampling by the researcher.

Surface cleaning of objects is essential to reveal diagnostic features necessary for raw material identification. However, some of these characteristics may not be clearly visible when consolidating resins are used.

In this study, both optical and scanning electron microscopy revealed a bright layer on the surface of materials from La Draga that obscured anatomical features and limited raw material identification (Figure 119). It is therefore essential to sample materials prior to restoration processes to ensure the accuracy of subsequent analyses. In addition, samples should be thoroughly cleaned, as soil and sediment particles (Figure 119) can also obscure key features for identification. While these particles can often be removed during microscopic analysis, the removal of resins requires the use of chemical solvents, depending on the polarity of the consolidant used. This process can further compromise the integrity of the samples, highlighting the importance of careful planning and execution of conservation efforts.

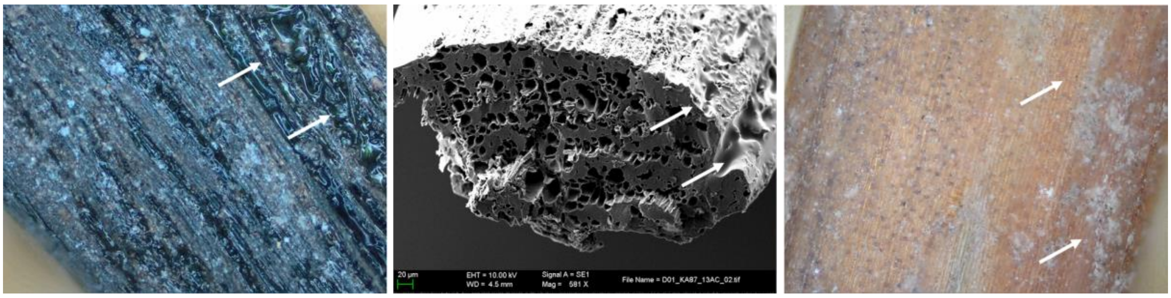

Figure 119. Limitations in key features observing: a, b) Bright surface due to the use of different consolidants, c) soil particles on the epidermis.

As mentioned above, taphonomy can affect and compromise the integrity of materials, thereby affecting the results of analyses performed on them, such as those in the current thesis related to raw material identification and processing. It is therefore crucial to first examine the objects macroscopically or with a binocular microscope to obtain an initial impression of the materials and the potential raw materials they may be composed of, if possible before sampling. It is important for the researchers who will be analysing and studying the samples, particularly for raw material identification, to observe the objects first hand. This allows them to select the parts and elements most likely to contain the anatomical structures required for their analysis, leading to more reliable and promising results.

It is also important to keep a detailed record of the sampling process, including the specific location of each sample, and to document this photographically, as is done in some research studies. Such specific documentation of the exact location of samples, whether taken from active or passive elements, was not collected at the sites investigated in this thesis. However, this type of information could be valuable for future analysis. In addition, it is crucial to consider a representative number of samples from each object.

In the case of the materials from Cueva de los Murciélagos, for example, it was relatively easy to establish that all the objects were made from the same raw material, thus allowing for intraspecific differences. However, in the case of the baskets from Coves del Fem and La Draga, the charred conditions of preservation obscured the possible use of different raw materials in the same object. It is therefore advisable to take more than one sample, especially if there are irregularities in the raw materials or if the object/fragment is of considerable size, in order to make this sample process representative of the entire archaeological item. This approach could provide information on the reuse of different plant materials or by-products from other activities, e.g. the use of stalks from agricultural practices for the production of fibre-based objects without distinguishing between raw materials. Although this method is not specified in any publication, it reflects the practice of researchers working in different laboratories, such as in Central Europe.

7.1.3. Plant-fibres immersed in dental calculus.

Dental calculus, a calcified form of bacterial plaque, forms during an individual's lifetime and requires the presence of saliva for its development, thus precluding post-mortem inclusions. This makes dental calculus a valuable material for archaeological research (Blatt et al. 2011; Hendy et al. 2013; Cristiani et al. 2016; Juhola et al. 2019), as it can trap and preserve a variety of remains - such as starch grains, pollen, phytoliths and plant fibres - over long periods of time. Analysing dental calculus can provide insights into the diet and oral hygiene practices of ancient populations, as well as the use of teeth as tools (Sperduti et al. 2018; Lozano et al. 2021; Wilman et al. 2021; Díaz-Navarro et al. 2023; Romero et al. in press).

However, identifying plant fibres in dental calculus can be challenging, and the risk of introducing foreign material during analysis can affect results. To minimise contamination, researchers take several precautions, including using clean and disinfected equipment, regularly cleaning work surfaces, using environmental control samples, and conducting analyses in fume hoods. It is also important to note that most research on dental calculus microremains has focused primarily on starch and phytoliths. While other categories of microremains, such as plant fibres, are occasionally mentioned, little emphasis is often placed on their recovery or identification.

Decalcification is essential for the isolation of microremains embedded in dental calculus samples and can be carried out using a variety of methods, including strong inorganic acids such as HCl, weak organic acids, or chelating agents such as EDTA. While HCl is fast acting, it can potentially damage soft tissues and compromise cellular integrity, whereas EDTA is milder and preserves organic matter without affecting tissue structure (Gupta et al. 2014;

Sheehan and Hrapchak 1980). Following these guidelines, the current research has attempted to find a better decalcification method for the extraction of plant fibres. This methodological approach evaluated the use of EDTA and HCl at two different concentrations (0.2M and 0.5M) as decalcifiers for the preservation and analysis of plant fibres within archaeological dental calculus. The results showed that neither EDTA nor HCl, at the concentrations tested, affected the histological structure of plant fibres after 170 hours of treatment. However, samples treated with EDTA showed a higher recovery rate of plant fibres, suggesting that EDTA may be more effective for such studies (Gismondi et al. 2018; Hendy et al. 2018). After being tested on modern plant fibre specimens, this methodology was then applied to control dental calculus samples from the medieval site of Castell de Besora (Barcelona). The results showed that 0.5M EDTA was the most effective decalcifying agent, striking a balance between preserving the integrity of the control plant fibres, achieving an efficient decalcification rate due to its concentration, and successfully recovering microremains from the dental calculus. Then 0.5M EDTA was used for no more than 170h to research early Neolithic samples from the Cova del Pasteral site (La Cellera de Ter, Girona).

Previous studies have discussed how the presence of plant fibres in dental calculus may originate from non-masticatory use of teeth, such as in craft activities, although the analysis of dental calculus content regarding the presence of plant fibres should be combined with other anthropological studies and approaches to reach a positive conclusion on the commonly-known use of teeth as a third hand, such as Activity Induced Dental Modification (AIDM) (Radini et al. 2019; Lozano et al. 2021). From a methodological perspective, the study included in this paper references similar research, including the work of Le Moyne and Crowther (2021), who analysed starch granule recovery and found that prolonged exposure to 0.5M HCl did not significantly alter starch morphology. Their findings, along with those of others (Tromp et al. 2017; Soto et al. 2019), support the use of EDTA over HCl, particularly where the preservation of DNA, protein and micro-remnants is critical, given the limited availability of ancient dental calculus.

The results of the present study could not definitively link the fibres to specific activities due to the lack of contextual data, although it highlights the potential of dental calculus in preserving microremains that can provide information on past human behaviour. It was also noted that the identification of plant fibres is challenging due to the low resolution of diagnostic features and the similarity between different plant species. Finally, with regard to the archaeological remains found in the dental calculus of the case study, the presence of monocotyledonous plant tissues (Poaceae) is consistent with established Neolithic agricultural practices in the study area. These findings are consistent with archaeobotanical research from nearby sites, such as La Draga, where various monocot species have been documented (Antolín 2013; Piqué et al. 2021; Herrero-Otal et al. 2021). The study concludes that although the exact origin of the plant fibres in the tartar samples remains uncertain (crafting, feeding, among others), their preservation suggests that tartar can be a valuable resource for understanding ancient human activities, especially when combined with other archaeological and anthropological evidence (Romero et al. 2021a, 2021b; Berihuete-Azorín et al. 2018a). Further research is therefore needed at the midpoint of archaeobotanical and anthropological studies for a more in-depth understanding in this area.

7.2. Plant fibres used during the Mesolithic and Early Neolithic.

7.2.1. The use of raw material from the Mesolithic to the Neolithic.

The identification of plants used in craft production provides new insights into the past landscape and adds to previous archaeobotanical research. The plant species identified in this study are consistent with previous knowledge of the historic vegetation surrounding the settlements and provide additional evidence for the use of plant-based productions by the sites' inhabitants. The use of plant resources is related to their availability in the site surroundings, which is directly influenced by their geographical location.

The systematic analysis of the fibres used as raw material at the Cueva de los Murciélagos site confirmed the use of *Stipa tenacissima* for craft purposes (Martínez-Sevilla et al. 2023). The use of this species was already suggested by previous studies through macroscopical observation, although no anatomical analysis was carried out (Alfaro 1980, 1984). In the current study, microscopic examination revealed microanatomical characteristics visible in modern esparto samples, which are absent in other plants of the Poaceae family with esparto-like properties (such as *Stipa gigantea* and *Lygeum spartum*). These plants also grow in the vicinity of the site and have also been traditionally used for fibre production, although less commonly than 'true' esparto grass (*Stipa tenacissima*). No other plants were found in the analysis of fibre-based products from the site, suggesting that the Mesolithic and Neolithic human groups that occupied or used the cave as a burial site relied on the natural resources available locally. Although palynological studies (Revelles 2023) suggest that other hydrophytic plants should have been present relatively close to the cave, there is no evidence of their use according to the current archaeological record at the site.

The evidence for the use of plant fibres at Cueva de los Murciélagos provides a unique opportunity to document a long tradition in the use of plants in material culture, beginning in the Mesolithic with the last hunter-gatherer groups and continuing at least until the arrival of the first farming communities in the area in the Early Neolithic. Some Middle Neolithic materials dated at the site reveal a continuity in the use of this raw material spanning thousands of years. *Stipa tenacissima* is still used today in traditional crafts and its use goes back to prehistory, as shown by the materials studied here. However, these are not the oldest remains found in Iberia. The oldest direct evidence of the use of esparto grass discovered to date was found at Coves de Santa Maira (9600±40-7370±40 BC, Alacant), where three charred fragments of braided cord and an untwisted fibre of this material were documented (Aura-Tortosa et al. 2019). Nevertheless, the fibre-based assemblage from Cueva de los Murciélagos is the largest and best preserved not only in the area, but in the whole of southern Europe.

In relation to the use of esparto grass in prehistoric craftwork, several Iberian archaeological sites have provided evidence of its use, largely thanks to the arid preservation conditions that prevail across much of the peninsula. On the east coast, fragments of a woven basket made of esparto grass have been found at Cova de les Cendres (4510±40 cal BC; Alacant) (Bernabeu Aubán and Fumanal García 2009). However, the majority of finds are from southern Iberia and date to more recent chronologies. Notable examples include the remains of a plaited cord at Villa Filomena (3000-1800 cal BC; Castelló), fragments of cords and plaited baskets at Cabezo Redondo (2429-2065 cal BC; Alacant), braided cords and plaited, twisted and coiled baskets at Ifré (2360-1910 cal BC; Almería) (Alfaro 1984), a braided cord and remains of woven baskets at Las Angosturas de Gor (2350-1919 cal BC, Granada) (Cacho et al. 1996), and a corded net documented at Castellón Alto (1900-1600 cal BC, Granada) (Molina et al. 2003).

The analysis of raw materials used in fibre-productions from all the sites included in this thesis has yielded results consistent with historical and ethnographic studies of the area. Different species from herbaceous, woody and shrub families have been documented, including monocotyledonous groups such as Poaceae, Cyperaceae, Typhaceae and Juncaceae, as well as bast fibres such as stinging nettle (Urticaceae) and lime tree strips (Malvaceae) (Herrero Otal et al. 2021; Romero-Brugués et al. 2021b).

The environments around the Coves del Fem and La Draga sites have been well defined by several archaeobotanical studies (Revelles et al. 2015, Alcolea 2018, Piqué et al. 2022). In fact, the palaeoenvironment at La Draga is one of the best known in the Iberian Peninsula, mainly due to the exceptional preservation of organic materials at the site.

All the monocot species identified in fibre-based products at La Draga and Coves del Fem are well documented in the archaeobotanical studies carried out at both sites, confirming their availability in the surroundings of the sites at the time of the occupations. The use of these monocot families for plant crafts have been recorded in other latitudes. For example, at Çatalhöyük (ca. 7400-6000 BC; Turkey), fibre-based artefacts were made from wild panicoid grasses, sedges, and cereal straw, with occasional use of common reed (*Phragmites australis*) (Wendrich and Ryan 2012). At the Fayum site (ca. 5450-4400 BC; Egypt), baskets were made primarily from wheat straw and grasses. There is also evidence that *Typha* sp. species were used, although this has not been definitively confirmed (Wendrich et al. 2017; Wendrich and Holdaway 2018). In Iberia, at the site of Cueva del Moro (1530-1425 cal BC; Huesca), monocot and willow fibres were found to have been used in the production of baskets (Alcolea and Rodanés 2019).

In the case of La Draga, regional availability of lime tree has been confirmed by palynological studies (Revelles et al. 2014, 2015; Revelles and van Geel 2016) and carpological analysis (Antolín and Buxó 2011) carried out at the site. The archaeobotanical evidence suggests that *Tilia* sp. species were present around the settlement during the Neolithic period. Today, the lime family, including *Tilia platyphyllos* and *Tilia cordata*, can be found near Lake Banyoles. The frequent presence of lime bark in fibre-based crafts suggests a deliberate selection and specialised use of this natural resource at the La Draga archaeological site, but this will be developed further on.

Due to its strength and flexibility, lime bark has been one of the most important natural resources for fibre production in ancient Europe. Its selection as a raw material was typically based on practical considerations such as suitability and local availability. The use of lime bark as a source of fibre has been documented at several prehistoric sites in Europe dating back to the Mesolithic period. Notable examples include the Antrea site (8400-8300 cal BC; Finland), where fragments of nets made from twisted cords were discovered (Bender Jørgensen 1992; Miettinen et al. 2008; Wigforss 2014), and the Friesack-4 site (7700 BC; Germany), where fishing nets and braided cords made from lime fibre were found (Gramsch 1992). Other important examples of twisted cords made from lime fibres are the cords from Wetzikon-Robenhausen (3700-3300 BC; Switzerland), the cords from Arbon Bleiche (3385-3370 BC; Switzerland) (Altorfer and Médard 2000; Médard 2003, 2008; Rast-Eicher and Dietrich 2015), and fibre-based artefacts associated with the Tisenjoch Iceman (Junkmanns et al. 2019).

Other plants such as alder (*Alnus* sp.) have also been used since prehistoric times, more specifically in northern Europe, in Ireland (Raftery 1970). However, although these taxa were present in the surroundings of La Draga and Coves de Fem, no archaeological evidence of their use has been found.

Whereas flax (*Linum usitatissimum*) bast fibre is one of the most frequent fibre-based materials used in prehistoric times (Médard 2003; Harris 2014; Gleba and Harris 2019; Gleba et al. 2021), there is no evidence of flax in La Draga. Flax does not appear in the archaeological record of the Iberian Peninsula until the second half of the 6th millennium BC (Peña-Chocarro 1999; Pérez-Jordà and Carrión-Marco 2011; Rovira 2007; Stika 2005). However, the use of bast fibres at La Draga is well documented, in this case represented by nettle (*Urtica* sp.), recorded among the cord assemblage (Piqué et al. 2018; Herrero-Otal et al. 2023). This taxon was also recorded in the surrounding palaeoenvironment (Antolín 2013; Antolín and Buxó 2011).

In La Draga, lime tree strips were exclusively used for sewing elements in basketry and for the production of cords, indicating a deliberate choice of raw material (Herrero-Otal et al. 2021, 2023). The presence of different types of wood in the forests, including lime, suggests a form of forest management similar to that observed in other European regions during the Neolithic (Coles et al. 1978). Together with the probable use of nettle for cord production (Piqué et al. 2018; Herrero-Otal et al. 2023), this indicates a selective approach to the gathering of raw materials based on the physical and mechanical properties of the fibres. The results suggest that there was a deliberate selection of materials with specific functional properties, appropriate for the intended use.

7.2.2. Describing the first stages of the *chaîne opératoire* of fibre-based productions.

The production of fibre-based objects using various plant species involves a complex *chaîne opératoire*, deeply rooted in an understanding of the environment, biological cycles, mechanical properties and technological potential of these plants, regardless of their prehistoric chronology. It is essential to recognise the human ability to transform these natural resources into manufactured goods used in everyday life to satisfy multiple needs. The *chaîne opératoire* begins with the careful selection of specific plant families and species, followed by the harvesting and collection of these plants at the optimum time, taking into account their biological cycles and environmental conditions. In the case of fibre-based production, these steps include not only the initial sourcing of natural resources, but also the preparation and storage of the materials. The exact steps involved vary according to the species used, particularly between monocotyledons and dicotyledons.

While archaeological evidence for the steps in this *chaîne opératoire* is limited, ethnographic data and traditional knowledge provide valuable insights into the various factors to be considered at each stage. In general terms, once the materials have been collected, they are usually dried and then slightly rehydrated before use. This drying process prevents shrinkage during manufacture, ensures higher quality and facilitates handling. As a result, the timing of harvesting and material sourcing does not necessarily coincide with the time of object production. Once dehydrated, the raw material can be stored indefinitely, allowing flexibility in production and greater control over the quality of the materials used (Wendrich and Ryan 2012).

Different plant species require different harvesting techniques, often using specific tools. For example, some plants, such as certain Poaceae or Typhaceae species, are harvested with sickle blades, while others, are pulled from the ground by hand or with tools that facilitate the process. In the case of Cyperaceae or Juncaceae, they are usually pulled from the ground without tools. However, certain Poaceae plants, such as *Stipa tenacissima*, can be difficult to pull by hand, so a wooden or metal stick is often used. This involves wrapping a bundle of esparto leaves around the stick, and then pulling it off the plant (Kuoni 1981; M'hamdi and Anderson 2013).

However, there is no specific archaeological evidence to indicate where the materials were collected or the season in which these plants were harvested. It is generally assumed that the optimal time for collection is between late spring and early autumn, depending on the species. Further research is needed to confirm this in the archaeological record.

In the case of Cueva de los Murciélagos, several aspects of the use of *Stipa tenacissima* can be considered for both the Mesolithic and Neolithic periods (Martínez-Sevilla et al. 2023). Although there is currently no direct archaeological evidence of harvesting practices, the materials suggest that esparto was probably pulled from the ground in both periods. When esparto leaves are pulled, the basal part remains linear, but when dry they fold and form a hook known as a 'head', which can be observed in certain parts of the archaeological material from the site. Depending on the artisan preferences, these heads may be cut either before or after the object is made. These 'heads' are visible in some of the materials from the site (both Mesolithic and Neolithic) evidencing that the leaves were gathered by pulling them from the ground. In contrast, some other 'heads' appear cut, which suggests that the artisans from Cueva de los Murciélagos paid particular attention to the finishing touches, like contemporary fibre artisans, to enhance the beauty, finesse and care of the final products.

There is no archaeological evidence of esparto being stored in the cave. However, recent fieldwork has uncovered small bundles of two or three esparto leaves tied together, in keeping with the traditional practice of knotting bundles of esparto and storing them until needed. These materials have not yet been analysed and their chronology is unknown, so it remains unclear whether they are prehistoric, historic or more recent. Nevertheless, the intentionality of the knotting suggests a purposeful human activity.

In addition, when preparing esparto as a raw material, several traditional methods can be used to improve the working properties, shape and appearance of the finished products. Traditional artisans typically harvest esparto leaves in the summer and dry them for about a month to produce raw esparto. This dried esparto can then be rehydrated by soaking it in water for about 24 hours, making it ready for use in handicrafts. The raw, intact leaves can also be further processed by a method known as retting, in which the esparto is submerged in stagnant water for about a month, depending on the artisan's preference. This process involves anaerobic fermentation, which breaks down certain organic components, resulting in retted esparto that is more resistant and flexible, as stated by traditional artisans (Kuoni 1981). Retted esparto can be rehydrated in a similar way to raw esparto, or it can be physically processed by crushing the leaves with a wooden mallet to extract the fibres, producing 'crushed' esparto. More recently, industrial methods have introduced the practice of combing the finest fibres to further refine the material.

In the Mesolithic phase at the Cueva de los Murciélagos site (Phase I), esparto leaves were probably rehydrated to make them malleable for craft use. Current artisans state that the fine fibres with which this set of artefacts was made can only be achieved by retted esparto grass. However there is no evidence of crushing or retting in the Mesolithic materials. The presence of decorative geometric motifs on some of the Mesolithic baskets made with dyed fibres suggests that the dyed fibres were dipped in a liquid containing components, as yet unidentified, to achieve the colouring. This is an ongoing area of research within the MUTERMUR project.

The smaller diameter of the esparto leaves used in Mesolithic objects compared to those of the Neolithic phase suggests that younger leaves were selected for crafting the Mesolithic objects.

The practice of physically crushing esparto only appears in the Neolithic (Phase II). Although some histological differences in leaf cross-sections were noted in the archaeological materials, further research is needed to understand their significance. This does not imply that Mesolithic communities were unfamiliar with the physical processing of esparto grass; rather, it is simply not currently reflected in the available archaeological record from Cueva de los Murciélagos. In this regard, it is worth noting that the charred braid fragments from Cueva de Santa Maira (Alicante), dating from the Epipaleolithic (Aura-Tortosa et al. 2019), suggest that the fibres were physically crushed.

Furthermore, there is currently no information on the possibility of the Neolithic esparto grass being retted. As mentioned above, this is a line of research that is still under investigation. This new form of processing, together with the diversity of objects and techniques observed in this later phase of site use, indicates a significant expansion of morphotechnological and processing aspects during the Neolithic period in southern Iberia.

In the case of Coves del Fem, further studies are needed to provide a more detailed discussion of the processes involved in the *chaîne opératoire*, as the current data on basketry is limited to a single basket artefact and a small fragment of cordage, both associated with the same structure. More complete information will require future research. Nevertheless, the availability of raw materials just a few metres from the site suggests that these objects were produced locally.

At La Draga, in addition to the wild plant families mentioned above, three different species of Poaceae (grasses) have been identified through the analysis of the raw materials used for fibre production. Although it has not yet been possible to identify the specific Poaceae species, they could be either wild or cultivated. While several wild species of this family, such as *Phragmites australis*, are found in the surrounding area, crop cultivation at the site is well documented through carpological analysis of various species (Antolín 2013). These findings suggest the potential for plant materials to be reused for multiple purposes, such as both food and craft production. Although 'reuse' may not be the most precise term, it can reflect the practice of using leaves and stems of plants not suitable for human consumption (as opposed to grain seeds) to make fibre-based objects.

Furthermore, there is no evidence at La Draga for the process of obtaining lime tree strips or nettle, even though the process is known to be complex (Médard 2008; Myking et al. 2005). Only finished products made of these two dicotyledonous plants have been found at the site, with no direct evidence of bark strip extraction. The absence of *Tilia* sp. in the charcoal remains and its infrequent presence among the wooden remains suggest that the inhabitants of La Draga likely transported prepared strips to the site. *Urtica dioica* has been detected among the carpological remains (Antolín and Buxó 2011), but no stored dicotyledonous fibres have been discovered at La Draga.

There are several methods for extracting fibres from the stems of dicotyledonous plants. Traditional extraction techniques can vary depending on the expertise of the artisan, but generally follow a similar process. This involves manually harvesting the plants and removing the leaves from the stems, either by dehydration or by hand. This process makes the stem accessible and easier to work with. Alternatively, the material can be rinsed and retted to achieve the same end. When the stems are completely dried after retting, the fibres are extracted by hand, using tools such as wooden mallets to separate the bark from the stalk and to cut the fibres. The resulting fibres are soft yet strong, making them suitable for the manufacture of diverse objects (Andersson Strand 2012; Viotti et al. 2022). Although there is no archaeological evidence to confirm this in La Draga, ethnographic and experimental data suggest that the raw materials used in fibre crafts can be dried from the time they are harvested until the objects are made. As mentioned above, this practice prevents the materials from shrinking as they dry, preserves their quality and makes them easier to handle. Moreover, the time of harvesting and obtaining the raw material is not directly linked to the time when the tools or objects are made. The fibres can be stored for long periods and only need to be slightly rehydrated before use, allowing flexibility in the production process.

Although no specific evidence of plant fibre storage was found at the La Draga site, three rolls of *Clematis* sp. were recovered. These objects were not included in the current analysis, as they were previously examined by Piqué et al. (2018) and were considered to have been prepared and stored for future use. In addition, a roll of cord, the raw material of which was analysed in the current paper (D04 JI92-2), provides further evidence for the storage of finished products, although it does not represent the storage of raw fibres.

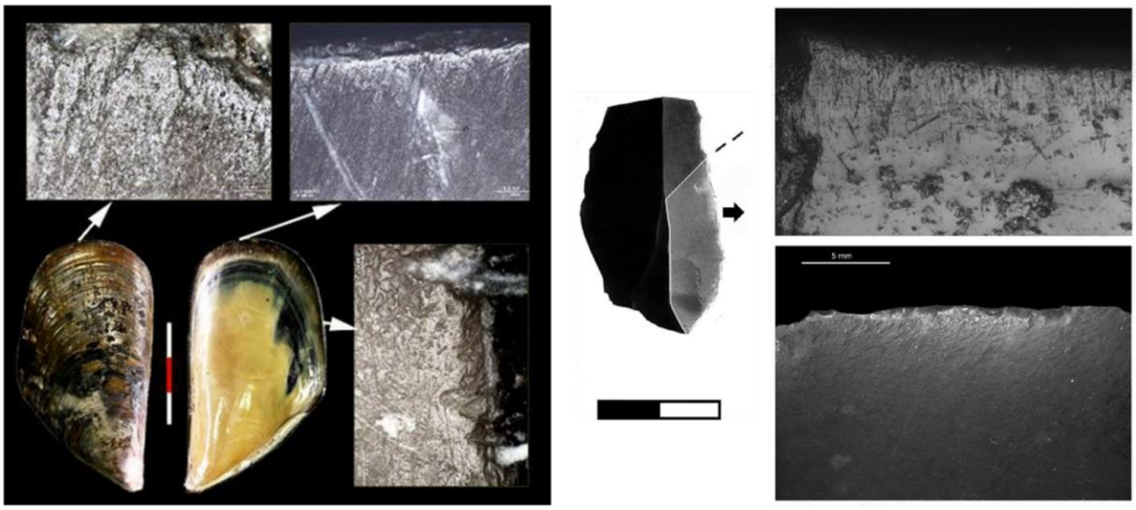

Figure 120. Left: Use-wear studies on Mytilus galloprovincialis shells from La Draga (Clemente and Cuenca 2011). Right: Use-wear studies on lithic artefacts (Gibaja 2011).

In terms of production, several objects related to the processing of plant fibres were identified at La Draga and analysed by comparing wear patterns with experimental tools. The results of functional analysis of objects of different nature (malacofaunal, lithics, wood and bone tools) suggest local fibre crafting. Use-wear studies detected that shells of

Mytilus galloprovincialis seemed to be used for processing fibres (Figure 120) (Clemente and Cuenca 2011), as well as some lithic artefacts (Figure 120) (Gibaja 2011). Bone tool analysis was able to determine that at least six awls were used for working with plant fibres (De Diego et al. 2017; De Diego 2023). Other perforated bone tools recovered from the site were also used in a variety of fibre processing activities, including extraction, spinning, weaving and rope-making. These tools, with two or three perforations, probably represent different stages in the *chaîne opératoire* for the production of fibre-based objects. They may have functioned as tensioners for threads or ropes and would be effective in the production of two-strand ropes, as demonstrated by experimental studies (De Diego et al. 2017; De Diego 2023). These hypotheses are supported by similarities in wear patterns between archaeological and experimental tools, suggesting that they were used to work with plant fibres in a similar way (De Diego et al. 2018; De Diego 2023). However, analysis of the wear patterns did not distinguish between different plant families or species. Although other tools probably related to fibre work were found at La Draga, such as a wooden comb, the use-wear analysis did not provide any results due to the restoration process (De Diego 2023).

Regarding the processing of the fibres, both the monocotyledonous and dicotyledonous plant families found in the archaeological cord and basket remains from La Draga show signs of physical processing, such as splitting the fibres into smaller units (Figure 121).

Figure 121. Signs of fibres physical processing in La Draga.

The availability of raw materials in the immediate vicinity, together with the tools associated with plant processing found at the La Draga site, suggest that these fibre-based objects were probably produced locally. The identification of several plant families used in various fibre-based crafts extends previous studies and provides a more detailed understanding of the local vegetation, confirming the presence of species that were previously underrepresented or unrecorded in other archaeobotanical studies. For example, *Tilia* sp. was underrepresented in the pollen record and absent in the anthracological analysis, while *Urtica dioica* was noted in the carpological analysis (Antolín and Buxó 2011).

7.2.3. Fibre-based objects in their corresponding archaeological contexts.

The direct evidence of fibre-based production studied in this thesis has been recovered from three different types of archaeological sites. Cueva de los Murciélagos is considered to be a burial cave, based on 19th century reports, while Coves del Fem and La Draga correspond to domestic contexts.

In Cueva de los Murciélagos, both Mesolithic and Neolithic assemblages are thought to be associated with burials (de Góngora 1868). However, since these materials were collected almost two hundred years ago, and due to the limited preservation and lack of dating of the human remains, it is unclear whether all the objects were originally placed in the cave or how they were associated with other anthropological or archaeological remains. The differences observed between the Phase I and Phase II assemblages at the site are likely to reflect differences in the nature of human activity in the cave during these periods. The most common fibre-based artefacts in the assemblage are baskets and basket fragments, which show considerable diversity in terms of shape, size, raw material processing and state of preservation. The next most common category is cord sandals, although individual cords themselves are less common than other types of fibre-based artefacts.

With regard to the materials from the earliest phase (Phase I), the Mesolithic, all the objects consist of relatively small, simple-twined baskets with a close weave. Some of these baskets still contain various materials, such as bundles of hair, mineral pigments or *Papaver somniferum* capsules (noted by de Góngora (1868)). The absence of macroscopic signs of wear, together with the delicate nature of their production and unique contents of the baskets, suggest that they were probably used for specific purposes, possibly related to Mesolithic burial practices.

Neolithic containers show a greater variety in shape, size, raw material preparation and production technique than those from the Mesolithic period. Most of these Neolithic containers are found in fragments, making it difficult to determine whether they were originally flat objects, such as mats, or three-dimensional objects. This variation in shape and size suggests a wider range of possible uses. According to de Góngora's descriptions (1868), the people buried in the cave were dressed in esparto grass textiles, hats and sandals. However, sandals are the only items of clothing that have survived in museum collections. Some of these sandals show signs of wear, while others appear to have been unworn, suggesting that some individuals were buried in their everyday clothes. The other Neolithic basket elements cannot be related to specific functions as their contextual association is unknown. However, their function as clothing can be discarded due to their morphology, rigidity or size.

The objects from both Coves del Fem and La Draga were recovered from domestic contexts, and show a higher degree of fragmentation. This is not due to their function or use, but to their taphonomy. Thus, the basket fragments are suggested to be probably parts of discarded elements. The fragmentation of the baskets at these sites prevents the identification of their original shapes or whether they were two- or three-dimensional objects. However, the location of the materials and their association with cereal remains suggest a storage function in some cases (Romero-Brugués 2021).

7.2.4. The use of raw materials in Mesolithic and Neolithic basketry in Iberian Peninsula.

The direct evidence for fibre production discussed in this thesis corresponds to the oldest archaeological evidence of this type found in southern Europe. In the case of the Cueva de los Murciélagos site, these findings allowed us to observe the socio-economic transition from the last hunter-gatherers to the first farmers in southern Iberia. Although the use of esparto grass was maintained in both periods, the range of treatments applied to this raw material, as well as the diversity of techniques and objects, is much greater in the Neolithic. This case is unique because other European sites with similar chronologies do not display some of the techniques represented in the collection of objects from Cueva de los Murciélagos, such as the *cofín* technique, although others, such as coiled basketry, are consistent with those found in other contemporary European materials.

Similarly, the cord and basketry assemblages from Coves del Fem and La Draga are also consistent with the oldest recorded fibre-based production in Europe, in terms of both raw materials and technology. These examples, together with those from Cueva de los Murciélagos, suggest that the technique of basket-weaving may have been introduced by the first inhabitants in the area, who lived at the crossroads of a hunter-gatherer and agro-pastoral economy.

Furthermore, the identification and processing of raw materials at the three sites analysed in this thesis has complemented other archaeobotanical studies and provided a more detailed understanding of ancient plant landscapes. In addition, this research provides an insight into prehistoric plant fibre production: a relatively underdeveloped area in traditional archaeological research. As this thesis demonstrates, the study of these materials can lead to the formulation of diverse hypotheses and research questions, opening up a wide area for further exploration, especially in the Iberian Peninsula, where such studies have been particularly scarce.

Despite the limited number of sites investigated, some general observations can be made about the raw materials used for basket and rope production during the Mesolithic and Neolithic periods. The analysis of a single case of Mesolithic basketry, while revealing, does not provide sufficient evidence to identify trends in raw material use beyond the well-established tradition of esparto grass, which has been used for millennia. This continuity suggests the transmission of ecological and technological knowledge across generations, which continues to the present day.

In Neolithic basketry, there are notable differences between the northern and southern regions of the Iberian Peninsula. In the south, only esparto grass has been documented, whereas in the north a wide variety of plant taxa were used. The availability of plants in each region probably played a crucial role in this selection process. Climate, soil types and vegetation patterns influenced the distribution and accessibility of raw materials such as esparto grass. The absence of esparto grass in northern Iberia can be attributed to its natural distribution areas, which are distant from sites such as La Draga and Coves del Fem. Conversely, in south-eastern Iberia, other grasses, rushes and cattails were available, but were not used at Cueva de los Murciélagos. The consistent preference for esparto grass, when available, over other taxa is probably due to its exceptional properties.

Esparto grass fibres are resistant to decay, light, strong, flexible and easy to work with; qualities that have made it a popular material for craftwork. Its versatility is evident in the Neolithic artefacts from Cueva de los Murciélagos, where it was used to make cords, a variety of containers, mats and footwear. Furthermore, the wide range of techniques documented at the site - such as twisting, braiding, coiling, and *cofín* - highlights the adaptability of the material (Alfaro 1980, 1984; Martínez-Sevilla et al. 2023).

In contrast, the situation in northeastern Iberia was quite different. In the Neolithic more diverse plant taxa were used (including rushes, Poaceae grasses, cattails, lime bark and bast fibres), with some objects combining several taxa. However, the techniques documented in basketry production were mainly limited to coiling.

The low technical variability combined with high raw material diversity in northeastern Iberia contrasts sharply with the high technical variability and low raw material diversity found in southeastern Iberia. These two different basketry traditions may be linked to the presence of an exceptional material, such as esparto grass, which is still used in Iberian basketry today. However, it is also important to consider that human choices could have been influenced by social rules and the transmission of knowledge from one generation to the next, which, in the case of esparto grass, could have contributed to the homogeneity of raw material use. The preference for esparto grass in southeastern Iberia or the great diversity of taxa in northeastern Iberia may be related to different basket-making traditions. While in the south specialised techniques maximised the potential of esparto grass, in the north the use of different materials may have stimulated technological innovation, as different coiling techniques have been documented.

CHAPTER VIII – CONCLUSIONS AND FINAL CONSIDERATIONS

8. Conclusions and final considerations.

8.1. Conclusions.

The present research has obtained valuable insights into various aspects of prehistoric human groups, particularly Mesolithic to Neolithic communities in the south-eastern and north-eastern regions of the Iberian Peninsula. These findings have been achieved through the study of a type of material that is rarely preserved in the archaeological record due to its perishable nature and which therefore has traditionally been overlooked in archaeological research: plant fibres. This thesis has considered evidence of plant fibres from four archaeological sites in those regions: Cueva de los Murciélagos (7986-3740 cal BC; Albuñol, Granada), Coves del Fem (ca. 6065-4545 cal BC; Ulldemolins, Tarragona), La Draga (5324-4977 cal BC; Banyoles, Girona) and Cova del Pasteral (ca. 5000-3000 cal BC, Girona).

This study has identified a wide range of plant species used for the production of plant-based artefacts during those periods in the area. More specifically, the main conclusions for each of the objectives outlined in Chapter I are as follows:

(i) From a methodological point of view, this research has led to the creation of the first reference collection for the identification of plant fibres in the Archaeobotany Laboratory of the Prehistory Department at the Universitat Autònoma de Barcelona (UAB). This collection establishes the main microscopic characteristics for the identification of different families and species used traditionally and archaeologically for fibre-based handicrafts. The reference collection includes images of the microanatomy obtained by optical and scanning electron microscopy of both monocotyledonous and dicotyledonous plants, with a greater emphasis on the former, as they are the main type of plants identified in this study. Different parts of the plants, including stems and leaves, have been included in the reference collection based on the species and the ethnographic and traditional uses of each part. Research on dicotyledonous plants carried out by other European researchers has also been followed.

(ii) The diagnostic characteristics established for this study include features visible in both macroscopic and microscopic observation of the samples. Microscopic features, such as those visible on the epidermal surface (including the morphology of epidermal cells, the presence of stomata and associated cells, and the presence and nature of appendages), as well as features observed in cross-sections (such as the appearance, morphology and distribution of vascular tissues, including xylem, phloem, sclerenchyma and parenchyma), are the microanatomical structures used for identification. These key features have been crucial for the taxonomic identification of the archaeological materials studied.

(iii) A methodology for sampling plant fibres has also been proposed, taking into account their preservation conditions, depending on whether the evidence of plant fibres is from plant-based artefacts or other types of remains.

(iii.i) The analysis of fibre-based artefacts from three different sites in the Iberian Peninsula (Cueva de los Murciélagos, Coves del Fem and La Draga) has furnished new data for understanding the use, management and technological knowledge of Mesolithic and Neolithic human groups in the south-eastern and north-eastern regions of the Iberian Peninsula. The results of this research indicate that carbonised samples are more suitable for microscopic observation, although dehydrated samples can also be examined. However, waterlogged samples are the most difficult to analyse. Due to the extreme fragility of these materials, it is important to sample them prior to the application of consolidants, which are nonetheless critical for their recovery. Therefore, a balance between sampling and consolidant application is essential.

(iii.ii) For non-artefactual materials, a methodology has been explored for the recovery of plant fibres immersed in dental calculus. The samples were analysed to detect archaeological evidence of plant fibres in non-perishable materials, such as mineralised bacterial plaque, as these are rare in archaeological contexts due to their high perishability under most environmental conditions. This approach is based on the possibility that teeth were used in the processing of plant fibres - as a 'third hand' - as has been documented ethnographically in several societies. The conclusion of this part of the research is that the use of EDTA and HCl, the most commonly used decalcifiers in dental calculus analysis, does not affect the key features required for identification of plant fibres at concentrations of 0.02M and 0.05M for a maximum of 170 hours. However, considering the amount of plant fibre recovered from both the control samples (from the Castell de Besora site) and the case study samples (from the Cova del Pasteral site), the use of 0.05M EDTA is preferred. This is also consistent with the results of other researchers focusing on other plant residues, such as starch grains. Despite the positive recovery of plant fibres, their identification remains a challenge, so this process should also be supported by the presence of other microremains. From an anthropological perspective, the identification of the proposed use of teeth as a 'third hand' should involve a combination of anthropological, archaeological and archaeobotanical approaches. The identification of plant fibres in dental calculus samples alone is not sufficient, as their presence may be due to other activities, such as the consumption of food.

(iv) The identification of plant fibres used in Mesolithic craftwork has been approached through the analysis of Mesolithic baskets from the Cueva de los Murciélagos site, where the use of *Stipa tenacissima* (esparto grass) has been detected. The continued use of this plant in the Neolithic period highlights its versatility and importance in craft practices. A variety of techniques and methods for working esparto grass have also been documented in the Early and Middle Neolithic periods, demonstrating an evolving understanding of the material's properties and potential. These findings suggest that prehistoric populations possessed sophisticated knowledge of plant resources and their management. This knowledge probably played a crucial role in the development and practices of early agricultural societies. The materials from Cueva de los Murciélagos provide valuable insights into the transition from the last hunter-gatherer communities to the first agricultural societies in southern Iberia, showing that the use of esparto grass dates back to at least 8000 BC and continues to form part of the cultural fabric today. This continuity in the use of esparto grass reflects not only its durability and utility, but also a deep-rooted cultural tradition that has endured for thousands of years. The continued presence of esparto grass in handicrafts demonstrates its importance in the daily lives and technological advancements of prehistoric communities, bridging the gap between ancient and modern uses of this remarkable natural resource.

The research at Coves del Fem, although currently focused on a single basket artefact and a small fragment of cordage, offers preliminary data about the fibre-based production practices of Neolithic communities in the region. Similarly, the finds from La Draga provide important information on the fibre production techniques used by Neolithic groups. The analysis of the materials, which include three different species from the families Poaceae, Cyperaceae and Typhaceae, as well as the use of lime-tree (*Tilia* sp.) and nettle (*Urtica* sp.) fibres, indicates a wide range of plant species used for craft purposes. The proximity of raw materials to these sites suggests that many of these objects were likely produced locally, demonstrating the ability of the inhabitants to use readily available resources for their crafting needs. These results highlight the importance of effective local resource management and the diversity of plants that could be used for fibre production. The basketry techniques observed, together with the deliberate selection of specific raw materials and plant parts, reflect a high level of technical knowledge. Overall, the plant remains analysed in this study reveal the extensive expertise of the community in terms of both technical skills and in-depth understanding of plant properties.

(v) The description of the *chaîne opératoire* in the three archaeological sites has not been possible at the same level. The analysis of esparto grass at Cueva de los Murciélagos provides important insights into the elaborate techniques used by prehistoric communities to produce fibres. The results suggest that both Mesolithic and Neolithic populations at the site were skilled in the selection and processing of esparto grass, which had to be carefully pulled from the ground, dried, and then rehydrated to make it malleable for craft use. The evidence of cut 'heads' and the presence of hooked ends on some leaves indicate a nuanced approach to material preparation, reflecting a focus on both the functionality and aesthetic quality of Mesolithic objects. During the Neolithic there is evidence of further advances in esparto processing techniques, such as the possible introduction of retting and crushing to increase fibre flexibility and strength. This evolution in processing methods suggests a continued and expanding use of esparto grass in craftwork, highlighting its importance in the cultural and technological development of early agricultural societies. Although direct evidence of the storage of raw materials is still lacking, the discovery of small bundles tied together suggests deliberate collection and possible storage strategies (although their chronology is not yet known). Overall, the treatment of esparto grass at Cueva de los Murciélagos reveals a dynamic tradition of fibre use spanning thousands of years, demonstrating continuity, innovation and adaptation in the use of natural resources.

Although there is no direct evidence of specific fibre processing methods in Coves del Fem and La Draga, such as retting, the use of lime tree bark strips in some baskets (and some specific parts of the baskets) and the presence of well-finished products suggest some kind of fibre extraction method, and a well-developed knowledge of the selection and preparation of fibres. These practices reflect a broader understanding of resource management, as it is likely that the inhabitants transported prepared materials to the site, as in the case of bark strips. The evidence also suggests that these early agricultural societies adopted flexible production strategies, preserving and storing plant materials to ensure quality and adaptability in their craft activities, as confirmed by the presence of rolls of *Clematis* sp. Overall, the results from both sites are indicative of the sophisticated technological and environmental knowledge possessed by Neolithic communities in the management and use of plant resources. Further studies are needed to fully understand the *chaîne opératoire* involved in the production of these artefacts, which will help to elucidate the technological capabilities and adaptive strategies of these early agricultural societies.

(vi) This study has obtained valuable insights into the palaeoenvironmental conditions of the Iberian Peninsula during the Mesolithic and Neolithic periods. The plant material recovered from the three archaeological sites complements previous archaeobotanical studies (anthracological, carpological and palynological, among others), documenting the presence of species from diverse plant communities. These plants were collected in specific environments according to their seasonal cycles. This study therefore enhances our understanding of the dynamic relationship between prehistoric humans and their environment, underscoring how resource availability shaped the technological developments of early farming societies in the Iberian Peninsula.

(vii) The materials analysed in this thesis display unprecedented diversity of basket types and techniques compared to other Mesolithic and Neolithic sites on the Mediterranean coast. The archaeological sites of Cueva de los Murciélagos, Coves del Fem and La Draga offer a comprehensive view of fibre-based production and plant resource management practices from the Mesolithic to the Neolithic in the Iberian Peninsula. At Cueva de los Murciélagos, in southern Iberia, evidence for the use of esparto grass spans both the Mesolithic and Neolithic periods, illustrating the continuity and evolution of craft techniques, including the selection, drying and possible retting and crushing of fibres. In contrast, the Coves del Fem site, in the north-eastern region, provides more limited but still valuable data, with evidence consisting mainly of a single basket artefact and a fragment of cordage, indicating local production and suggesting dependence on proximate resources for craft activities. Meanwhile, La Draga offers a unique perspective on Neolithic fibre use, with the identification of several Poaceae species and the use of lime-tree and nettle fibres, suggesting a diverse range of plant materials for craft purposes and denoting a complex understanding of plant resources akin to that found in Central Europe. Together, these sites demonstrate the technological and ecological knowledge, as well as the resource management strategies, of prehistoric populations in the Iberian Peninsula, reflecting both continuity and innovation in fibre production techniques, as they represent the oldest and best-preserved examples of fibre-based production in southern Europe.

8.2. Final considerations.

8.2.1. Exploring other methodologies for the analysis of the archaeological plant-fibre record.

Having worked on this topic within the framework of the current thesis, it has shown the limitations of the methodologies that can be employed for the study of plant fibre use in archaeology. However, new technical and methodological advances can be applied to analyse direct and indirect evidence of plant fibres in archaeology. Various analytical techniques can be explored to identify the raw materials in plant fibre artefacts, with the choice of method depending on factors such as the condition of the sample, the feasibility of sampling and the potential for destructive analysis. The new approaches in plant fibre identification can benefit from methods already explored for other purposes with good results. Some of the are summarized here.

Morphogeometry. Geometric morphometrics is an analytical method in biological research that focuses on the detailed quantification and analysis of the shape and form of biological structures. Unlike traditional morphometry, which relies on linear measurements such as length, width or height, geometric morphometry uses coordinate data to capture the complete geometry of shapes, enabling a more accurate and comprehensive analysis. This approach involves identifying and recording landmark points at homologous locations on the structures under investigation, allowing accurate shape comparisons between different samples. Geometric morphometrics has been used effectively for species identification in plants by analysing leaf shapes on a large scale (Cope et al. 2012). However, it can also be applied to microscopic features at the cellular level for more detailed analysis, enabling its use in fibre identification.

Stable isotopes. The use of stable isotopes for the study of plant remains (mainly anthracological and carpological remains) has increased over the last twenty-five years in the archaeobotanical community. These studies have shed light on various aspects of human-environment interactions, such as crop management (Riehl 2008; Ferrio et al. 2011; Wallace et al. 2013; Araus et al. 2014; Fiorentino et al. 2014), water availability for crops (Araus and Buxó 1993; Araus et al. 1997, 1999; Ferrio et al. 2005), water management practices (Araus et al. 1997, Heaton et al. 2009, Ferrio et al. 2005; Wallace et al. 2015) and crop productivity (Araus et al. 2001; Ferrio et al. 2004, 2006; Aguilera et al. 2008), as well as palaeoenvironmental reconstruction (Becker et al. 1991; White et al. 1994; Trimborn et al. 1995). The study of all these aspects has usually focused on those mentioned above, basically applied to agricultural practices, although it can also explore the management and processing of natural resources, such as plant fibres.

Chemotaxonomy. Chemotaxonomy - or chemosystematics - is based on the differences and similarities between the biochemical composition of organisms (mainly plants), allowing them to be classified and identified when classical botanical methods are confusing. The biological compounds analysed in these studies are primary and secondary metabolites. The methodology is based on the fact that different genera and families of plants produce different chemical products that can be used for taxonomic classification and identification of plants (Ankanna et al. 2012; Singh 2016; Courel et al. 2019; Jardine et al. 2019). There are no published studies on the use of chemotaxonomy in the study of plant fibres, although it could provide information on the selection of specific plants, even the taphonomic degradation of the material, or the processing of materials, such as retting. The fact that retting consists in immersing the fibres for variable periods of time, which is a kind of maceration, and thus an organic material would decompose, could be reflected in the chemical profiles determined by chemotaxonomy. The application of this technique should be studied and tested in the coming years.

DNA analysis. Although DNA (deoxyribonucleic acid) is easily degraded by various biotic and abiotic processes, it has been shown to survive under certain preservation conditions, such as cold, aridity and/or low oxygen, and still reveal information about organisms in the past, such as plants. In archaeology, aDNA (ancient DNA) has been used for cultivated (Brown et al. 1993; Brown and Brown 1994; Jones et al. 1996; Brown 1999; Jones and Brown 2000) and uncultivated plants (Parducci and Petit 2004; Gugerli et al. 2005; Bennett and Parducci 2006) to provide information about agricultural practices and the palaeoenvironment. In the case of fibres, DNA can help to map the diversity of species by typing specific genetic profiles of species. Some researchers claim that this is a very promising technique (Lukesova and Holst 2024), but aDNA is usually destroyed taphonomically, as stated above.

8.2.2. Contribution of the research. Research significance.

Identifying the raw materials used in the production of plant-based objects is a key area of archaeobotanical research. This line of research provides important insights into past palaeoenvironmental conditions and complements data from such fields as palynology, carpology and anthracology, among others.

A comprehensive and systematic analysis of fibre-based artefacts can shed light on numerous aspects of how prehistoric human groups understood and managed their environment and natural resources. This research, when integrated with other related studies, opens a new window into understanding the relationship between the last hunter-gatherer societies and the first agricultural communities, and the environments in which they lived in north-eastern Iberia. That period marked a critical juncture in the settlement patterns of human groups and the study of plant fibres offers new perspectives on how those early communities adapted to and interacted with their environment.

The identification of different species, including monocots, herbaceous dicots and bark strips from arboreal dicots, attests the use of both wild and possibly cultivated plants by early human groups. This suggests that riparian and cultivated areas close to archaeological sites served as sources of raw materials for the production of everyday artefacts such as cords, baskets and even sandals. In addition, studies of more durable archaeological materials associated with fibre processing indicate that these items were likely to have been produced locally, highlighting the economic importance of these areas not only for dietary and ecological purposes, but also for the production of fibre-based objects.

The identification of these plant families and genera opens up new opportunities to explore hypotheses regarding the management of these wild species. It raises important questions such as: How were these environments managed? When were these materials collected and how were they processed? How long were the fibres treated to make them malleable, and when were they processed? Were the materials stored for long periods and used throughout the year, even when the plants were not available because of their biological cycles? Did these early communities understand biological cycles and perhaps engage in propagation practices? Answering these questions will contribute towards a more profound understanding of the relationship between early human groups and their environment, particularly in the context of fibre production.

A final remark on the importance of integrating fibre-based artefact analysis into wider archaeological research: it provides a more detailed understanding of the technological and ecological knowledge possessed by prehistoric communities. By combining these findings with other archaeological evidence, we can reconstruct a more comprehensive picture of how these early societies adapted to their environment, exploited natural resources and developed complex cultural practices. The results achieved in the current thesis not only enrich our understanding of the past, but also bear witness to the intricate links between early human innovation and environmental management; moreover, they provide valuable lessons for the study of human-environment interactions throughout history, as well as an important list of questions to be explored in the future for the further development of archaeobotanical research on plant fibres.

REFERENCES AND LIST OF FIGURES AND TABLES

REFERENCES

A

Abbo, S., Zezak, I., Lev-Yadun, S., Shamir, O., Friedman, T., Gopher, A. (2015) Harvesting wild flax in the Galilee, Israel and extracting fibers – bearing on Near Eastern plant domestication. Israel Journal of Plant Sciences 62(1-2): 52-64.

Adler, C.J., Dobney, K., Weyrich, L.S., Kaidonis, J., Walker, A.W., Haak, W., Bradshaw, C.J.A., Townsend, G., Sołtysiak, A., Alt, K.W., Parkhill, J., Cooper, A. (2013) Sequencing ancient calcified dental plaque shows changes in oral microbiota with dietary shifts of the Neolithic and Industrial revolutions. Nature Genetics, 45: 450-455.

Adovasio, J.M. (2010) Basketry technology. A guide to identification and analysis. Aldine. Chicago.

Adovasio, J.M. (2018) Textile and basketry impressions from Jarmo. Paléorient, 3: 223-230.

Adovasio, J.M., Hyland, D.C., Soffer, O., Klíma, B., Svoboda, J. (1999) Textil, kosíkárství a síte v mládem paleolitu Moravy [Textiles, basketry, and nets in Upper Paleolithic Moravia]. Archeologické Rozhledy 51: 58-94.

Adovasio, J.M., Illingworth, J.S. (2004) Prehistoric perishable fiber technology in the Upper Ohio Valley. In Drooker, P.B. (Ed.) Perishable material culture in the Northeast. University of the State of New York. State Education Department. New York State Museum: 19-30.

Adovasio, J.M., Lynch, T.F. (1973) Preceramic textiles and cordage from Guitarrero Cave, Perú. American Antiquity, 38: 84-90.

Adovasio, J.M., Maslowski, R.F. (1980) Cordage, basketry and textils. In Lynch, T.F. (Ed.) Guitarrero Cave: early man in the Andes. Department of Anthropology. Cornell University. Nova York: 253-290.

Adovasio, J.M., Maslowski, R.F. (1988) Textile impressions on ceramic vessels at Divostin, in Divostin and the Neolithic of Central Serbia. In McPherron, A., Srejović, D. (Eds.) Ethnology Monographs 10. Pittsburgh (PA). Department of Anthropology. University of Pittsburgh: 345-357.

Adovasio, J.M., Soffer, O., Klíma, B. (1996) Upper Paleolithic fibre technology. Interlaced woven finds from Pavlov I, Czech Republic, c. 26 000 years ago. Antiquity, 70: 526-534.

Adovasio, J.M., Soffer, O., Page, J. (2008) El sexo invisible: una mirada a la historia de las mujeres. Ed. Lumen. ISBN: 978-8426416513.

Aguer, C. (2006) 8. La restauración dels objectes de fusta de La Draga. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) Els objectes de fusta del poblat neolític de la Draga. Excavacions de 1995-2005. CASC-Museu d'Arqueologia de Catalunya, Girona.

Aguilera, M., Araus, J. L., Voltas, J., Rodríguez-Ariza, M. O., Molina, F., Rovira, N., Buxó, R., Ferrio, J.P. (2008) Stable carbon and nitrogen isotopes and quality traits of fossil cereal grains provide clues on sustainability at the beginnings of Mediterranean agriculture. Rapid Communication in Mass Spectrometry, 22(11): 1653-1663.

Agustí, B., Alcalde, G., Burjachs, F., Buxó, R., Juan-Muns, N., Oller, J., Ros, M.T., Rueda, J.M., Toledo, A. (1986) Els nivells ceràmics de la Cova 120 (Sales de Llierca, la Garrotxa. Tribuna d'arqueologi, 1985-1986: 25-31.

Agustí-Farjas, B. (2024) Informe de l'estudi antropològic: Cova del Pasteral (La Cellera de Ter). Sector 1. Anthropological technical report.

Akeret, O., Jacomet, S. (1997) Analysis of plant macrofossils in goat/sheep faeces from the Neolithic lake shore settlement of Horgen Scheller -and indication of prehistoric transhumance? Vegetation History and Archaeobotany, 6: 235-239.

Alcaraz, F., Clemente, M., Barreña, J.A., Álvarez-Rogel, J. (1999) Manual de teoría y práctica de Geobotánica. ICE Universidad de Murcia y Diego Marín. Murcia.

Alcolea Gracia, M. (2017) Paisaje vegetal y gestión de recursos leñosos durante la transición del Epipaleolítico-Neolítico en el Valle del Ebro. PhD Disseartation, Universidad de Zaragoza, Zaragoza.

Alcolea, M. (2018) Donde hubo fuego: estudio de la gestión humana de la madera como recurso en el valle del Ebro entre el Tardiglaciar y el Holoceno Medio, Zaragoza, PUZ, Monografías Arqueológicas, 53.

Alcolea, M., Rodanés, J.M. (2019) Ephemeral Archaeology South of the Central Pyrenees (Huesca, NE Iberia): The Exceptional Preservation of Woody Objects in Moro de Alins Cave-site. Environmental archaeology, 28(5): 328-344.

Alday, A. (2006) El Mesolítico de muescas y denticulados en la cuenca del Ebro y el litoral mediterráneo peninsular: síntesis de los datos. In Alday, A. (Ed.) Mesolítico de muescas y denticulados en la cuenca del Ebro y el litoral mediterráneo peninsular. Diputación Foral de Álava, Departamento de Cultura: 303–317.

Alday, A., Soto, A. (2017) La Sociedad Mesolítica de la Península Ibérica. In Pérez-Díaz, S., Ruiz-Fernández, J., López-Sáez, J-A., García-Hernández, C. (Eds.) Cambio climático y cultural en la PenínsulaIbérica: una perspectiva geohistórica y paleoambiental. Universidad de Oviedo, Oviedo: 75–91.

Alday, C. (2021) Fibre production among the coastal hunter-gatherers of south America's West coast. New narratives from plant fibre technologies. PhD Dissertation. Wolfson College, University of Cambridge, Cambrigde.

Alfaro, C. (1980) Estudio de los materiales de cestería procedentes de la Cueva de los Murciélagos (Albuñol, Granada). Trabajos de Prehistoria, 37: 109-139.

Alfaro, C. (1984) Tejido y cestería en la Península Ibérica. Historia de su técnica e industrias desde la prehistoria hasta la romanización. Bibliotheca Praehistorica Hispana, 21. CSIC Instituto Español de Prehistoria (Madrid).

Alfaro, C. (1989) Le tissage, la corderie et la vannerie dans les motifs décoratifs de la céramique du premier néolithique dans la région de Valence (Espagne). In Tissage, corderie, vannerie. IX Recontres Internationales d'Archéologie et d'Histoire, Antibes, Octobre 1988. Éditions APDCA, Juan-le-Pins: 103-112.

Alfaro, C. (2012) Textiles from the Pre-Pottery Neolithic site of Tell Halula (Euphrates Valley, Syria). Paléorient, 38(1-2): 41-54.

Altamirano, M. (2014) Los peines óseos de Los Castillejos en la Peñas de los Gitanos (Montefrío, Granada). Actas del II Congreso de Prehistoria de Andalucía: 361-371.

Altorfer, K., Médard, F. (2000) Nouvelles découvertes textiles sur le site de Wetzickon-Robenhausen (Zürich, Suisse). Sondages 1999. Montagnac. Mergoil: 35-75.

Andersen, S.H. (1985) Tybrind Vig. A preliminary Report on a Submerged Ertebolle Settlement on the West Coast of Fyn. Journal of Danish Archaeology, 4. Odense University Press.

Andersson Strand, E. (2012) The textile chaîne opératoire: Using a multidisciplinary approach to textile archaeology with a focus on the Ancient Near East. Paléorient, 38-1-1: 21-40.

Andonova, M. (2021) Ancient basketry on the inside: X-ray computed microtomography for non-destructive assessment of small archaeological monocotyledonous fragments: examples from Southeast Europe. Heritage Science, 9: 158.

Andonova, M., Marinova, E., Dimitrova, D. (2023) Burial rush matting: integrated analysis of a twilled mat fragment from the Thracian Kitova tumulus (South-East Bulgaria). Vegetation History and Archaeobotany 32(2): 145-156.

Andonova, M., Nikolow, V. (2021) Pots on mats: mat-impressed salt extraction pottery at Chalcolithic Provadia-Solnitsata, Bulgaria. Antiquity, 96(385): 51-66.

Andreaki, V., Barceló, J.A., Antolín, F., Gassman, P., Hajdas, I., López-Bultó, O., Martínez-Grau, H., Morera, N., Palomo, A., Piqué, R., Revelles, J., Rosillo, R., Terradas, X. (2022) Absolute chronology at the waterlogged site of La Draga (Lake Banyoles, NE Iberia): Bayesian chronological models integrating tree-ring measurement, radiocarbon dates and microstratigraphical data. Radiocarbon: 1-42.

Andrews, R. L., Adovasio, J.M. (1996) The origins of fiber perishables East of the Rockies. In Petersem. J.B. (Eds.) A most indispensable art: native fiber perishables from Eastern North America. University of Tennessee Press. Knoxville: 30-49.

Andrews, R.L., Adovasio, J.M., Carlisle, R.C. (1986) Perishable industries from Dirty Shame Rockshelter. Maiheur County, Oregon: a Series of Chapters. Department of Anthropology, University of Pittsburgh. Pittsburgh.

Ankanna, S., Suhrulatha, D., Savithramma, N. (2012) Chemotaxonomical studies of some important monocotyledons. Botany Research International, 5(4): 90-96.

Antolín, F. (2013) Of cereals, poppy, acorns and hazelnuts. Plant economy among early farmers (5500-2300 cal BC) in the NE of the Iberian Peninsula. An archaeobotanical approach. PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

Antolín, F., Berihuete, M., Blanco, À., Buxó, R., Garcia, L., Marlasca, R., Navarrete, V., Saña, M., Verdún, E. (2017) El rebost domèstic i el rebost salvatge. In Palomo, A., Piqué, R., Terradas, X. (Eds.) La Revolució neolítica: La Draga, el poblat dels prodigis. Museu d'Arqueologia de Catalunya, Departament de Cultura de la Generalitat de Catalunya, 45-50. ISBN: 978-84-393-9650-5.

Antolín, F., Buxó, R. (2011) 10. L'explotació de les plantes: contribución a la historia de l'agricultura i de l'alimentació vegetal del neolític a Catalunya. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona, 147-174.

Antolín, F., López, V., Mestres, J., Gibaja, J.F. (2018) Bellotas y cereales. Primeras observaciones sobre el registro carpológico de una estructura del V milenio cal. ANE en el yacimiento de Pou Nou-2 (Sant Pere Molanta-Barcelona). Cuadernos do GEEvH, 7(2): 10-28.

Antolín, F., Saña, M. (2022) Les activitats de subsistència en el neolític antic del nord-estpeninsular: les pràctiques agrícoles i ramaderes, la cacera, la pesca i la recol·lecció. Cypsela 22: 125-146.

Aranbarri, J., González-Sampériz, P., Iriarte, E., Moreno, A., Rojo-Guerra, M., Peña-Chocarro, L., Valero-Garcés, B., Leunda, M., García-Prieto, E., Sevilla-Callejo, M., Gil-Romera, G., Magri, D., Rodríguez-Lázaro, J. (2015) Human–landscape interactions in the Conquezuela–Ambrona Valley (Soria, continental Iberia): From the early Neolithic land use to the origin of the current oak woodland. Palaeogeography, Palaeoclimatology, Palaeoecology, 436: 41-57.

Aranda, G., Lozano, A., Escudero, J., Sánchez, M., Alarcón, E., Fernández, S., Díaz-Zorita, M., Barba, V. (2017) Cronología y temporalidad de los recintos de fosos prehistóricos: el caso de Marroquíes Bajos (Jaén). Trabajos de Prehistoria, 73(2): 231-250.

Araus, J.L., Buxó, R. (1993) Changes in carbon isotope discrimination in grain cereals from the northwestern Mediterranean basin during the past seven millennia. Australian Journal of Plan Physiology, 20: 117-128.

Araus, J.L., Febrero, A., Buxó, R., Camalich, M.D., Martin, D., Molina, F., Rodríguez Ariza, O., Romagosa, I. (1997a) Changes in carbon isotope discrimination in grain cereals from different regions of the western Mediterranean Basin during the past seven millennia.

Palaeoenvironmental evidence of a differential change in aridity during the late Holocene. Global Change Biolology, 3: 107-118.

Araus, J.L., Febrero, A., Català, M., Molist, M., Voltas, J., Romagosa, I. (1999) Crop water availability in early agriculture: Evidence from carbon isotope discrimination of seeds from a tenth millennium BP site on the Euphrates. Global Change Biolology. 5: 201-212.

Araus, J.L., Ferrio, J.P., Voltas, J., Aguilera, M., Buxó, R. (2014) Agronomic conditions and crop evolution in ancient Near East agriculture. Nature Communications, 5: 3953.

Araus, J.L., Slafer, G.A., Romagosa, I., Molist, M. (2001) FOCUS: Estimated wheat yields during theemergence of agriculture based on the carbon isotope discrimination of grains: Evidence from a 10th millenium BP site on the Euphrates. Journal of Archaeological Sciences, 28: 341-350.

Arber, A. (1950) The Natural Philosophy of Plant Form. Cambridge University Press, Cambridge.

Argelés, T., Bonet, A., Clemente, I., Estévez, J., Gibaja, J., Lumbreras, L.G., Piqué, R., Ríos, M., Taulé, M.A., Terradas, X., Vila, A., Wunsch, G. (1995) Teoría para una praxis. Splendor realitatis. In Oliveira, Jorge, V. (Coord.) I Congresso de Arqueologia peninsular: Trabalhos de Antropologia e Etnologia, 35(l): 501-507.

Arnold, D., Espejo, E. (2013) El textil tridimensional. La naturaleza del tejido como objecto y como sujeto. Fundación Xavier Albó and Instituto de Lengua y Cultura Aymara, La Paz.

Aura Tortosa, J.E., Pérez-Jordà, G., Carrión Marco, Y., Seguí Seguí, J.R., Jordá Pardo, J.F., Miret i Estruch, C., Verdasco Cebrián, C.C. (2019) Cordage, basketry and containers at the Pleistocene-Holocene boundary in southwest Europe. Evidence from Coves de Santa Maira (Valencian region, Spain). Vegetation History and Archaeobotany, 29: 581-594.

Aura-Tortosa, J.E., Jordà Pardo, F.J., Morales Pérez, J.V., García-Puchol, O., González-Rablas Sastre, J., Avezuela, B. (2009) Epipaleolítico y Mesolítico en Andalucía Oriental primeras notas a partir de los datos de la Cueva de Nerja (Málaga, España). In: Utrilla, P., Montes, L. (Eds.) El Mesolítico geométrico en la Península Ibérica: 343-360.

B

Baena, J. (1997) Arqueología experimental, algo más que un juego. Boletín de Arqueología Experimental, 1(1): 2-4.

Bahn, P.G. (2001) Palaeolithic weaving – a contribution form Chauvet. Antiquity, 75(288): 271-272.

Bailey, E.L.G., Spikins, P. (Eds). (2008) Mesolithic Europe. Cambridge University Press. European Journal of Archaeology. 11(2-3): 276-277.

Banck-Burgess, J. (2018) 10: Textile manufacture in the prehistoric pile dwellings of south-west Germany: planned investigation. In Siennicka, M., Rahmstorf, L., Ulanowska, A. First Textiles: The Beginnings of Textile Production in Europe and the Mediterranean: 105-116.

Banck-Burgess, J. (2023) Textile terminology and the importance of a generic term for textile manufacturing techniques in prehistoric times. THEFFO Volume II: 37-46.

Bañón Cifuentes, M.C. (2010) El campus spartarius romano¿una herencia púnica administrada por Roma? Instituto de Estudios Albacetenses "Don Juan Manuel". Serie IV – Cuadernos albacetenses, 14. ISBN: 978-84-96800-41-0.

Barber, E.W. (1994) Women's Work: The First 20.000 Years. Women, Cloth and Society in Early Times. New York: W.W. Norton & Company.

Barreña, J.A., Rivera, D., Alcaraz, F.J., Obón, C. (2006) The Esparto Grass Question: A systematic Approach for a Long-Lasting Problem in Stipa L. (Gramineae). Novon, 16: 5-16

Bartl, K. (1998-1999) Akkar survey 1997. Archaeological surface investigations in the plain of Akkar / Northern Lebanon. Preliminary results. Butlletin d'Archéologie et d'Architecture Libannaises, 3: 169- 179.

Bate, L.F. (1998) El proceso de investigación en Arqueología, Barcelona, Editorial Crítica. ISBN: 9788474238808.

Bazzanella, M., Mayr, A., Rast-Eicher, A. (2003) Telai preistorici tra Neolitico ed età del Bronzo. In Bazzanella, M., Mayr, A., Moser, L., Rast-Eicher, A. (Eds.) Textiles. Intrecci e tessuti dalla preistoria europea Intrecci e tessuti dalla preistoria europea. Trento: 87-97.

Beamer, J. (2020) Experimental Archaeology and Tacit Learning: Textiles in the Classroom. EXARC Journal Issue 2020/3.

Becher, P., Tyree, M.T., Tsuda, M. (1999) Hydraulic conductances of angiosperms versus conifers: Similar transport sufficiency at the whole-plant level. Tree Physiology, 19: 445-452.

Becker, B., Kromer, B., Trimborn, P. (1991) A stable-isotope tree-ring timescale of the Late Glacial/Holocene boundary. Nature, 353: 647-649.

Bender Jørgensen, L. (1992) North European textiles until AD 1000. Aarhus: Aarhus University Press. ISBN: 87-72888-416-9.

Bennet, K.D., Parducci, L. (2006) DNA from pollen: principles and potential. The Holocene, 16: 1031-1934.

Berger, J.F., Guilaine, J. (2009) The 8200 cal BP abrupt environmental change and the Neolithic transition: A Mediterranean perspective. Quaternary International, 200: 31-49.

Bergfjord, C., Holst, B. (2010) A procedure for identifying textile bast fibres using microscopy: Flax, nettle/ramie, hemp and jute. Ultramicroscopy, 110(9): 1192-1197.

Berghuijs, K. (2013) Black and white negatives. Basketry impressions from Late Neolithic Tell Sabi Abyad (Syria). University of Leiden. Leiden.

Berihuete-Azorín, M, Arranz Otaegui, A., López-Doriga, I.L. (2018a) Prehistoric plant underground storage structures in Europe. Conference: subsistence strategies in the Stone age, direct and indirect evidence of finish and gathering. Russian Academy of Sciences, Saint Petersburg.

Berihuete-Azorín, M., Girbal, J., Piqué, R., Palomo, A., Terradas, X. (2018b) Punk's not dead. Fungi for tinder at the Neolithic site of La Draga (NE Iberia), PloS ONE, 13(4): e0195846.

Berihuete-Azorín, M., Lozovskaya, O., Herrero-Otal, M., Piqué i Huerta, R. (2023) Fishing nets and string at the Final Mesolithic and Early Neolithic Site of Zamostje 2, Sergiev Posad (Russia). Open Archaeology, 9(1): 20220283.

Berihuete-Azorín, M., Martín Seijo, M., López-Bultó, O., Piqué, R. (2020) The missing woodland resources Archaeobotanical studies of the use of plant raw materials. Firenze: Barkhuis.

Bernabeu Aubán, J., Fumanal García, M.P. (2009) La excavación, estratigrafía y dataciones C14. In Bernabeu Aubán, J., Molina Balaguer, L. (Eds.) La Cova de les Cendres (Moraira-Teulada, Alicante). Diputació d'Alacant, Alacant: 31-52.

Bernabeu, J., Aura, J.E., Badal, E. (1993) Al oeste del edén: las primeras sociedades agrícolas en la Europa mediterránea. Ed. Síntesis. Madrid.

Bernabeu, J., Barton, C.M., Pardo, S., Berginc, S.M. (2015) Modeling initial Neolithic dispersal. The first agricultural groups in West Mediterranean. Ecological Modelling 307: 22-31.

Bernabeu, J., Fumanal, M.P (2009) La excavación. Estratigrafía y dataciones C14. In Bernabeu, J., Molina, L. (Eds.) La Cova de les Cendres (Moraira-Teulada, Alicante). MARQ Serie Mayor, 6: 55-84.

Billamboz, A., Maier, U., Matuschik, I., Müller, A., Out, W., Karlheinz Steppan, K., Vogt, R., Affolter, J., Feldtkeller, A. (2010) Die jung- und endneolithischen Seeufersiedlungen von Sipplingen 'Osthafen' am Bodensee: Besiedlungs- und Wirtschaftsdynamik im-eng begrenzten Naturraum des Sipplinger Dreiecks. In Matuschik, I., Strahm, C., Eberschweiler, B., Fingerlin, G., Hafner, A., Kinsky, M., Mainberger, M., Schöbel, G. (Eds.) Vernetzungen. Festschrift für H. Schlichtherle. Freiburg im Breisgau. Lavori Verlag: 253-286.

Binford, L.R. (1968) Post-Pleistocene adaptations. In Binford, S, R., Binford, R.I. (Eds.) New Perspectives in Archaeology. Aldine, Chicago: 313-341.

Birrell, V. (1959) The textile arts. A Handbook of Fabric Structure and Design Processes: Ancient and Modern Weaving, Braiding, Printing, and Other Textile Techniques. Harper.

Blatt, S.H., Redmond, B.G., Cassman, V., Sciulli, P.W. (2011) Dirty teeth and ancient trade: Evidence of cotton fibres in human dental calculus from Late Woodland, Ohio. International Journal of Osteoarchaeology, 21(6): 669-678.

Bleicher, N., Staub, P. (2022) A question of method and place? A critical reappraisal of the methods of dendroarchaeology, anthracology, archaeobotany and roudwood analysis on the question when systematic woodland management began in Europe. Quaternary International, 659(2): 3-10.

Blondiaux, J., Charlier, P. (2008) Palaeocytology in skeletal remains: microscopic examination of putrefaction fluid deposits and dental calculus of skeletal remains from French archaeological sites. International Journal of Osteoarchaeology, 18: 1-10.

Bocquentin, F., Sellier, P., Murail, P. (2005) Tooth abrasion and task activity in the Natufian population of Mallaha (Israel). Comptes Rendus Palevol, 4: 351–357.

Bocquet-Appel, J.P. (2002). Paleoanthropological traces of Neolithic demographic transition. Current Anthopology, 43: 638-650.

Bogaard, A. (2004) Neolithic Farming in Central Europe. An Archaeobotanical Study of Crop Husbandry Practices. Routledge. London. ISBN: 9780203358009.

Bogaard, A., (2005) Garden agriculture and the nature of early farming in Europe and the Near East. World Archaeology, 37(2): 177-196.

Bogdanovic, I., Palomo, A., Piqué, R., Rosillo, R., Terradas, X (2017) Los últimos cazadores-recolectores en el NE de la Península Ibérica: evidencias de ocupaciones humanas durante el VI milenio cal BC. In Barceló, J.A., Bogdanovic, I., Morell, B. (Eds.) IberCrono. Cronometrías Para la Historia de la Península Ibérica. Proceeding of the Congreso de Cronometrías Para la Historia de la Península Ibérica. Barcelona: 35-45.

Böhm, S., Probst-Böhm, A., Mischka, D., Million, S., Andonova-Katsarski, M., Stelzner, I., Banck-Burgess, J. (2023) The THEFBO project. Initial insights into the analysis and results of neolithic textiles and the natural sciences. THEFFO Volume II: 13-36.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, R., Bonani, G. (2001) Persistent Solar Influence on North Atlantic Climate During the Holocene. Science, 294(5549): 2130–2136.

Borojevic, K., Mountain, R. (2013) Microscopic identification and sourcing of ancient egyptian plant fibres using longitudinal thin sectioning. Archaeometry, 55(1): 81-112.

Bosch, À. (1985) La Cova d'el Pasteral (La Cellera de Ter, La Selva): un jaciment neolític sobre la vall mitja del Ter. In Homenatge al Dr. Josep Maria Corominas, vol II. Centre d'Estudis Comarcals de Banyoles. Quaderns del Centre d'Estudis Comarcals de Banyoles: 29-56.

Bosch, À., Chinchilla, J., Tarrús, J. (2000) (Eds.) El poblat lacustre neolític de La Draga. Excavacions de 1990-1998, Museu d'Arqueologia de Catalunya-CASC, Girona.

Bosch, À., Chinchilla, J., Tarrús, J. (2006) Els objectes de fusta del poblat neolític de la Draga. Excavacions de 1995-2005. CASC-Museu d'Arqueologia de Catalunya, Girona.

Bosch, À., Chinchilla, J., Tarrús, J. (2011) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Museu d'Arqueologia de Catalunya-CASC, Girona.

Bosch, À., Tarrús, J. (2011) 2. Els vasos ceràmics: una nova visió. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona: 19-70.

Bosch, A., Tarrús, J. (2017) La ceràmica. In Palomo, A., Piqué, R., Terradas, X. (Eds.) La Revolució neolítica: La Draga, el poblat dels prodigis. Museu d'Arqueologia de Catalunya, Departament de Cultura de la Generalitat de Catalunya: 79-82. ISBN: 978-84-393-9650-5.

Boucherat, T. (2009) Fils et cordes d'origines végétales. Approches technologiques et outillage au Paléolithique Supérieur et Mésolithique.

Boyadjian, C. (2018) Plant Micro-remains in Dental Calculus. In Smith, C. Encyclopedia of Global Archaeology, 1-16.

Braidwood, R. (1940) Report f two sondages on the coast of Syria south of Tartous. Syria, 21: 183-226.

Bravermanová, M., Brezinová, H. (1999) Nekolik poznámek k clánku 'Textil, kosíkarství a site v mladém paleolitu Moravy' [Some thoughts on 'Textiles, basketwork and nets in Upper Paleolithic Moravia']. Archeologické Rozhledy, 51: 113-118.

Bravo, P., Hinojo, E., Subirà, M.E., Allièse, F., Masclans, A., Santana, J., Gibaja, J.F. (2015) Les sépultures néolitiques de Can Gambús-2 (Sabadell, Espagne): nouvelles données sur les pratiques funéraires de la culture des Sepulcros de fosa. L'Anthropologie, 119(1): 38-57.

Březinová, H. (2003) Nejstarši doklady textilní výroby a jejich experimentální ověrení. Rekonstrukce a experiment v archeologii, 4: 195-200.

Bronk Ramsey, C. (2009) Bayesian Analysis of Radiocarbon Dates. Radiocarbon, 51(1): 337-360.

Bronk Ramsey, C. (2021) OxCal v.4.4.4. https://c14.arch.ox.ac.uk/oxcal.html

Broudy, E. (1979) The book of looms. A history of the handloom from ancient times to the present. London: Brown University Press.

Brown, T.A., Allaby, R.G., Brown, K.A. Ódonoghue, K., Sallares, R. (1993) DNA in wheat seeds from European archaeological sites. Experientia, 50: 571-575.

Brown, T.A., Brown, K.A. (1994) Ancient DNA: using molecular biology to explore the past. BioEssays, 16: 719-726.

Bucchi, A., Burguet-Coca, A., Expósito, I., Bocanera, FJA., Lozano, M. (2019) Comparisons between methods for analysing dental calculus samples from El Mirador cave (Sierra de Atapuerca, Spain). Archaeol Anthropol Sci, 11: 6305–6314.

Buckley, S., Usai, D., Jakob, T., Radini, A., Hardy, K. (2014) Dental calculus reveals unique insights into food items, cooking and plant processing in prehistoric central Sudan. Public Library of Science ONE, PLOSOne, 9(7): e100808.

Burjachs, F. (2000) El paisatge del neolític antic. Les dades palinològiques. In Bosch, À., Chinchilla, J., Tarrús, J. (Eds.) El Poblat Lacustre Neolític de la Draga. Excavacions de 1990 a 1998; Centre d'Arqueologia Subaquàtica de Catalunya, Girona: 46-50.

Burke, B. (2010) From Minos to Midas. Ancient cloth production in the Aegean and in Anatolia. Oxford: Oxbow Bookds, Oxford and Oakville.

C

Cacho, C., Papi, C., Sánchez-Barriga, A., Alonso, F. (1996) La cestería decorada de la Cueva de los Murciélagos (Albuñol, Granada). Complutum Extra, 6(1): 105-122.

Callahan, E. (1981) Pamunkey Housebuilding: An experimental Study of Late Woodland Construction Technology in the Powhatan Confederacy. PhD Dissertation, Catholic University of America, Washington.

Callahan, E. (1999) What is Experimental Archaeology? In Wescot, D. (Ed.) Primitive technology: a book of earth skills, Gibbs Smit: 248.

Calvo, S. (2019) Aproximación i caracterización de la tecnología de fabricación de los recipientes cerámicos en las minas prehistóricas de Gavà. PhD Dissertation, Universitat Autònoma de Barcelona, Bellaterra.

Campillo, D., Vives, E. (1985) Estudi de les restes humanes de la cova d'El Pasteral. In Homenatge al Dr. Josep Maria Corominas, vol II. Centre d'Estudis Comarcals de Banyoles. Quaderns del Centre d'Estudis Comarcals de Banyoles: 29-56.

Carcaillet, C., Ali, A.A., Blarquez, O., Genries, A., Mourier, B., Bremond, L. (2009) Spatial variability of fire history in subalpine forests: From natural to cultural regimes. Écoscience, 16(1): 1-12.

Cardito, L.M. (1996) Las manufactura textiles en la Prehistoria: las placas de telar en el Calcolítico peninsular". Zephyrus: Revista de prehistoria y arqueología, 49: 125-145.

Carr, C., Maslowski, R.F. (1995) Cordage and fabrics: relating form, technology and social processes. In Carr, C., Neitzel, J.E. (Eds.) Style, society and person. Archaeological and Ethnological perspectives. Plenum Press, Nova York: 297-343.

Carrasco Rus, J., Martínez-Sevilla, F. (2014) Las cronologías absolutas del Neolítico Antiguo en el sur de la península ibérica. Nuevas dataciones. Archivo de Prehistoria Levantina, 30: 57-80.

Carrasco Rus, J., Pachón Romero, J.A. (2009) Algunas cuestiones sobre el registro arqueológico de la Cueva de los Murciélagos de Albuñol (Granada) en el contexto Neolítico andaluz y sus posibles relaciones con las representaciones esquemáticas. Cuadernos de Prehistoria y Arqueología de la Universidad de Granada, 19: 227-287.

Carrión, J., van Geel, B. (1999) Fine-resolution Upper Weichselian and Holocene palynological record from Navarrés (Valencia, Spain) and a discussion about factors of Mediterranean forest succession. Review of Palaeobotany and Palynology, 106(3-4): 209-236.

Carrión, J.S., Fernández, S., González-Sampériz, P., Gil Romera, G., Badal, E., Carrión, Y., López-Merino, L., López-Sáez, J.A., Fierro, E., Burjachs, F. (2010) Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands. Review of Palaeobotany and Palynology 162: 458–475.

Carrión, J.S., Fuentes, N., González-Sampériz, P., Sánchez Quirante, L., Finlayson, J.C., Fernández, S., Andrade, A. (2007) Holocene environmental change in a montane region of southern Europe with a long history of human settlement. Quaternary Science Reviews, 26(1-2): 1455-1475.

Caruso-Fermé, L., Piqué, R. (2014) Landscape and forest exploitation at the ancient Neolithic site of La Draga (Banyoles, Spain). Holocene, 24(3): 266-273.

Castells, E., Araya-Piqué, V., Behncké, A. Piqué, R. (2020) Buxus sempervirens and Laurus nobilis leaves from an archaeological site at 7300 cal BP (La Draga, Spain) provide a better understanding of past vegetation and human activities. Holocene, 31: 570-578.

Castro, P.V., Fregeiro, M.I., Oltra, J., Sanahuja, M.E., Escoriza, R. (2005) Trabajo, producción y Neolítico. III Congreso Neolítico de la Península Ibérica, 114-124.

Castro, Z. (1990) Información gráfica en plaquetas del Parpalló: consideraciones sobre inicios de tecnologías vegetales. Cypsela 8: 15-20.

Castroviejo, S. (Coord. Gen.). (1986-2012). Flora Iberica. Real Jardín Botánico. CSIC. Madrid.

Cauvin, J. (1994) Naissance des divinités, naissance de l'agriculture. CNRS Éditions. Paris.

Cauvin, J. (2000) The Origins of Agriculture in the Near East: A Symbolyc Interpretation. Cambridge University Press, Cambridge.

CERES-MAN. Museo Arqueológico Nacional, Madrid. Ministerio de Cultura, Gobierno de España. Online database inventory. Available: https://ceres.mcu.es/pages/SimpleSearch?Museo=MAN.

Charlton, W.H. (1996) Rope and the art of knot-tying in the seafaring of the Ancient Eastern Mediterranean. Office of Graduate Studies of Texas A&M University. PhD dissertation. Texas.

Childe, V.G. (1952) New Light on the Most Ancient East. Routledge & Kegan, Londres.

Chinchilla, J. (2000) La conservació dels materials. L'extracció i restauració dels materials. 2. Metodología i conservació. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre neolític de La Draga. Excavacions de 1990-1998, Museu d'Arqueologia de Catalunya-CASC, Girona.

Chinchilla, J., García, I. Aguer, C. (2017) Difícil de conservar. In Palomo, A., Piqué, R., Terradas, X. (Eds.) La Revolució neolítica: La Draga, el poblat dels prodigis. Museu d'Arqueologia de Catalunya, Departament de Cultura de la Generalitat de Catalunya, 45-50. ISBN: 978-84-393-9650-5.

Clarke, D.L. (1968) Analytical Archaeology. London: Methuen.

Clemente, I., Cuenca, D. (2011) Instrumentos de trabajo de concha en el yacimiento neolítico de La Draga. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona: 137-145.

Cohen, M.N. (1981) La crisis alimentaria en Prehistoria. Alianza Universidad, Madrid.

Coles, J. (1979). Experimental Archaeology, Academic Press (London).

Coles, J.M., Heal, S.V.E., Orme, B.J. (1978) The use and character of wood in prehistoric Britain and Ireland. Proceedings of the Prehistoric Society, 44: 1-45.

Colombaroli, D., Vannière, B., Chaprone, E., Magny, M., Tinner, W. (2008) Fire-vegetation interactions during the Mesolithic-Neolithic transition at Lago dell'Accesa. The Holocene, 18(5): 679-692.

Conolly, T.J., Kallenbach, E., Barker, P., Mccabe, S.K. (2017) Netting in the Northern and Western Great Basin. Journal of California and Great Basin, 37(2): 143-167.

Cooper, K. (2009) The technology of Prehistoric to Late Roman yarn production. Grin Verlag, Nordestedt, Alemanya.

Cope, J.S., Corney, D., Clark, J.Y. Remagnino, P., Wilkin, P. (2012) Plant species identification using digital morphometrics: A review. Expert Systems with Applications, 39: 7562-7573.

Copeland, L. (1999) The Early pottery Neolithics of Tell Nebi Mend (Qadesh). Syria. Neo-Lithics, 1(99): 10-12.

Cortés, M., Morales, A., Simón, M.D., Bergadà, M.M., Degado, A., López, P., López-Sáez, J.A., Lozano, M.C., Riquelme, J.A., Roselló, E., Sánchez, A., Vera, J.L. (2008)

Palaenvironmental and cultural dynamics of the coast of Málaga (Andalucía, Spain) during the Upper Plestocene and Early Holocene. Quaternary Science Reviews, 27: 2176-2193.

Costa, M., Morla, C., Sainz, H. (Eds.) (1997) Los bosques ibéricos. Una interpretación geobotánica. Editorial Planeta. Madrid.

Courel, B., Adam, P., Schaeffer, P. (2019). The potential of triterpenoids as chemotaxonomic tools to identify and differentiate genuine, adulterated and archaeological balsams. Microchemical Journal, 147: 411-421.

Coward, F. (2010) Small worlds, material culture and ancient near eastern social networks. In: Dunbar R, Gamble C, Gowlett J (eds) Social brain, distributed mind. Oxford University Press, Oxford: 453-483.

Crawford, K.M., Zambryski, P.C. (1999) Plasmodesmata signaling: Many roles, sophisticated statutes. Current Opinion in Plant Biology, 2: 382-387.

Cristiani, E., Radini, A., Borić, D., Robson, H.K., Caricola, I., Carra, M., Mutri, G., Oxilia, G., Zupancich, A., Šlaus, M., Vujević, D. (2018) Dental calculus and isotopes provide direct evidence of fish and plant consumption in Mesolithic Mediterranean. Science Reports, 8: 8147.

Cristiani, E., Radini, A., Edinborough, M., Borić, D. (2016) Dental calculus reveals Mesolithic foragers in the Balkans consumed domesticated plant foods. Proceedings of the National Academy of Sciences (PNAS), 113: 10298-10303.

Cristiani, E., Radini, A., Edinborough, M., Borić, D. (2016) Dental calculus reveals Mesolithic foragers in the Balkans consumed domesticated plant foods. Proceedings of the National Academy of Sciences, 113: 10298-10303.

Croes, D.R. (1977) Basketry from the Ozette village archaeological site: a technological, functional and comparative study. Washington Archaeological Research Center. Washington State University. Pullman. Washington.

Cucart-Mora, C., Gómez-Puche, M., Romano, V., Fernández-López de Pablo, J., Lozano, S. (2022) Reconstructing Mesolithic social networks on the Iberian Peninsula using ornaments. Archaeological and Anthropological Sciences, 14: 174.

Cuenca Solana, D., Clemente Conte, I., Oliva Poveda, M., Gutiérrez Zugasti, I. (2014) Estudio de la manufactura y/o uso de instrumentos de trabajo y elementos de adorno de concha desde la metodología del anàlisis funcional. Archaeofauna, 23: 9-24.

D

D'Agostino, A., Gismondi, A., Di Marco, G., Lo Castro, M., Olevano, R., Cinti, T., Leonardi, D., Canini, A. (2019) Lifestyle of a Roman Imperial community: ethnobotanical evidence from dental calculus of the Ager Curensis inhabitants. Journal of Ethnobiology and Ethnomedicine, 15: 62.

De Bary, A. (1884) Comparative Anatomy of the Vegetative Organs of the Phanerogams and Ferns. Clarendon Press, Oxford.

De Diego, M. (2023) Tecnología textil y del trabajo de la piel en el Neolítico Antiguo de La Draga, Banyoles (España) (5.300-4.900 cal BC). Aproximación funcional y experimental a los instrumentos óseos y de madera. PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

De Diego, M., Piqué, R., Palomo, A., Terradas, X., Clemente, I., Mozota, M. (2017) Traces of textile technology in the Early Neolithic lakeside settlement of La Draga (Banyoles, Catalonia) from an experimental perspective. In: Alonso, R., Baena, J., Canales, D. (Eds.) Playing with the time. Experimental archaeology and the study of the past. Universidad Autónoma de Madrid, Madrid: 139-144.

De Diego, M., Piqué, R., Palomo, A., Terradas, X., Saña, M., Clemente, I., Mazota, M. (2018) Evidence of textile technology in the Early Neolithic site of La Draga (Banyoles, Spain). Some hypotheses. In: Siennicka, M., Rahmstorf, L., Ulanowska, A. (Eds.) First textiles. The beginnings of textile manufacture in Europe and the Mediterranean. Oxbow Books, Oxford: 69-80.

de Góngora, M. (1868) Antigüedades Prehistóricas de Andalucía. C. Moro (Madrid).

De La Fuente, C., Flores, S., Moraga, M. (2013) DNA from human ancient bacteria: a novel source of genetic evidence from archaeological dental calculus. Archaeometry, 55: 767-778.

Dearing, J. (1994) Reconstructing the history of soil erosion. In Roberts, N. (Ed.) The changing Global Environment. Oxford. Blackwell: 242-261.

Del Río Sánchez, J. (2023) Flora y Vegetación del Litoral de Granada. Departamento de Zoología, Universidad de Granada, Granda. Available online: Dotterweich, M. (2008) The history of soil erosion and fluvial deposits in small catchments of central Europe: deciphering the long-term interaction between humans and the environment – a review. Geomorphology, 101: 192-208.

Desrosiers, S. (2010) Textile terminologies and classifications. Some methodological and chronological aspects. In Michel, C., Nosch, M.L. (Ed.) Textile terminologies in the Ancient Near East and Mediterranean from the third to the first millennia BC. Ancient Textiles Series, 8: 23-51.

di Lernia, S., Massamba N'siala, I., Mercuri, A.M. (2012) Saharan prehistoric basketry. Archaeological and archaeobotanical analysis of the early-middle Holocene assemblage from Takarkori (Acacus Mts., SW Libya). Journal of Archaeological Science, 39(6): 1837-1853.

Díaz-Navarro, S., García-González, R., Cirotto, N., Haber Uriarte, M. (2023) New insight into prehistoric craft specialisation. Tooth-tool use in the Chalcolithic burial site of Camino del Molino, Murcia, SE Spain. Journal of Archaeological Science Reports, 50: 104066.

Dierick, M., Van Loo, D., Van den Bulcke, J., Van Acker, J., Cnudde, V., Van Hoorebeke, L. (2014) Recent micro-CT scanner development at UGCT. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 324: 35-40.

Domingo, I. Palomo, A., Terradas, X., Berrocal-Barberà, A., Bogdanovic, I., López-Bultó, O., Rosillo Turrà, R., Piqué, R. (2023) Nuevo hallazgo de arte mueble de estilo Paleolítico en el Noreste peninsular: la plaqueta grabada de les Coves del Fem (Ulldemolins, Tarragona). MUNIBE Antropología-Arkeologia, 74: 5-22

Drescher-Scneider, R., de Beaulieu, J.L., Magny, M., Walter-Simonner, A.V., Bossuet, G., Millet, L., Brugiapaglia, W., Drescher, A. (2007) Vegetation history, climate and human imparct over the last 15,000 years al Lago dell'Accesa (Tuscany, Central Italy). Vegetation History and Archaeobotany, 16(4): 279-299.

Dupré., M., Fumanal., M.P., Martínez Gallego, J., Pérez-Obiol, R., Roure, J.M., Usera, J. (1996) The Laguna de San Benito (Valencia, Spain): Paleoenvironmental reconstruction of an endorheic system. Quaternaire, 7(4): 177-186.

Dusar, B., Vestraeten, G., Notebaert, B., Bakker, J. (2011) Holocene environmental change and its impact on sediment dynamics in the Eastern Mediterranean. Earth Science Reviews, 108(3-4): 137-157.

E

Eames, A.J. (1936) Morphology of Vascular Plants. Lower Groups. McGraw-Hill, New York.

Edholm, S., Wilder, T. (1999) Cordage. In Wescott, D. (Ed.) Primitive technology, a book of earth skills, selection of articles from the Bulletin of Primitive Technology. Society of Primitive Technology. Utah.

El Hadidi, N.M.N., Hamdy, R. (2011) Basketry accessories: footwear, bags and fans in ancient Egypt. Journal of Archaeological Science, 38(5): 1050-1061.

Emery, I. (1952) Naming the direction of the twist in yarn and cordage. Museum of New Mexico. Santa Fe. El Palacio, 59(8): 251-262.

Emery, I. (1980) The primary structures of fabrics. An illustrated classification 2. Washington, D.C. ISBN: 0823043940.

Evert R.F. (2006) Esau's Plant Anatomy: Meristems, Cells and Tissues of the Plant Body. Their Structure, Function, and Development. 3rd edition. John Wiley and sons, Inc. ISBN: 978-84-282-1443-3.

F

Fajardo, J., Verde, A., Rivera, D., Obón, C., Leopold, S. (2015) Traditional Craft Techniques of Esparto Grass (Stipa tenacissima L.) in Spain. Economy Botany, 69(4): 1-7.

Fernández González, F. (1997) Bioclimatología. In Izco, J. (Ed.): Botánica. Ed. McGraw Hill. Madrid: 607-682.

Fernández, S., Fuentes, N., Carriós, J.S. González-Sampériz, P., Montoya, E., Gil, G., Vega-Toscano, G., Riquelme, J.A. (2007) The Holocene and Upper Pleistocene pollen sequence of Carihuela Cave, southern Spain. Geobios, 40: 75-90.

Fernández-López de Pablo, J., Gómez-Puche, M. (2009) Climate change and population dynamics during the Late Mesolithic and the Neolithic transition in Iberia. Documenta Praehistorica, XXXVI: 67-96.

Fernández-López de Pablo, J., Gutiérrez-Roig, M., Gómez-Puche, M., McLaughlin, T.R., Silva, F., Lozano, S. (2019) Palaeodemographic modelling supports a population bottleneck during the Pleistocene-Holocene transition in Iberia Nature Communications, 10: 1872.

Ferrer, J. (2021) Informe de l'estudi geològic de la cova d'El Pasteral. Technical geological report.

Ferrio, J.P., Alonso, N., Voltas, J., Araus, J.L. (2004) Estimating grain weight in archaeological cereal crops: A quantitative approach for comparison with current conditions. Journal of Archaeological Sciences, 31: 1635-1642.

Ferrio, J.P., Alonso, N., Voltas, J., Araus, J.L. (2006) Grain weight changes over time in ancient cereal crops: Potential roles of climate and genetic improvement. Journal of Cereal Sciences, 44: 323-332.

Ferrio, J.P., Araus, J.L., Buxó, R., Voltas, J., Bort, J. (2005) Water management practices and climate in ancient agriculture: Inferences from the stable isotope composition of archaeobotanical remains. Vegetation History and Archaeobotany, 14: 510-517.

Ferrio, J.P., Voltas, J., Araus, J.L. (2011) Global change and the origins of agriculture. In Araus, J.L., Slafer, G.A. (Eds.) Crop Stress Management and Global Climate Change. Wallingford: CAB International: 1-14.

Finné, M., Woodbridge, J., Labuhn, I. and Roberts, N. (2019) Holocene hydro-climatic variability in the Mediterranean: a synthetic multi-proxy reconstruction. The Holocene, 29: 847-863.

Fiorentino, G., Ferrio, J. P., Bogaard, A., Araus, J.L., Riehl, S. (2014) Stable isotopes in archaeobotanical research. Vegetation History and Archaeobotany, 24: 215–227.

Fiorin, E. (2015) The necropolis of Can Reiners (7th c. AD, Mallorca, Spain): demography, health and lifestyle. PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

Fiorin, E., Cristiani, E. (2024) A protocol for the extraction of microremains from archaeological human dental calculus. Protocols.io.

Fiorin, E., Sáez, L., Malgosa, A. (2019) Ferns as healing plants in medieval Mallorca, Spain? Evidence from human dental calculus. International Journal of Osteoarchaeology, 29: 82-90.

Fluharty, S.M. (2003) An ethnobotanical analysis of basketry. Oregon State University. Master dissertation, Oregon.

Fontanals, M. (2015) Estudi dels modes de subsistència de les comunitats neolítiques del nor-est de la Península Ibèrica: Reconstrucció paleodietètica a parts dels isòtops estables. PhD Dissetation. Universitat Autònoma de Barcelona, Bellaterra.

Fontanals, M., Subirà, M.E., Díaz-Zorita, M., Gibaja, J.F. (2017). First insight into the Neolithic subsistence economy in the north-east Iberian Peninsula: paleodietary reconstruction through stable isotopes. American Journal of Physical Anthropology, 162: 36-50.

Forbes, R.J. (1964) Fibres and fabrics of antiquity. Washing, bleachng, fulling, and felting: dyes and dyeing: spinning: sewing, basketry and weaving. Studies in ancient technology 4 Leiden, Netherlands.

Foster, A.S. (1949) Practical Plant Anatomy, 2nd edition. Van Nostrand, New York.

Fowler, M.L. (1959) Summary Report of the Modoc Rock Shelter 1952, 1953, 1955, 1956. Illinois State Museum Report of Investigations 8. Springfield.

G

Galili, E., Schick, T. (1990) Basketry and a wooden bowl from the Pottery Neolithic sumberged site of Kefar Samir. Mitekufat Haeven. Journal of the Israel Prehistoric Society, 23(5): 142-151.

Galván, B. (1980) El trabajo del junco y la palma entre los canarios prehispánicos. Revista de Historia Canaria, 172: 43-48.

Gamble, C. (1998) Palaeolithic society and the release from proximity: a network approach to intimate relations. World Archaeology, 29: 426-449.

Garay-Palacios, B. (2021) Estudi de l’aprofitament i la gestió de recursos vegetals a les Coves del Fem (Ulldemolins, Catalunya) entre 4941-4545 cal BC. Master Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

García Borja, P., Salazar-García, D.C., Pérez Fernández, A., Pardo Gordó, A., Casanova Vañó, V. (2011) El Neolítico antiguo cardial y la Cova de la Sarsa (Bocairent, València). Nuevas perspectivas a partir de su registro funerario. MUNIBE (Antropología-Arkeologia), 62: 175-195.

Garcia Petit, L. (2011) 13. Estudi de les restes d'au. In Bosch, A., Chinchilla, J., Tarrús, J. (eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona: 213-222.

García, A. (2020) Memòria de la intervenció arqueològica a la Cova del Pasteral (La Cellera de Ter, la Selva). Archaeological technical report.

García-Puchol, O., Salazar García, D.C. (Eds.) (2017) Times of Neolithic Transition along the Western Mediterranean. Fundamental Issues is Archaeology. Springer. ISBN 978-3-319-52937-0.

Garrido, R. (2014) El Campaniforme en la Península Ibérica. In Almagro, M. (Eds.) Protohistoria de la península ibérica: del Neolítico a la romanización. Universidad de Burgos. Fundación Atapuerca.

Geib, P.R., Jolie, E. (2008) The role of basketry in Early Holocene small seed explotation: implications of a ca. 9000 years-old basket from Cowboy Cave, Utah. American Antiquity, 73(1): 83-102.

Gibaja, J.F (2003) Comunidades neolíticas del Noreste de la Península Ibérica. British Archaeological Reports, 1140.

Gibaja, J.F. (2004) Prácticas funerarias durante el Neolítico en Cataluña. Mainake, 26: 9-27.

Gibaja, J.F. (2011) La función de los instrumentos líticos tallados. El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005. Museu d'Arqueologia de Catalunya, Generalitat de Catalunya: 91-100.

Gibaja, J.F., Clop, X. (2012) El Neolítico en Cataluña. In Rojo, M., Garcia, I. (Eds.) El Neolítico en la Península Ibérica y su contexto europeo. Cátedra Press, Madrid: 333-370.

Gibaja, J.F., Majó, T., Chambon, P., Ruiz Ventura, J., Subirà, M.E. (2010) Prácticas funerarias durante el Noelítico. Los enterramientos infantiles en el noreste de la Península Ibérica. Complutum, 21(2): 47-68.

Gibby, E. (1999) Rediscovering flax. In Wescott, D. (Ed.). Primitive technology. A book of Earth Skills, from the Society of Primitive Technology. Gibbs Smith Publisher. Salt Lake City: 144-145.

Gillis, C., Nosch, M.L.B. (2007) First aid for the excavation of archaeological textiles. The Danish National Research Foundation's. Centre for Textile Research (CTR). Oxbow Books, Oxford. ISBN: 978-1842172230.

Girbal, J. (2000) Les fulles i els bolets de soca. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre neolític de La Draga. Excavacions de 1990–1998. Monografies del CASC. Museu d'Arqueologia de Catalunya-CASC, Girona: 53.

Girbal, J. (2011) Els bolets de soca. In Bosch, A., Chinchilla, J., Tarrús, J. (eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona: 175-176.

Gismondi, A., D'Agostino, A., Canuti, L., Di Marco, G., Martínez-Labarga, C., Angle, M., Rickards, O., Canini, A. (2018) Dental calculus reveals diet habits and medicinal plant use in the Early Medieval Italian population of Colonna. Journal of Archaeological Science Reports, 20: 556-564.

Gleba, M., Bretones-García, M.D., Cimarelli, C., Vera-Rodríguez., J.C., Martínez-Sánchez, R.M. (2021) Multidisciplinary investigation reveals the earliest textiles and cinnabar-coloured cloth in Iberian Peninsula. Science Reports, 11: 21918.

Gleba, M., Harris, S. (2019) The first plant bast fibre technology: identifying splicing in archaeological textiles. Archaeological and Anthropological Sciences, 11: 2329-2346.

Gómez-Moreno Martínez, M. (1933) La cerámica primitiva ibérica, in Homenagem a Martins Sarmento no centenario do seu Nascimento (Ediçao da Sociedade Martins Sarmento): 125-136.

Gómez-Moreno Martínez, M. (1949) La cerámica primitiva ibérica, in Misceláneas. Historia del Arte y Arqueología. Primera Serie. La antigüedad (Consejo Superior de Investigaciones Científicas): 104.

González-Sampériz, P. (2004) Evolución paleoambiental del sector central de la cuenca del Ebro durante el Pleistoceno superior y Holoceno. Instituto Pirenaico de Ecología. Zaragoza.

González-Sampériz, P., Aranbarri, J., Pérez-Sanz, A., Gil-Romera, G., Moreno, A., Leunda, M., Sevilla-Callejo, M., Corella, J.P., Morellón, M., Oliva, B., Valero-Garcés, B. (2017) Environmental and climate change in the southern Central Pyrenees since the last glacial maximum: a view from the lake records. Catena 149: 668-688.

González-Sampériz, P., Utrilla, P., Mazo, C., Valero, B., Sopena, M.C., Morellón, M., Sebastián, M., Moreno, A., Mantínez Bea, M. (2009) Patterns of human occupation during the early Holocene in the Central Ebro Basin (NE Spain) in response to the 8.2 ka climatic event. Quaternary Research, 71(2): 121-132.

Gramsch, B. (1992) Friesack Mesolithic wetlands. In Coles, B. (Ed.) The Wetland revolution in prehistory: proceedings of a conference held by the Prehistoric Society and WARP at the University of Exeter. London: 65-72.

Gramsch, B., Kernchen, I. (2023) Early Holocene tree bast strings, ropes and nets from Friesach 4, Branderburg. THEFFO Volume II: 47-58.

Gravel-Miguel, C. (2016) Using species distribution modeling to contextualize Lower Magdalenian social networks visible through portable art stylistic similarities in the Cantabrian region (Spain). Quaternary International, 412: 112-123.

Gronenborn, D. (2009) Climate fluctuations and trajectories to complexity in the Neoltihic towards a theory. Documenta Praehistorica XXXVI: 97-110.

Guerra-Doce, E., Abarquero Moras, F.J., Romero-Brugués, S., Herrero-Otal, M., Homs, A., García Cuesta, J.L., López Sáez, J.A., Piqué, R., Delibes de Castro, G. (2024) Brine-boiling not using briquetage? Technica, socio-economical and ritual aspects of salt production at the Villafáfila lagoons (central Iberia) in Late Chalcolithic/Bronze Age. Quaternaty Science Reviews, 336: 108758.

Guerrero, E., Molist, M., Kuijt, I., Anfruns, J. (2009) Seated memory: new insights into Near Eastern Neolithic mortuary variability from Tell Halula, Syria. Current Anthropology, 50(3): 385-386.

Gugerli, F., Parducci, J., Petit, R.J. (2005) Ancient plant DNA: review and prospects. New Phytologist, 166: 409-418.

Guinovart Escarré, J. (2004) Filadors de corda: les meves memòries. Quaderns de Vilaniu, 46: 41-57.

Gupta, S., Jawanda, M.K., Sm, M., Bharti. A. (2014) Qualitative histological evaluation of hard and soft tissue components of human permanent teeth using various decalcifying agents – A comparative study. Journal of Clinical and Diagnostic Research, 8: 69-72.

Guttenberg, H. von (1940) Der primäre Bau der Angiospermenwurzel. Handbuch der Pflanzenanatomie, Band 8, Lief 39. Gebrüder Borntraeger, Berlin.

H

Haberlandt, G. (1914) Physiological Plant Anatomy. Macmillan, London.

Haïdar-Boustani, M., Ibáñez, J.J., Arranz, A., Gratuze, B., Himi, M., Khalidi, L., Teira, L. (2011) Nouveaux travaux archéologiques à Tell Labwé Sud (Béqaʿnord) Campagne 2011: rapport préliminaire. Bulletin d’Archéologie et d’Architecture Libanaises, 15: 5-28.

Hardy, K., Buckley, S., Copeland, L. (2018) Pleistocene dental calculus: recovering information on Palaeolithic food items, medicines, paleoenvironment and microbes. Evolutionary Anthropology, 27: 234-246.

Hardy, K., Moncel, M.H., Kerfant, C., Lebon, M., Bellot-Gurlet, L., Mélard, N. (2020) Direct evidence of Neanderthal fibre technology and its cognitive and behavioral implications. Nature Scientific reports, 10: 4889.

Hardy, K., Radini, A., Buckley, S., Sarig, R., Copeland, L., Gopher, A., Barkai, R. (2016) Dental calculus reveals potential respiratory irritants and ingestion of essential plant-based nutrients at Lower Palaeolithic Qesem Cave Israel. Quaternary International, 398: 129-135.

Harris, S. (2014) Flax fibre: Innovation and Change in the Early Neolithic. A Technological and Material Perspective. Textile Society of America 2014 Biennial Symposium Proceedings: New Directions: Examining the Past, Creating the Future, Los Angeles, CA.

Harris, S. (2019) Chapter 13: The Sensory Archaeology of Textiles. In Day, J., Skeates, R. (Eds.) Routledge Handbook of Sensory Archaeology. London: Routledge: 210-232.

Harris, S., Jones, A.M. (2017) Beautiful things: textiles and fibre artefacts from an Early Bronze Age cremation, Whitehorse Hill, England. In Bravermanová, M., Březinová, H., Malcolm-Davies, J. (Eds.) Archaeological Textiles – Links Between Past and Present. NESAT XIII. Liberec - Praha.

Haugan, E., Holst, B. (2013) Determining the fibrillar orientation in bast fibres using polarized light microscopy: the modified Herzog test (red plate test) explained. Journal of Microscopy, 252(2): 159-168.

Haugan, E., Holst, B. (2014) Flax look-alikes: pitfalls of ancient plant fibre identification. Archaeometry, 56(6): 951-960.

Heaton, T.H.E., Jones, G., Halstead, P., Tsipropoulos, T. (2009) Variations in the 13C/12C ratios of modern wheat grain, and implications for interpreting data from Bronze Age Assiros Toumba, Greece. Journal of Archaeological Sciences, 36: 2224-2233.

Heizer, R.F. (1963) Domestic Fuel in Primitive Society. The Journal of the Royal Antropological Institute of Great Britain and Ireland, 93(2): 186-194.

Hendy, J., Charlton, S., Radini, A. (2013) Ancient dental plaque: an unexpected journey into the past. The Post Hole: Issue 29.

Hendy, J., Warinner, C., Bouwman, A., Collins, M.J., Fiddyment, S., Fischer, R., Hagan, R., Hofman, C.A., Holst, M., Chaves, E., Klaus, L., Larson, G., Mackie, M., McGrath, K., Mundorff, A.Z., Radini, A., Rao, H., Trachsel, C., Velsko, I.M., Speller, C.F. (2018) Proteomic evidence of dietary sources in ancient dental calculus. Proceedings of the Royal Society B: Biological Sciences, 285: 20180977.

Hendy, J., Welker, F., Demarchi, B., Speller, C., Warinner, C., Collins, M.J. (2018) A guide to ancient protein studies. Nature: ecology and evolution, 2: 791-799.

Herrero-Otal, M., Fiorin, E., Malgosa-Morera, A. (2018) Explotación de Recursos en Época Medieval - Análisis del Contenido del Cálculo Dental de la Necrópolis de Cal Guardià (VII-IX cal AD; Argentona, Barcelona). In Malgosa, A., Aluja, M.P. (Eds.) La Antropología Física en la Era de la Genómica: 193-206. ISBN: 978-84-948252-4-8.

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R. (2021) Plants used in basketry production during the Early Neolithic in the north-eastern Iberian Peninsula. Vegetation History and Archaeobotany, 30: 729-742.

Herrero-Otal, M., Romero-Brugués, S., Piqué Huerta, R. (2023) Describing the neolithic cord production process: Raw materials, techniques and experimental archaeology in La

Draga (Girona, Spain; 5207–4862 cal BC). Journal of Archaeological Sciences Reports, 50: 104092.

Hetherington, A.M., Woodward, F.I. (2003) The role of stomata in sensing and driving environmental change. Nature, 424: 901-908.

Hillbrand, M., van Geel, B., Hasenfratz, A., Hadorn, Ph., Haas, J.N. (2014). Non-pollen palynomorphs show human- and livestock-induced eutrophication of Lake Nussbaumersee (Thurgau, Switzerland) since Neolithic times (3840 BC). The Holocene, 24(5): 559-568.

Hole, F. (1959) A Reanalysis of Basal Tabbat Al-Hammam, Syria, Syria, Archéologie, Art et histoire, 36(3-4): 149-183.

Hollander, D., Schwartz, M. (2000) Annealing, distilling, reheating and recycling: bitumen processing in the Ancient Near East. Paléorient, 26(2): 83-91.

Hollen, N., Saddler, J., Langford, A.L., Kadolh, S.J. (1979) Textile, 6th Ed. Macmillan Pub. Ltd. New York: 348-357.

Holmes, W.H. (1884) Prehistoric Textile Fabrics of the United States, Derived from Impressions on Pottery. Bureau of American Ethnology, Third Annual Report. Washington: 393-425.

Hurcombe, L.M. (2008) Organics from inorganics: using experimental archaeology as a research tool for studying perishable material culture. World Archaeology, 40(1): 83-115.

Hurcombe, L.M. (2014) Perishable material culture in Prehistory. Investigating the missing majority. Routledge, London.

Hurley W.M. (1979) Prehistoric cordage: Identification of impressions of pottery. Aldine Manuals on Archeology 3. University of Toronto, Toronto.

Hyland, D.C., Adovasio, J.M., Illingworth, J.S. (2003) The Perishable Artifacts. In MacNeixh, R.S., Libby, J.G. (Eds.) Pendejo Cave. University of New Mexico Press. Albuquerque: 297-416.

I

Iacconi, C., Autret, A., Desplanques, E., Chave, A., King, A., Fayard, B., Moulherat, C., Leccia, É., Bertrand, L. (2023) Virtual technical analysis of archaeological textiles by synchrotron microtomography. Journal of Archaeological Science, 149: 105686.

Ibáñez Hernández, T., Rovira Marsal, J. (2011) La cestería en la Litera. Benjamin González Vidal (1912-2009), cestero de Tamarite de Litera. Litera, 3: 107-123.

Ibañez, J. J., Haïdar-Boustani, M., Arranz, A., Himi, M., Khalldl, L., Teira, L., García, J. (2012) Trabajos arqueológicos en el yacimiento neolítico de Tell Labwe sur (Bekaa norte, Líbano). Informes y trabajos: excavaciones en el exterior, 9: 414-427.

Ibáñez-Estévez, J. J., Clemente-Conte, I., Gassin, B., Gibaja, J. F., González Urquijo, J. E., Márquez, B., Philibert, S., Rodríguez Rodríguez, A. (2008) Harvesting Technology During The Neolithic in SW Europe. Proceedings of the International Congress Verona (Italy). ISBN: 9781407302713.

Ingersoll, D., Yellen, J.E., Macdonald, V. (1979) Experimental Archaeology. In Press, C.U. (Ed.), American Antiquity.

Innes, J.B., Zong, Y., Wang, Z., Chen, Z. (2014) Climatic and palaeoecological changes during the mid- to Late Holocene transition in eastern China: high-resolution pollen and non-pollen palynomorph analysis at Pingwang, Yangtze coastal lowlands. Quaternary Science Reviews, 99: 164-175.

International Committee for Phytolith Taxonomy (ICPT) (2019) International Code for Phytolith Nomenclature (ICPN) 2.0, Annals of Botany, 124(2): 189-199.

Iriarte, M.J. (2009) Vegetation landscape and the anthropisation of the environment in the Central sector of the Northern Iberian Peninsula: current status. Quaternary International, 200: 66-76.

J

Jalut, G., Dedoubat, J.J., Fontugne, M., Otto, T. (2009) Holocene circum-Mediterranean vegetation changes: climate forcing and human impact. Quaternary International, 200: 4-18.

Jardine, P.E., Gosling, W.D., Lomax, B.H., Julier, A.C.M., Fraser, W.T. (2019) Chemotaxonomy of domesticated grasses: a pathway to understanding the origins of agriculture. Journal of Micropalaeontology, 38: 83-95.

Jolie, E. (2006) The technomechanics of Plains Indian coiled gambling baskets. Plains Anthropologist 51 (197): 17-49.

Jolie, E. (2022) Basketry Shields of the Prehispanic Southwest. KIVA, 88.

Jolie, E., Lynch, T.F., Geib, P.R., Adovasio, J.M. (2011) Cordage, textiles, and the Late Pleistocene Peopling of the Andes. Current Anthropology, 52(2): 285-296.

Jones, M., Brown, T.A. (2000) Agricultural origins: the evidence of modern and ancient DNA. The Holocene, 10: 769-776.

Jordà Cerdà, F. (1974) Formas de vida económica en el arte rupestre levantino. Zephyrus, 225: 209-223.

Jordà Cerdà, F., Alcàcer Grau, J. (1951) Las pinturas rupestres de Dos Aguas (València). Servicio de Investigación Prehistórica. Trabajos varios 15. València.

Jordà Cerdà, F., Jordá Pardo, J., González-Tablas, F.J., Aura, J.E., Sanchidrián, J.L. (1983) La cueva de Nerja. Revista de Arqueología, 29: 58-65.

Juan, J., Martí, B. (2002) Poblamiento y procesos culturales en la Península Ibérica del VII al V milenio A.C. (8000–5500 BP): Una cartografía de la neolitización. In Badal, E., Bernabeu, J., Martí, B. (Eds.), El paisaje en el Neolítico mediterráneo. Saguntum extra 5. Universitat de València, València: 45–87.

Juhola, T., Henry, A.G., Kirkinen, T., Laakkonen, J., Väliranta, M. (2019) Phytoliths, parasites, fibers, and feathers from dental calculus and sediment from Iron Age Luistari cemetery, Finland. Quaternary Sciences Reviews, 222: 10588-105896.

Junkmanns, J., Klügl, J., Schoch, W., Di Pietro, G., Hafner, A. (2019) Neolithic and Bronze Age archery equipment from Alpine Ice-Patches: a review on components, construction techniques and functionality. Journal of Neolithic Archaeology: 283-314.

Jurgens, C.J. (2005) Zooarcheology and Bone Technology from Arenosa Shelter (41VV99), Lower Pecos Region, Texas. PhD Dissertation, The University of Texas, Austin.

K

Kelterborn, P. (1987) Principles of Experimental Research in Archaeology 1987, Bulletin of Experimental Archaeology, 8: 11-12.

Kemp, B.J., Vogelsang-Eastwood, G. (2001) The ancient textile industry at Amarna. London: Egypt Exploration Society.

Kirkbride, D. (1969) Early Byblos and the Beqa'a. Mélanges de l'Université Saint Joseph, 45: 45-60.

Klippel, W.E. (1971) Graham Cave Revisited: a re-evaluation of its cultural position during the Archaic Period. Memoir 9. Missouri Archaeological Society, Columbia.

Körber-Grohne, U., Feldtkeller, A. (1998) Pflanzliche Rohmaterialien und Herstellungstechniken der Gewebe, Netze, Geflechte sowie anderer Produkte aus den neolithischen Siedlungen Hornstaad, Wangen, Allensbach und Sipplingen am Bodensee. Siedlungsarchäologie im Alpenvorland. Landesdenkmalamt Baden-Württemberg. Stuttgart.

Kouli, K., Dermitzakis, M.D. (2008) Natural and cultural landscape of the Neolithic settlement of Dispilió: palynological results. Hellenic Journal of Geosciences, 43: 29-39.

Kuoni B (1981) Cestería tradicional ibérica. Ediciones del Serbal, Barcelona. ISBN: 8485800117.

Kuzmin, Y.V., Keally, C.T., Jull, A.J.T., Burr, G.S., Klyuev, N.A. (2012) The earliest surviving textiles in East Asia from Chertovy Vorota Cave, Primorye Privince, Russian Far East. Antiquity, 86: 325-337.

Kvavadze, E., Bar-Yosef, O., Belfer-Cohen, A., Boaretto, E., Jakeli, N., Matskevich, Z., Meshveliani, T. (2009) 30000-year-old wild flax fibers. Science, 325(5946): 1359.

L

Le Moyne, C., Crowther, A. (2021) Effects of chemical pre-treatments on modified starch granules: recommendations for dental calculus decalcification for ancient starch research. Journal of Archaeological Science Reports, 35: 102762.

Legrand, A. (2007) Fabrication et utilisation de l'outillage en matières osseuses du Néolithique de Chypre: Khirokitia et Cap Andreas-Kastros. Oxford, B.A.R. International Series.

Legrand, A., Sidéra, I. (2007) Methods, Means, and results when studying european bone industry. In Gates St-Pierre, C., Walker, R.B. (Eds.) Bones as Tools: Current Methods and Interpretations in Worked Bone Studies, Oxford, B.A.R. International Series, 1622: 67-80.

Legrand-Pineau, A. (2011) 6. L'industrie osseuse. In Bosch, A., Chinchilla, J., Tarrús, J. (eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona: 111-124.

Leroi-Gourhan, A. (1983) Los primeros artistas de Europa. Introducción al arte parietal paleolítico, Ediciones Encuentro Madrid, España.

Leroi-Gourhan, A., Jaques, A. (1979) Lascaux Inconnu. XII supplément à "Gallia Prehistoire". Editions du Centre National de la Recherche Scientifique, Paris.

Lieverse, A.R. (1999) Diet and the Aetiology of Dental Calculus. International Journal of Osteoarchaeology, 232: 219-232.

Lillios, K.T., Blanco-González, A., Lee Drake, B., López-Sáez, J.A. (2016) Mid-late Holocene climate, demography and cultural dynamics in Iberia: A multi-proxy approach. Quaternary Science Reviews, 135: 138-153.

Logan, W.D. (1952) Graham Cave: an archaic Site in Montgomery County, Missouri. Memoir 2. Missouri Archaeological Society. Columbia.

López, P. (1978) La problemática cronológica del Neolítico Peninsular. In: Almagro-Gorbea, M., Fernández-Miranda, M. (Eds.) C-14 y Prehistoria de la Península Ibérica. Fundación Juan March-Serie Universitaria, Madrid: 45-56.

López, P. (1980) Estudio de la cerámica, industria ósea y lítica de la Cueva de los Murciélagos de Albuñol (Granada). Trabajos de Prehistoria, 37: 164-180.

López-Bultó, J.O. (2015) Processos d'obtenció, transformación i ús de la fusta en l'assentament neolític antic de la Draga (5320-4800 cal BC). PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

López-Bultó, O., Gassman, P., Bertin, I., Piqué, R. (2023) Sorting the Trees: The Role of Laurus nobilis in the Woodland Management Practices at La Draga (Banyoles, Spain). International Journal of Wood Culture, 3(1-3): 329-348.

López-Bultó, O., Piqué, R. (2018) Wood Procurement at the Early Neolithic site of La Draga (Banyoles, Barcelona). Journal of Wetland Archaeology, 18(1): 56-76.

López-Bultó, O., Piqué, R., Antolín, F., Barceló, J. A., Palomo, A., Clemente, I. (2020) Digging sticks and agriculture development at the ancient Neolithic site of la Draga (Banyoles, Spain). Journal of Archaeological Science: Reports, 30: 102193.

López-Merino, L. (2009) Paleoambiente y antropización en Asturias durante el Holoceno. PhD Dissertation. Universidad Autónoma de Madrid, Madrid.

López-Sáez, J.A. (2002) Análisis paleopalinológico del yacimiento Dehesa de Río Fortes (Mironcillo, Ávila). Boletín del Seminario de Estudios de Arte y Arqueología, 68: 42-48.

López-Sáez, J.A., López García, J.A., López-Merino, L. (2006) La transición mesolítico-neolítico en el valle medio del Ebro y en el Prepirineo aragonés desde una perspectiva paleoambiental: dinámica de la antropización y origen de la agricultura. Revista Iberoamericana de Historia, 1: 4-11.

López-Sáez, J.A., López-García, P., López-Merino, L., Cerrillo Cuenca, E., González Cordero, A., Prada, A. (2005) Prehistoric landscapes in North Extremadura between the VIth and the IVthh millenia cal BC. Journal of Iberian Archaeology, 7: 23-35.

López-Sáez, J.A., López-Merino, L. (2007) Coprophilous fungi as a source of information of anthropic activities during the Prehistory in the Amblés Valley (Ávila, Spain): The archaeopalynological record. Revista Españolla de Micropaleontologia, 39(1-2): 103-116.

Lozano, M., de Castro, J.M.B., Carbonell, E., Arsuaga, J.L. (2008) Non-masticatory uses of anterior teeth of Sima de los Huesos individuals (Sierra de Atapuerca, Spain). Journal of Human Evolution, 55: 713–728.

Lozano, M., Jiménez-Brobeil, S.A., Willman, J.C., Sánchez-Barba, L.P., Molina, F., Rubio, A. (2021) Argaric craftswomen: Sex-based division of labor in the Bronze Age southeastern Iberia. Journal of Archaeological Sciences, 127: 105236.

Lukesová, H., Holst, B. (2021) Is cross-section shape a distinct feature in plant fibre identification? Archaeometry, 63(1): 216-226.

Lukesova, H., Holst, B. (2024) Identifying plant fbres in cultural heritage with optical and electron microscopy: how to present results and avoid pitfalls. Heritage Science, 12: 12.

Lumbreras, L.G. (1987) Métodos y técnicas en Arqueología. Boletín de Antropología americana, 16: 51-83.

M

M'hamdi, M. Anderson, P.C. (2013) Approche ethnoarchéologique d'outils et techniques de moisson de l'alfa (Stipa tenacissima) dans la région des Hautes Steppes en Tunisie : Premières observations et analyses. In Anderson, P.C., Cheval, C., Durand, A. Regards croisés sur les outils liés au travail des végétaux. An interdisciplinary focus on plant-working tools. Actes des XXXIIIe recontres internationals d'archéologie et d'histoire d'Antibes. APDCA, Antibes: 75-88. ISBN: 2-904110-53-4.

MacKenzie, L., Speller, C.F., Holst, A., Keefe, K., Radini, A. (2022) Dental calculus in the industrial age: human dental calculus in the Post-Medieval period, a case study from industrial Manchester. Quaternary International, 653-654: 114-126.

Maicas, R., Montero, I. (1998) Estudio y valoración del yacimiento Neolítico y Calcolítico de Loma de El Arteal (Cuevas de Almanzora, Almería). En Boletín del Seminario de estudios de Arte y Arqueología, LXIV: 59-90.

Maier, U. (1999) Agricultural activities and land use in a Neolithic village around 3900 B.C.: Hornstaad Hörnle IA, Lake Constance, Germany. Vegetation, History and Archaeobotany, 8: 87-94.

Maier, U., Schlichtherle, H. (2011) Flax cultivation and textile production in Neolithic wetland settlements onLake Constance and in Upper Swabia (south-west Germany). En Vegetation History and Archaeobotany, 20(6): 567–578.

Maiti, R.K. (1995) Fibras vegetales en el mundo: aspectos botánicos, calidad y utilidad. Editorial Trillas. Mèxic.

Marinova, E., Tonkov, S., Bozilova, E., Vajsoc, I. (2012) Holocene anthropogenic landscapes in the Balkans: the palaeobotanical evidence from southwestern Bulgaria. Vegetation History and Archaeobotany, 21: 413-427.

Márquez-Romero, J. E., Jiménez-Jáimez, V. (2013) Monumental ditched enclosures in southern Iberia (fourth–third millennia BC). Antiquity, 87(336): 447-460.

Martín Socas, D., Cámalich Massieu, M.D., González Quintero, P. (2004) La Cueva de El Toro (Sierra de El Torcal-Antequera-Málaga). Un modelo de ocupación ganadera en el territorio andaluz entre el VI i II milenios A.N.E. Arqueología Monografías.

Martín, A., Bordas, A., Martí, M. (1996) Bòbila Madurell (Sant Quirze del Vallès, Barcelona). Estratègia económica y organización social en el neolítico medio. Proceedings of the I Congreso del Neolítico en la Península Ibérica. Formación e implantación de las comunidades agrícolas. Rubricatum, 1: 423-434.

Martín, A., Edo, M., Tarrús, J., Clop, X. (2010) Le Néolitique ancient de Catalogna (VI-première moté du V millenaire av. J.C.). Les séquences chronoculturels. In Manen, C., Convertini, F., Binder, D., Sénépart, I. (Eds.) Premières societés paysannes de Méditerrannée occidental. Structures des productions céramiques. Mémoire société Préhistorique Française, 51: 197-214.

Martín, A., Miret, J., Blanck, R.M., Aliaga, S., Enrich, R., Colomer, S., Albizuri, S., Bosch, J. (1998) Campanya d'excavacions arqueològiques 1987-1988 al jaciment de la Bòbila Madurell-Can Feu (Sant Quirze del Vallès, Vallès Occidental). Arrahona, 3: 9-23.

Martínez Rodríguez, F., Alcázar Godoy, J. (1992) Enterramientos prehistóricos en Alcalá del Valle (Cádiz). En Revista de Arqueología, 133: 10-19.

Martínez Rodríguez, F., Pereda Acién, C., Alcázar Godoy, J. (1989) Primeros datos sobre una necrópolis prehistórica de excepcional interés: El Cerro de la Casería de Tomillos (Alcalá del Valle, Cádiz). Anuarios Arqueológicos de Andalucía (Sevilla), 3: 59-65.

Martínez-Sevilla, F. (2018) Brazaletes de piedra neolíticos en la península ibérica (VI-V milenio a.C.): tecnología, funcionalidad y circulación. British Archaeological Reports. International Series 2913 (Oxford).

Martínez-Sevilla, F. (2022) Actividad arqueològica puntual de prospección superficial y excavación mediante sondeos en la Cueva de los Murciélagos (Albuñol, Granada). EXP:BC.03.143/22 14100/Ref. Archaeological technical report.

Martínez-Sevilla, F., Herrero-Otal, M., Martín-Seijo, M., Jonathan Santana, Lozano Rodríguez, J.A., Maicas Ramos, R., Cubas, M., Homs, A., Martínez Sánchez, R.M., Bertin, I., Barroso Bermejo, R., Bueno Ramírez, P., de Balbín Behrmann, R., Palomo Pérez, A., Álvarez-Valero, A.M., Peña-Chocarro, L., Murillo-Barroso, M., Fernández-Domínguez, E., Altamirano-García, M., Pardo-Martínez, R., Iriarte-Cela, M., Carrasco Rus, J.L., Alfaro Giner, C., Piqué Huerta, R. (2023) The earliest basketry in Southern Europe: hunter-gatherer and first farmers plant-based technology preserved in the Cueva de los Murciélagos (Albuñol, Spain). Science Advances, 9(39): eadi3055.

Martín-Seijo, M. (2021) Plant-based crafts from Iron Age contexts of north-western Iberia: Technological know-how and materiality. The missing woodland resources: Archaeobotanical studies of the use of plant raw materials. Advances in Archaeobotany, 6: 97-110.

Martín-Seijo, M., Rico Rey, A., Teira Brión, A., Picón Platas, I., García González, I., Abad Vidal, E. (2010) Guía de Arqueobotánica. Xunta de Galícia. Conselleria de Cultura e Turismo, Dirección Xeral do Patrimonio Cultural. ISBN: 978-84-4534893-2.

Masaubach, M. (2012) Potencialidad de estudios arqueobotánicos sobre tártaro dental de cazadores-recolectores de la provincia de La Pampa, Argentina. Revista Argentina de Antropología Biológica, 14: 105-113.

Mason, O.T. (1885) Basket-work of the North American Aborigines. Report of the United Stated National Museum, Part III: 291-306.

Mason, O.T. (1901) The technic of Aboriginal American Basketry. American Anthropologist N. S. 3, 1901: 109-128.

Mason, O.T. (1904) Indian Basketry: studies in a textile art without machinery. Doubleday, Page & Co. Nova York.

Mathieu, J.R. (2002) Introduction - Experimental Archaeology: Replicating Past Objects, Behaviors, and Processes. BAR (International Series): 1035.

Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlén, W., Maasch, K.A., Meedker, L.D., Meyerson, E.A., Gassem F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E.J. (2004) Holocene climate variability. Quaternary Research, 62: 243-255.

Mazăre, N.P. (2011) Textiles and pottery: insights into Neolithic and Cooper Age pottery manufacturing techniques from Romania. Archaeological textiles newsletter, 53: 28-33.

McLaughlin, TR., Gómez-Puche, M., Cascalheira, J., Bicho, N., Fernández-López de Pablo, J. (2021) Late Glacial and Early Holocene human demographic responses to climatic and environmental change in Atlantic Iberia. Philosophical Transactions of the Royal Society B, Biological Sciences, 376: 20190724.

Médard, F. (2000) L'artisanat textile au Neolithique. L'exemple de Delley-Portalban II (Suisse) 3272–2462 avant J.C. Collection Prehistoires, 4. Montagnac.

Médard, F. (2003) Vestiges textiles et activités de filage sur le site néolithique d'Arbon-Bleiche 3 (TG Suisse), Bulletin de la Société Botanique de France, 100(2): 375-391.

Médard, F. (2008) L'acquisition des matières textiles d'origine végétale en préhistoire. L'apport des données expérimentales et ethnographiques. Les nouvelles de l'archéologie, 114: 23-28.

Médard, F. (2012) 18: Switzerland: Neolithic Period. In Gleba M, Mannering U (eds) Textiles and Textile Production in Europe from Prehistory to AD 400. Oxbow Books. Ancient textiles series, vol. 11: 367-377. ISBN: 978-1-84217-463-0.

Mellaart, J. (1975) The Neolithic of the Near East (The World of Archaeology). Charles Scribner's Sons. London. ISBN: 0684144832.

Mercuri, A.M., Sadori, L., Uzquiano, P. (2011) Mediterranean and north-African cultural adaptations to mid-Holocene environmental and climatic changes. The Holocene 21(1): 189-206.

Mickleburgh, H.L., Pagán-Jiménez, J.R. (2012) New insights into the consumption of maize and other food plants in the pre-Columbian Caribbean from starch grains trapped in human dental calculus. Journal of Archaeological Science, 39(7): 2468–2478.

Middleton, W.D. (1994) Extraction of Opal Phytoliths from Herbivore Dental Calculus. Journal of Archaeological Science, 21: 469-473.

Miettinen, A., Sarmaja-Korjonen, K., Sonninen, E., Junger, H., Lempiäinen, T., Ylikoski, K., Mäkiaho, J.P., Carpelan, C., Jungner, H. (2008) The palaeoenvironment of the Antrea Net Find. Karelian Isthmus. Finnish Antiquarian Society, 16: 71-87.

Milner G.R., Larsen, C.S. (1991) Teeth as artifacts of human behavior: Intentional mutilation and accidental modification. In Kelley, M.A., Larsen, C.S. (Eds.) Advances in Dental Anthropology Wiley-Liss, New York: 357-378.

Mindeleff, C. (1896) Aboriginal Remain in Verde Valley, Arizona. Bureau of American ethnology, 13th Annual Report: 176-261.

Mineo, M., Mazzuco, N., Rottoli, M., Remolins, G., Caruso-Fermé, L., Gibaja, J.F. (2023) Textiles, basketry and cordage from the Early Neolithic settlement of La Marmotta, Lazio. Antiquity, 97(392): 314-330.

Minguell, A., Palomo, A., Piqué, R., Rosillo, R., Terradas, X. (2023) Las Coves del Fem (Sierra del Montsant, Tarragona): aproximación a las técnicas de talla aplicadas en el Neolítico Antiguo. In García Rivero, D. (Coord.) Actas del VII Congreso sobre Neolítico en la Península Ibérica. Editorial Universidad de Sevilla, Sevilla.

Miškolciová, L. (2015) Coiling basketry evidence from the Late Neolithic site Tell Arbid Abyad (Syria). Institute of Archaeology and Museology. Centre of Prehistoric Archaeology of the Near East.

Molina, F., Rodríguez-Ariza, M.O., Jiménez, S., Botella, M. (2003) La sepultura 121 del yacimiento argárico de El Castellón Alto (Galera, Granada). Trabajos de Prehistoria, 60(1): 153-158.

Molist, M., Anfruns, J., Cruells, W., Clop, X., Saña, M. (2004) Estudio del asentamiento de Tell Halula (valle del Éufrates, Siria): aportaciones para el estudio de la emergència de las sociedades agrícolas en el Próximo Oriente. Revista Bienes Culturales, IPCE, 3: 45-62.

Morales, J., Mulazzani, S., Belhouchet, L., Zazzo, A., Berrio, L., Eddargach, W., Cervi, A., Hamdi, H., Saidi, M., Coppa, A., Peña-Chocarro, L. (2015) First preliminary evidence for basketry and nut consumption in the Capsian culture (ca. 10,000–7500 BP): Archaeobotanical data from new excavations at El Mekta, Tunisia. Journal of Anthropological Archaeology, 37: 128-139.

Morales, J.I., Fontanals, M., Oms, F.X., Vergés, J.M. (2010) La chronologie du Néolithique ancien cardial du nord-est de la Péninsule Ibérique. Datations, problématique et méthodologie. L'Anthropologie, 114(4): 427-444.

Morales, J.I., Oms, F.X. (2012) Las últimas evidencias mesolíticas del NE peninsular y el vacío pre-neolítico. Rubricatum: Revista del Museu de Gavà, 5: 35-42.

Morales, R., Tardío, J., Aceituno, L., Molina, M., Pardo de Santayana, M. (2011) Biodiversidad y etnobotànica en España. Memorias de la Real Sociedad Española de Historia Natural, 2(9): 157-207.

Mordant, D. (2024) Une référence pour la vannerie mésolithique de Noyen-sur-Seine (Seine-et-Marne): les paniers de la Cueva de los Murciélagos à Albuñol (Espagne). Tome, 121(1): 91-95.

Morell, B. (2019) La cronología comoo medio de interpretación social: los contextos funerarios del NE de la Península Ibérica entre finales del V e inicios del IV milenio cal. BC. PhD Dissertation, Notebaert, B., Berger, J.F. (2014) Quantifying the anthropogenic forcing on soil erosion during the Iron Age and Roman Period in southeastern France. Anthropocene, 8: 59-69.

Mozota, M., Gibaja, F.J. (2015) "For a few awls more". Bone tools in northeastern Iberia Neolithic burials (4th-5th millennia cal BC). A morpho-technical and functional approach. Journal of Archaeological Science: Reports, 5: 65-77.

Müller-Neuhof, B. (1998) A preliminary note on the pottery neolithic at Tell Hmaira (Lebanon). Neo-Lithics, 3(98): 4-6.

Muñoz López-Astilleros, K. (1999) El "ídolo-placa" de la Granja de Céspedes (Badajoz). Una aproximación a la simbología del fenómeno megalítico del occidente peninsular. Museo Arqueológico Nacional.

Muñoz Ovalle, I. (2017) Espacios fúnebres, prácticas mortuorias y cronología en el cementerio Azapa-115: aproximaciones entorno a la estructura sociald de los agricultores prehispánicos del período medio. Estudios Atacameños, 54: 5-36.

Murdy, W.H. (1960) The strengthening system in the stem of maize. Annals of the Missouri Botanical Garden, 67: 205-226.

Muscio, E., Anaya, J. (2018) Braided rope with vegetable fibers for the construction of the Inca bridge of Q'eswachaka (Peru). In Wouters, I., Van de Voorde, S., Bertels, I., Espion, B., De Jonge, K., Zastavni, D. (Eds.) Building Knowledge, Constructing Histories. Brussels: 977-991.

Myking T, Hertzberg A, Skrøppa T (2005) History, manufacture and properties of lime bast cordage in northern Europe. Forestry, 78(1): 65-71.

N

Nadel, D., Danin, A., Werker, E., Schick, T., Kislev, M. E., Stewart, K. (1994) 19000-year-old twisted fibers from Ohalo II. Current Anthropology, 35(4): 451-458.

Navarrete Belda, V. (2017) Domesticación animal y prácticas ganaderas iniciales en el noreste peninsular (5500-4700 cal ANE). Integración de los análisis de isótopos estables en arqueozoología. PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

Navarrete, V., Saña, M. (2013) Producción y consumo cárnico a inicios del Neolítico: animales domésticos en el poblado de la Draga (Banyoles), (5300-5000 cal BC). In López, J.A (Ed.) La producción de alimentos. Arqueología, historia y futuro de la dieta

Mediterránea. PHICARIA. Proceeding of the I Congreso sobre la producción en las sociedades Mediterráneas: Universidad Popular de Mazarrón, Murcia: 121-129.

Nieuwenhuyse, O.P., Bartl, K., Berghuijs, K., Vogelsang-Eastwood, G. (2012) The cord-impressed pottery from the Late Neolithic Northern Levant: case-study Shir (Syria). Paléorient, 38(1-2): 65-77.

Nishida, I., Nakano, M.; Kohmoto, M., Matsui, A. (2006) Saga-ken Saga-shi Higashimyo iseki (Higashimyo site. Saga City, Saga Préfecture). Kokogaku Kerikyu, 53(1): 104-106.

Nordenskjold, G. (1894) The cliff Dwellers of the Mesa Verde. Stockholm.

Norström, E., Gustavsson, E., Molin, F., Gummesson, S. (2019) Micro-fossil analysis of Mesolithic human dental calculus, Motala, Sweden-Indications of health status and paleo-diet. Journal of Archaeological Sciences Reports, 26: 101866.

Norton, R.E. (1990) Technology of plant materials used in artifacts. In Florian, M.E., Kronkright, D.P., Norton, R.E. (Eds.). The conservation artefacts made from plant material. Princeton University Press. Princeton: 83-138.

O

O'Connell, M., Molloy, K. (2001) Farming and woodland dynamics in Ireland during the Neolithic. Biology & Environment Proceedings of the Royal Irish Academy, 101B(1-2): 99-128.

Oliva Poveda, M. (2011) 7. Els objectes d'ornament. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d'Arqueologia de Catalunya-CASC, Girona: 125-132.

Oliva, M. (2017) Els ornaments personals. In Palomo, A., Piqué, R., Terradas, X. (eds.) La Revolució neolítica: La Draga, el poblat dels prodigis. Museu d'Arqueologia de Catalunya, Departament de Cultura de la Generalitat de Catalunya: 89-92. ISBN: 978-84-393-9650-5.

Oms, F.X., Martín, A., Esteve, X., Mestres, J., Morell, B., Subirà, M.E.m Gibaja, J.F. (2016) The Neolithic in Northeast Iberia: Chronocultural Phases and 14C. Radiocabon, 58(2): 291-309.

Out, W., Hänninen, K., Vermeeren, C. (2017) Usin branche age and diameter to identify wooland management: new developments. Environmental Archaeology: 1-14.

Out, W., Vermeeren, C., Hänninen, K. (2013) Branche age and diameter: useful criteria for recognaising woodland management in the present and past? Journal of Archaeological Science, 40(11): 4083-4097.

Ozenda, P. (1975) Sur les étages de végétation dans les montagnes du bassin méditerranéen. Documents de cartographie écologique XVI, 1-32.

P

Palomo, A. (2012) Tecnologia lítica i de la fusta de la prehistòria recente al nord-est peninsular. Anàlisi tecnomorfològica i experimental. PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

Palomo, A., Bogdanovic, I., Piqué, R., Rosillo, R., Terradas, X., Alcolea, M., Berihuete, M., Saña, M. (2020) The last foragers in the north-east of the Iberian Peninsula: New evidence of human occupation during the seventh/sixth millennia cal BC. In Borić, D., Antonović, D., Mihailović, B. (Eds.) Foraging assemblages. 9th International Conference on the Mesolithic in Europe. Belgrade: Serbian Archaeological Society: 273-278.

Palomo, A., Gibaja, J. F., Piqué, R., Bosch, A., Chinchilla, J., Tarrús, J. (2011) Harvesting cereals and other plants in Neolithic Iberia: the assemblage from the lake settlement at La Draga. Antiquity, 85(329), 759-771.

Palomo, A., Piqué, R., Terradas, X. (Eds.) (2013) Experimentación en arqueología. Estudio y difusión del pasado. Sèrie Monogràfica 25.1, 25.2, Museu d'Arquelogia de Catalunya, Generalitat de Catalunya.

Palomo, A., Piqué, R., Terradas, X., Bosch, À., Buxó, R., Chinchilla, J., Saña, M. Tarrús, J. (2014) Prehistoric occupation of Banyoles lakeshore: results of recent excavations at La Draga site, Girona, Spain. Journal of Wetland Archaeology, 14: 58-73.

Palomo, A., Piqué, R., Terradas, X., Lopez-Bultó, O., Clemente, I., Gibaja, J.F. (2013) Woodworking technology in the early neolithic site of La Draga (Banyoles, Spain). In P. Anderson, C. Cheval, A. Durand (Eds.), Regards croises sur les outils lies au travail des vegetaux. An interdisciplinary focus on plant-working tools. Antibes: APDCA: 383-396.

Palomo, A., Terradas, X., Piqué, R., Bosch, À., Buxó, R., Chinchilla, J., Saña, M., Tarrús, J., Bogdanovic, R., Rosillo, R., Revelles, J. (2016) Les intervencions arqueològiques al jaciment neolític lacustre de La Draga 2014-2015 (Banyoles-Pla de l'Estany). Tretzenes Jornades d'Arqueologia de les Comarques de Girona, Banyoles: 45-49.

Palomo, A., Terradas, X., Piqué, R., Rosillo, R., Bodganovic, I., Bosch, A., Saña, M., Alcolea, M., Berihuete, M., Revelles, J. (2018) Les Coves del Fem (Ulldemolins, Catalunya). Servei d'Arqueologia i Paleontologia – Tribuna d'Arqueologia 2015-2016. Departament de Cultura de la Generalitat de Catalunya. Direcció General del Patrimoni Cultural. Subdirecció General del Patrimoni Arquitectònic, Arqueològic i Paleontològic.

Papí Rodes, C. (1992-1994) Improntas de esterillas en cerámicas del Bronce final de la Penya Negra (Crevillente, Alicante) (campañas de 1983 y 1984). Lucentum XI-XIII: 39-49.

Pardo de Santayana, M., Morales, R., Aceituno, L., Molina, M. (2014) Inventario español de los conocimientos tradicionales relativos a la biodiversidad. Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid.

Parducci, L., Petit, R.J. (2004) Ancient DNA – unlocking plants' fossils secrets. New Phytol, 161: 335-339.

Payne, W.W. (1978) A glossary of plant hair terminology. Brittonia, 30: 239-255.

Peacock, E.E. (2001) Chapter 21: The contribution of experimental archaeology to the research of ancient textiles. In Walton Rogers, P., Bender Jørgensen, L., Rast-Eicher, A. (Eds.) The Roman textile industry and its influence. A birthday tribute to John Peter Wild. Oxbow Books. Oxford. ISBN: 1842170465.

Pearsall, D.M. (2015) Paleoethnobotany. A Handbook of Procedures (Third Edition). Left Coast Press, Walnut Creek, CA. ISBN: 9781611322996.

Peña Chocarro, L., Zapata, L., González Urquijo, J.E., Ibáñez, J.J. (2000) Agricultura, alimentación u uso del combustible: aplicación de modelos etnográficos en Arqueobotánica. Saguntum Extra, 3: 403-420.

Peña-Chocarro, L. (1999) Prehistoric agriculture In Southern Spain during the Neolithic and the Bronze Age. The application of ethnographic models. Oxford. BAR International Series S818. ISBN: 9781841710310.

Peñalba, M.C. (1994) The history of the Holocene vegetation in northern Spain from pollen analysis, Journal of Ecology, 82: 815-832.

Pérez de Micou, C. (2001) Cestería y Cordelería para los muertos. Chungará, 33: 137-144.

Pérez Obiol, R., Jalut, G., Julià, R., Pèlachs, A., Iriarte, M.J., Otto, T., Hernández Beloqui, B. (2011) Mid-Holocene vegetation and climatic history of the Iberian Peninsula. The Holocene 21(1): 75-93.

Pérez-Jordà, G., Carrión-Marco, Y. (2011) Los recursos vegetales. In Pérez Jordà, G., Bernabeu Aubán, J., Carrión Marco, Y., García Puchol, O., Molina Balaguer, L., Gómez Puche, M. (Eds.) La Vital (Gandía, València). Vida y muerte en la desembocadura del Serpis durante el III y el I Milenio a.C. Serie Trabajos Varios del SIP. Servei d'Investigacions Prehistòriques. Diputació de València, València. ISBN: 978-84-7795-613-6.

Pérez-Jordà, G., Peña-Chocarro, L. (2013) Agricultural production between the 6th and the 3rd millennium cal BC in the central part of the Valencia region (Spain). In Groot, M., Lentjes, D., Zeiler, J. (Eds.) Barely surviving of More Than Enough? The Environmental Archaeology of subsistence, specialisation and surplus Food Production. Sidestone. Press, Leiden: 81-100.

Pérez-Obiol, R. Julià, R. (1994) Climatic change on the Iberian Peninsula recorded in a 30.000 yr pollen record from Lake Banyoles. Quaternary Research, 41: 91-98.

Pérez-Obiol., Jalut, G., Julià, R., Pèlachs, A., Iriarte, M.J. Otto, T., Hernández-Beloqui, B. (2011) Mid-Holocene vegetation and climatic historic of the Iberian Peninsula. Holocene, 21(1): 75-93.

Pétrequin, P. (1986) Les sites littoraux néolithiques de Clairvaux-les-lacs (Jura), tome 1: problématique générale, l'exemple de la station III. Éditions de la Maison des Sciences de l'Homme. Paris.

Picornell, L. (2009) Antracología y etnoarqueología. Perspectivas para el estudio de las relaciones entre las sociedades humanas y su entorno. Complutum, 20(1): 133-151.

Piperno, D.R. (2006) Phytoliths: a Comprensive Guide for Archaeologists and Palaeocologists. AltaMira Press. New York. ISBN: 0759103852.

Piqué, R. (1999). Producción y uso del combustible vegetal: una evaluación arqueológica. Treballs d'Etnoarqueologia, 3. Editorial UAB-CSIC. Madrid.

Piqué, R. (2000) La gestió dels recursos llenyosos a La Draga. In Bosch, A., Chinchilla, J., Tarrús, J. (eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 1990-1998, Monografies del CASC. Museu d'Arqueologia de Catalunya-CASC, Girona: 140-149.

Piqué, R. (2006) Los carbones y las maderas de contextos arqueológicos y el paleoambiente. Revista Ecosistemas, 15(1): 31-38.

Piqué, R., Alcolea, M., Antolín, F., Berihuete M., Berrocal, A., Rodríguez-Anton, D., Herrero-Otal, M., López-Bultó, O., Obea, L., Revelles, J. (2021b) Mid-Holocene palaeoenvironment, plant resources and human interaction in northeast Iberia: an archaeobotanical approach. Applied Sciences, 11: 5056.

Piqué, R., Barceló-Álvarez, J. A., Bodganovic, I., Bosch, À., Palomo, A., Rosillo, R., Tarrús, J., Terradas-Batlle, X. (2019) Models of neolithization of Northeast of Iberian Peninsula: new evidence of human occupations during the vi millennium cal BC. 1st Conference on the Early Neolithic of Europe, at Museu Marítim de Barcelona: 65.

Piqué, R., Berihuete, M., Franch, A., Gassman, P., Girbal, J., Herrero-Otal, M., López-Bultó, O., Palomo, A., Rageot, M., Revelles, J., Romero-Brugués, S., Terradas, X. (2021c). Woody and non-woody forest raw material at the early Neolithic site of La Draga (Banyoles, Spain). In Berihuete, M., De Force, K., Martin, M., López Bultó, O., Piqué, R. (Eds.) The missing woodland resources: Archaeobotanical studies of the use of plant raw material. Barkhuis' series Advances in Archaeobotany.

Piqué, R., Berihuete-Azorín, M., Franch, A., Gassmann, P., Girbal, J., Herrero-Otal, M., López-Bultó, O., Palomo, A., Rageot, M., Revelles, J., Romero-Brugués, S., Terradas, X. (2022) Woody and non-woody forest raw material at the early Neolithic site of La Draga (Banyoles, Spain). In Piqué, R., Berihuete-Azorín, M., López-Bultó, O., Martín-Seijo, M. (Eds.), The missing woodland resources: Archaeobotanical studies of the use of plant raw materials, 6: 37-58.

Piqué, R., Palomo, A., Romero-Brugués, S., Herrero-Otal, M., Homs, A., Fanlo, J., López-Bultó, O., Tzerpou, E. (2024) Aproximació experimental a la cistelleria a partir de les empremtes de la ceràmica. El cas de la Cova Fonda (Vilabella, Tarragona). Arqueodebats, 2. Museu d'Arqueologia de Catalunya, Barcelona.

Piqué, R., Palomo, A., Terradas, X., Aguer, C., Bogdanovic, I., Chinchilla, J., García, I., Jover, A., López, O., Moitinho, V., Buxó, R., Bosch, A., Tarrús, J., Saña, M., Vivar, G. (2014) Registro, análisis y conservación de los objetos de madera del yacimiento neolítico de La Draga Banyoles, Catalunya. AA.VV. Arqueología subacuática española: actas del I Congreso de Arqueología Náutica y Subacuática Español. Cartagena, ARQUA Museo Nacional de Arqueología Subacuática. Universidad de Cádiz, Cádiz: 1141–1151. ISBN: 978-84-9828-472-0.

Piqué, R., Palomo, A., Terradas, X., Aguer, C., Bogdavonic, I., Chinchilla, J., García, I., Jover, A., López, O., Moitinho, V., Buxó, R., Bosck, À., Tarrús, J., Saña, M., Vivar, G. (2013) Registro, análisis y conservación de los objetos de madera del yacimiento neolítico de La Draga (Banyoles, Catalunya). In Nieto Prieto., X., Ramírez Pernía, A., Recio Sánchez, P. I Congreso de Arqueología Náutica y Subacuática Española. Cartagena: 1136-1148.

Piqué, R., Palomo, A., Terradas, X., Andreaki, V., Barceló, J.A., Bogdanovic, I., Bosch Lloret, À., Gassman, P., López-Bultó, O., Rosillo Turrà, R. (2021a) Models of Neolithisation of Northeastern Iberian Peninsula: New Evidence of Human Occupations During the Sixth Millennium cal BC. Open Archaeology, 7: 671-689.

Piqué, R., Romero, S., Palomo, A., Tarrús, J., Terradas, X., Bogdanovic, I. (2018) The production and use of cordage at the early Neolithic site of La Draga (Banyoles, Spain). Quaternary International, 468: 262-270.

Plants For A Future (PFAF) – Earth, plants people: https://pfaf.org/user/

Power, R.C., Salazar-García, D.C., Rubini, M., Darlas, A., Harvati, K., Walker, M., Hublin, J.J., Henry, A.G. (2018) Dental calculus indicates widespread plant use within the stable Neanderthal dietary niche. Journal of Human Evolution, 119: 27-41.

Power, RC., Wittig, RM., Stone, JR., Kupczik, K., Schulz-Kornas, E. (2021) The representativeness of the dental calculus dietary record: insights from Taï chimpanzee faecal phytoliths. Archaeological and Anthropological Sciences, 13: 1-11.

Preus, H.R., Marvik, O.J., Selvig, K.A., Bennike, P. (2011) Ancient bacterial DNA (aDNA) in dental calculus from archaeological human remains. Journal Archaeological Sciences, 38: 1827-1831.

Pryor, J., Carr, C. (1995) Chapter 8: Basketry of Northern California Indians. Interpreting Style Hierarchies. In Carr, C. Neitzel, J.E. (Eds.) Style, Society and Person. Archaeological and Ethnological Perspectives. Plenum, New York.

R

Radini, A. (2016) Particles of Everyday Life: Past Diet and Living Conditions as Evidenced by Microdebris Entrapped in Human Dental Calculus: A Case Study from Medieval Leicester and Surrounding. PhD thesis, University of York, York.

Radini, A., Buckley, S., Rosas, A., Estalrrich, A., De La Rasilla, M., Hardy K. (2016) Neanderthals, trees and dental calculus: new evidence from El Sidrón. Antiquity, 90: 290-301.

Radini, A., Nikita, E. (2023) Beyond dirty teeth: Integrating dental calculus studies with osteoarchaeological parameters. Quaternary International, 653-654: 3-18.

Radini, A., Nikita, E., Buckley, S., Copeland, L., Hardy, K. (2017) Beyond food: the multiple pathways for inclusion of materials into ancient dental calculus. American Journal of Physical Anthropology, 162(63): 71-83.

Radini, A., Tromp, M. Beach, A., Tong, E., Speller, C., McCormick, M., Dudgeon, J.V., Collins, M.J., Rühli, F., Kröger, R., Warinner, C. (2019) Medieval women's early involvement in manuscript production suggested by lapis lazuli identification in dental calculus. Science Advances, 5(1): eaau7126.

Radini, A., Tromp, M., Beach, A., Tong, E., Speller, C., McCormick, M., Dudgeon, J.V., Collins, M.J., Rühli, F., Kröger, R., Warinner, C. (2019) Medieval women's early involvement in manuscript production suggested by lapis lazuli identification in dental calculus, Science Advances, 5: eaau7126.

Raftery, J. (1970) Prehistoric coiled basketry bags. Journal of the Royal Society of Antiquaries of Ireland, 100: 167-168.

Ramil-Rego, P., Aira, M.J., (1996) Caracterización de la vegetación en las sierras septentrionales de Galicia desde el final del Tardiglaciar. Botánica Macaronésica, 23: 255-269.

Ramil-Rego, P., Aira, M.J., Taboada, M.T. (1994) Análisis polínico y sedimentodológico de dos turberas en las Sierras Septentrionales de Galicia (NO de España). Revue de Paléobiologie, 13: 9-28.

Ramos, M. (2012) La Arqueología experimental (AE): para una mejor interpretación de los datos en Arqueología histórica, Anuario de Arqueología, 4: 73-104.

Rast-Eicher, A. (2005) Bast before wool: The first textiles. “Hallstatt Textiles”. British Archaeological Report International Series 1351, Oxford: 117-132

Rast-Eicher, A., Dietrich, A. (2015) Neolithische und bronzezeitliche Gewebe und Geflechte: Die Funde aus den Seeufersiedlungen im Kanton Zürich. Monographien der Kantonsarchäologie Zürich 46. Baudirektion Kanton Zürich, Amt für Raumentwicklung Archäologie und Denkmalpflege, Dübendorf. ISBN: 978-3-7965-5015-7.

Rast-Eicher, A., Karg, S., Bender Jørgensen, L. (2021) The use of local fibres for textiles at Neolithic Çatalhöyük. Antiquity, 95(383): 1-16.

Renfrew, F.N. (1973) Palaeoetnobotany, The Prehistoric Food Plants of the Near East and Europe. London.

Renssen, H., Seppä, H., Crosta, X., Goosse, H., Roche, D.M. (2012) Global characterization of the Holocene Thermal Maximum. Quaternary Science Reviews, 48: 7-19.

Revelles, J. (2023) Informe del análisis palinológico del yacimiento de “Cueva de los Murciélagos” (Albuñol, Granada, España). Palynological technical report.

Revelles, J., Antolín, F., Berihuete, M., Burjachs, F., Buxó, R., Caruso, L., López, O., Palomo, A., Piqué, R., Terradas, X. (2014) Landscape transformation and economic practices among the first farming societies in Lake Banyoles (Girona, Spain). Environmental Archaeology, 19(3): 298-310.

Revelles, J., Burjachs, F., Morera, N., Barceló, J.A., Berrocal. A., López-Bultó, O., Maichere, C., Le Baillye, M., Piqué, R., Palomo, A., Terradas, X. (2017) Use of space and site formation processes in a Neolithic lakeside settlement. Pollen and non-pollen palynomorphs spatial analysis in La Draga (Banyoles, NE Iberia). Journal of Archaeological Sciences, 81: 101-115.

Revelles, J., Burjachs, F., Palomo, A., Piqué, R., Iriarte, E., Pérez-Obiol, R., Terradas, X. (2018) Human-environment interaction during the Mesolithic-Neolithic transition in the NE Iberian Peninsula. Vegetation history, climate change and human impact during the Early-Middle Holocene in the Eastern Pre-Pyrenees. Quaternary Science Reviews, 184: 183-200.

Revelles, J., Burjachs, F., van Geel, B. (2016) Pollen and non-pollen palynomorphs from the Early Neolithic settlement of La Draga (Girona, Spain). Review of Palaeobototany and Palynology, 225: 1-20.

Revelles, J., Cho, S., Iriarte, E., Burjachs, F., Van Geel, B., Palomo, A., Piqué, R., Peña-Chocarro, L., Terradas, X. (2015) Mid-Holocene vegetation history and Neolithic land-use in the Lake Banyoles area (Girona, Spain). Palaeogeography, Palaeoclimatology, Palaeoecology, 435: 70-85.

Revelles, J., van Geel, B. (2016) Human impact and ecological changes in lakeshore environments. The contribution of non-pollen palynomorphs in Lake Banyoles (NE Iberia). Review of Palaeobototany and Palynology, 232: 81-97.

Reynolds, P.J. (1999) The nature of Experiment in Archaeology. In Hardig, A.F. (Ed.) Experiment and Design. Archaeological. Studies in honour of John Cole: 157-169.

Ribé, G. (1996) Espacio y territorio entre el neolítico antiguo y medio en la región del Penedès. Bases y resultados de un programa de investigación arqueológica espacial en la Catalunya litoral y prelitoral. Proceedings of the I Congreso del Neolítico en la Península Ibérica. Formación e implantación de las comunidades agrícolas. Rubricatum, 1: 379-390.

Richerson, P.J., Boyd, R., Bettinger, R.L. (2001) Was agriculture impossible during the Pleistocene but mandatory during the Holocene? A climate change hypothesis. American Antiquity, 66: 387-411.

Riede, F. (2014) Eruptions and ruptures – a social network perspective on vulnerability and impact of the Laacher See eruption (c. 13,000 BP) on Late Glacial hunter-gatherers in northern Europe. Archaeological Review from Cambridge, 29: 67-102.

Riehl, S. (2008) Climate and agriculture in the ancient Near East: A synthesis of the archaeobotanical and stable carbon isotope evidence. Vegetation History and Archaeobotany, 17: 43-51.

Riera, S., Esteban Amat, A. (1994) Vegetation history and human activity during the last 6000 years on the central Catalan coast (northeastern Iberian Peninsula). Vegetation History and Archaeobotany 3(1): 7-23.

Rigaud, A. (2001) Les bâtons percés : décors énigmatiques et fonction possible. Gallia préhistoire, 43: 101-151.

Riuró, F. (1942) La cueva de El Pasteral, Ampurias IV: 189-204.

Rivas Martínez, S. (1982) Étages bioclimatiques, secteurs chorologiques et séries de végetation de l‟Espagne méditerranéenne. Ecología Mediterránea VIII(1/2): 275-288.

Rivas-Martínez, S., Asensi, A., Díez, B., Molero, J., Valle, F. (1987) Biogeographical synthesis of Andalusia (southern Spain). Journal of Biogeography, 24: 915-928.

Rivas-Martínez, S., Penas, A., Díaz, T.E. (2004) Bioclimatic & Biogeographic Maps of Europe. Universidad de León, León. Available online: www.globalbioclimatics.org.

Roberts, N., Brayshaw, D., Kuzucuoglu, C., Pérez, R., Sadori, L. (2011) The mid-Holocene climatic transition in the Mediterranean: causes and consequences. The Holocene, 21(1): 3-13.

Roberts, N., Fyfe, R.M., Woodbridge, J., Gaillard, M-J., Davis, B.A.S. and 7 others (2018). Europe's lost forests: a pollen-based synthesis for the last 11,000 years. Scientific Reports, 8: 716.

Roig, J., Coll, J.M., Gibaja, J.F., Chambon, P., Villar, V., Ruiz, J., Terradas, X., Subirà, M.E. (2010) La necrópolis de Can Gambús-1 (Sabadell, Barcelona). Nuevos conocimientos sobre las prácticas funerarias durante el Neolítico medio en el noreste de la Península Ibérica. Trabajos de Prehistoria, 67(a): 59-84.

Roland, J.C., Reis, D., Vian, B., Row, S. (1989) The helicoidal plant cell wall as a performing cellulose-based composite. Biology of the Cell, 67: 209-220.

Roland, J.C., Reis, D., Vian, B., Satiat-Jeunemaitre, B., Mosiniak, M. (1987) Morphogenesis of plant cell walls at the supramolecular level: Internal geometry and versatility of helicoidal expression. Protoplasma, 140: 75-91.

Romero, A., Basso Rial, R.E., Jover Maestre, F.J., Herrero-Otal, M., Cuesta-Aguirre, D.R., Fiorin, E., Malgosa, A., de Miguel Ibáñez, M.P., López Padilla, J.A. (In press) Dental evidence of textile-related task activities in the Bronze Age site of Laderas del Castillo (Alicante, Spain). Journal of Archaeological Science Reports.

Romero-Brugués, S. (2021) Cordes i cistells elaborats amb fibres vegetals entre el 2300-800 cal BC al Nord-Est peninsular i Balears: Tecnología, materia prima i funció. PhD Dissertation. Universitat Autònoma de Barcelona, Bellaterra.

Romero-Brugués, S., Herrero-Otal, M., Piqué, R., Rosillo, R., Terradas, X., López-Bultó, O., Berrocal-Barberà, A., Palomo, A. (2021a) Los implementos elaborados con fibras vegetales del neolítico antiguo de Coves del Fem, Ulldemolins (Tarragona). Munibe-Arkeologia i Antropologia, 72: 43-56.

Romero-Brugués, S., Piqué Huerta, R., Herrero-Otal, M. (2021b) The basketry at the early neolithic site of La Draga (Banyoles). Journal of Archaeological Sciences Reports, 35: 102692.

Romero-Brugués, S., Piqué, R., Picornell-Gelabert, Ll., Calvo, M., Fullola Pericot, J.M. (2018) The Production and Use of Cordage in the Balearic Bronze Age: The Cova des Pas (Ferreries, Menorca). Environmental archaeology, 26(1): 1-9.

Romero-Brugués, S., Tzerpou, E., Herrero-Otal, M., Homs, A., López-Bultó, O., Bodganovic, I., Fanlo, J., Palomo, A., Piqué, R. (2022) Approach to plant craft techniques from the mat impressions on the bases of Early Bronze Age ceramic vessels: The case of Cova Fonda (Spain). Journal of Archaeological Science Reports, 43: 103472.

Rooijakkers, C.T. (2012) Spinning animal fibres at late Neolithic Tell Sabi Abyad, Syria? Paléorient, 38(1-2): 93-102.

Rosillo, R., Bogdanovic, I., Morera, N. (2019) Informe de intervenció arqueológica a les Coves del Fem – Ulldemolins (Priorat), campanya 2019. Archaeological technical report.

Rosillo, R., Herrero, M., Agustí, B., Palomo, A., Berrocal, A. (2021a) Intervenció arqueológica en el complex arqueològic de la Cova del Pasteral. Agost de 2021. Archaeological technical report.

Rosillo, R., Herrero, M., Palomo A., Agustí, B. (2021b) Intervenció arqueològica en el complex arqueològic de la Cova del Pasteral. Novembre de 2021. Archaeological technical report.

Rosillo, R., Herrero., Agustí, B., Palomo, A. (2023) Intervenció arqueològica en el complex arqueològic de la Cova del Pasteral. Excavation technical report.

Rots, V. (2008) Hafting and raw materials from animals. Guide to the identification of hafting traces on stone tools. Anthropozoologica, 43(1): 43-66.

Rovira, J. (2006) Las producciones cerámicas con impronta basal de estera vegetal del calcolítico final-bronce antiguo/medio de la Península Ibérica: acerca de la alternancia de influjos y el origen del protourbanismo en la depresión central catalana como modelo de territorio basculante. Quaderns de Prehistòria i d’Arqueologia de Castelló, 25: 109-137.

Rovira, N. (2007) Agricultura y gestión de los recursos vegetales en el sureste de la Península Ibérica durante la Prehistoria reciente. PhD Dissertation. Barcelona, Universitat Pompeu Fabra, Barcelona.

Ruddiman, W.F. (2003) The anthropogenic greenhouse era began thousands of years ago. Climatic Change, 61(3): 261-293.

Ruddiman, W.F. (2013) The Anthopocene. Annual Review of Earth and Planetary Sciences, 41: 45-68.

Ruddiman, W.F., Ellis, E.C., Kaplan, J.O., Fuller, D.Q. (2015) Defining the epoch we live in. Science, 348: 38-39.

Ruiz de Haro, M.I. (2012) Orígenes, evolución y contextos de la tecnología textil: la producción del tejido en la Prehistòria y la Protohistoria. En Arqueología y Territorio, 9: 133-145.

Ruiz-Medrano, R., Xoconostle-Cazáres, B., Lucas, W.L. (2001) The phloem as a conduit for inter-organ communication. Current Opinion in Plant Biology, 4: 202-209.

Ryan, P. (2011) Plants as material culture in the Near Eastern Neolithic: Perspectives from the silica skeleton artifactual remains at Çatalhöyük. Journal of Anthropological Archaeology, 30: 292-305.

S

Sachs, J. (1875) Text-book of Botany, Morphological and Physiological. Clarendon Press, Oxford.

Sadori, L., Narcisi, B. (2001) The Postglacial record of environmental history from Lago di Pergusa, Sicily. The Holocene 11(6): 655-671.

Saña, M. (2011) 12. La gestió dels recursos animals. In Bosch, A., Chinchilla, J., Tarrús, J. (Eds.) El poblat lacustre del neolític antic de La Draga. Excavacions 2000-2005, Monografies del CASC (9). Museu d’Arqueologia de Catalunya-CASC, Girona: 177-212.

Saña, M. (2013) Domestication of animals in the Iberian Peninsula. En Colledge S, Conolly J, Dobney K, Manning K, Shennan S (Eds.) The origins and spread of domestic animals in southwest Asia and Europe. Walnut Creek: Left Coast Press: 195-220.

Schick, T. (1988) Nahal Hemar Cave. Cordage, basketry and fabrics. Atiqot, 18: 31-43.

Schick, T. (2010) Basketry finds from Gilgal. In Bar-Yosef, O., Goring-Morris, A.N., Gopher, A. (Eds.) Gilgal Early Neolithic occupations in the Lower Jordan Valley: the excavations of Tamar Noy. Oxbow, Oakville: 254-250.

Schüle, W. (1980) Orce und Galera. Zwei Siedlungen aus dem 3.bis I. Jahrtausend v. Chr. im Südosten der Iberischen Halbinsel. I. Übersicht über die Ausgrabungen 1962-1970. Mainz. Verlag Philipp von Zabern.

Schulz, P.D. (1977) Task activity and anterior tooth grooving in Prehistoric California Indians. American Journal of Anthropology, 46: 87-92.

Schwendener, S. (1874) Das mechanische Princip in anatomischen Bau der Monocotylen mit vergleichenden Ausblicken auf die übrigen Pfl anzenklassen. Wilhelm Engelmann, Leipzig.

Scott, G.R., Jolie, R.B. (2008) Tooth-tool use and yarn production in Norse Greenland. Alaskan Journal of Anthropology, 6: 253-264.

Sheehan, D.C., Hrapchak, B.B. (1980) Bone. In Theory and Practice of Histotechnology. 2nd edition. Columbus: Battelle Press: 89-117.

Shoada, S., Tripathi, D., Uenaka, H., Murakami, N., Nishihara, K. (2024) Archaeobotany: Microscopic and Molecular Techniques. In Nikita, E., Rehren, T. (Eds.) Encyclopedia of Archaeology (Second Edition). Academic press: 708-716. ISBN: 9780323918565.

Siennicka, M., Rahmstorf, L., Ulanowska, A. (2018) 1 Introduction. In Siennicka, M., Rahmstorf, L., Ulanowska, A. First Textiles: The Beginnings of Textile Production in Europe and the Mediterranean: 1-16.

Simonneau, a., Doyen, E., Chapron, E., Millet, L., Vannière, B., Di Giovanni, C., Bossard, N., Tachikawa, K., Bard, E., Albéric, P., Desmet, M., Roux, G., Lajeunesse, P., Berger, J.F., Arnaud, F. (2013) Holocene land-use evolution and associated soil erosion in the French Prealps inferred from Lake Paladru sediments and archaeological evidences. Journal of Archaeological Science, 40(4):1636-1645.

Singh, R. (2016) Chemotaxonomy: a tool for plant classification. Journal of Medicinal Plants Studies, 4(2): 90-93.

Smith, B.D., Zeder, M.A. (2014) The onset of the Anthopocene. Anthropocene, 4: 8-13.

Soffer, O. (2004) Recovering perishable technologies through use wear on tools: preliminary evidence for upper palaeolithic weaving and net making. Current Anthropology, 45: 407–413.

Soffer, O., Adovasio, J.M., Hyland, D.C. (2000) The “Venus” figurines: textiles, basketry, gender and status in the Upper Paleolithic. Current Anthropology, 41(4): 511-537.

Soffer, O., Adovasio, J.M., Hyland, D.C. (2001) Perishable Technologies and Invisible People: Nets, Baskets and 'Venus' Wear ca. 26,000 BP. Conference on the Significance of the survival of Organic Materials from Archaeological contexts. Gainesville, Florida.

Solazzo, C., Walton Rogers, P., Weber, L., Beaubien, H.F., Wilson, J., Collins, M. (2014) Species identification by peptide mass fingerprinting (PMF) in fibre products preserved by association with copper-alloy artefacts. Journal of Archaeological Science, 49: 524-535.

Solecki, R. (1963) Prehistory in Shanidar Valley, Northern Iraq. Science, 139: 3551. Washington.

Soriano, M.D. (2000) El món de la cistelleria: un llenguatge universal: exposició, [16 al 31 de maig de 2000 a la Sala d'Exposicions de la Delegació del CSIC a Catalunya]. Residència d'Investigadors CSIC-Generalitat de Catalunya.

Sos Baynat, V. (1962) Los ídolos-placas de Granja Céspedes (Badajoz). Badajoz: Diputación Provincial de Badajoz, Institución de Servicios Culturales.

Soto, M. (2015) Mimbres y tiempo. Estudio lingüístico-etnográfico de la cestería granadina. Revista de estudios filológicos 29. Universidad de Granada: 1-29.

Soto, M., Inwood, J., Clarke, S., Crowther, A., Covelli, D., Favreau, J., Itambu, M., Larter, S., Lee, P., Lozano, M., Maley, J., Mwambwiga, A., Patalano, R., Sammynaiken, R., Vergès, J.M., Zhu, J., Mercader, J. (2019) Structural characterization and decontamination of dental calculus for ancient starch research. Archaeolical and Anthropological Sciences, 11: 4847-4872.

Sperduti, A., Giuliani, M.R., Guida, G., Petrone, P.P., Rossi, P.F., Vaccaro, S., Frayer, D.W., Bondioli, L. (2018) Tooth grooves, occlusal striations, dental calculus, and evidence for fiber processing in an Italian eneolithic/bronze age cemetery. American Jorunal of Physical Anthropology, 167: 234-243.

Spindler, K. (1995) El hombre de los hielos. Círculo de Lectores. Barcelona.

Staubwasser, M., Weiss, H. (2006) Holocene climate and cultural evolution in the late prehistoric-early historic West Asia. Quaternary Research, 66: 372-387.

Stika, H.P. (2005) Early Neolithic agriculture in Ambrona, Prov. Soria, central Spain. Vegetation History and Archaeobotany 14: 189-197.

Stone, E.A. (2009) Wear on Magdalenian bone tools: a new methodology for studying evidence of fiber industries. In Andersson Strand, E.B., Gleba, M., Mannering, U., Munkholt, Ch., Ringgard, M. (Eds.) North European Symposium for Archaeological Textiles, 10(37): 225-232.

Styles, B.W., Ahler, S.R., Fowler, M.L. (1983) Modoc Rock Shelter Revisited. In Phillips, J. L., Brown, J.A. (Eds.) Archaic Hunter-Gatherers in the American Midwest. Academic Press. Nova York: 261-297.

Suomela, J.A., Vajanto, K., Räisänen, R. (2018) Seeking nettle textiles - Utilizing a combination of microscopic methods for fibre identification. Studies in Conservation, 63(7): 412-422.

T

Tarrús, J. (2008) La Draga (Banyoles, Catalunya), un poblat lacustre del neolític antic a l'Europa mediterrània. Catalan Historical Review, 1: 171-182.

Terradas, X., Gibaja, J.F., Borrell, F., Bosch, J., Palomo A. (2016) Des réseaux d'échanges entre les vallées du Rhône et de l'Èbre: un point de vue du nord-est de la péninsule Ibérique. In Perrin, T., Chambon, C., Gibaja, J.F., Goude, G. (Eds.) Le Chasséen, des Chasséens... Retour sur une culture nationale et ses parallèles, Sepulcres de fossa, Cortalloid, Lagozza. Archives d'Écologie Préhistorique. Toulouse: 191-202.

Terradas, X., Piqué, R., Palomo, A., Antolín, F., López, O., Revelles, J., Buxó, R. (2017) Chapter 8: Farming Practices in the Early Neolithic According to Agricultural Tools: Evidence from La Draga Site (Northeastern Iberia). In García-Puchol, O., Salazar-García, D.C. (Eds.) Times of Neolithic Transition along the Western Mediterranean, Fundamental Issues in Archaeology. ISBN: 978-3-319-52937-0.

Testart, A. (1982) The significance of food storage among hunter-gatherers: residence, patterns, population densities and social inequalities. Current Anthropology, 23: 523-537.

Theobald, W.L., Krahulik, J.L., Roolins, R.C. (1979) Trichome description and classifi cation. In Metcalfe, C.R., Chalk, L (Eds.) Anatomy of the Dicotyledons, 2nd ed., vol. I, Systematic Anatomy of Leaf and Stem, with a Brief History of the Subject, Clarendon Press, Oxford: 40-53.

Thomas, J. (1988) Neolithic explanations revisited: the mesolithic-neolithic transition in Britain and South Scandinavia. Proceeding of the Prehistoric Society, 54: 59-66.

Thompson, G.A., Schulz, A. (1999). Macromolecular trafficcking in the phloem. Trends Plant Sciences, 4: 354-360.

Tinner, W., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, V., van der Knaap, V.O., Henne, P.D., Pasta, S., D'Angelo, S., La Mantia, T. (2009) Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. Quaternary Science Reviews, 28: 1498-1510.

Tobler, F. (1957) Die mechanischen Elemente und das mechanische System. Handbuch der Pfl anzenanatomie, 2nd ed., Band 4, Teil 6, Histologie. Gebrüder Borntraeger, Berlin-Nikolassee.

Tomlinson, P.B (1961) Anatomy of the Monocotyledons. 2. Palmae. Clarendon Press, Oxford.

Trimborn, P., Becker, B., Kromer, B., Lipp, J. (1995) Stable isotopes in tree rings: a palaeoclimatic tool for studying climatic change. In Frenzel, B., Stauffer, B., Weiss, M.M. (Eds.) Problems of stable isotopes in tree-rings, lake sediments and peat-bogs as climatic evidence for the Holocene Palaeoclimate Research. Strasbourg: European Science Foundation: 163-170.

Troll, W. (1954) Praktische Einführung in die Pfl anzenmorphologie, vol. 1, Der vegetative Aufbau. Gustav Fischer, Jena.

Tromp, M., Buckley, H., Geber, J., Matisoo-Smith, E. (2017) EDTA decalcification of dental calculus as an alternate means of microparticle extraction from archaeological samples. J. Archaeol. Sci.: Reports, 14: 461-466.

Tutin, T.G., Hetwood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M., Webb, D.A. (1980) Flora europaea. Cambridge University Press. Cambridge.

U

Uphof, J.C., Humel, K. (1962) Plant Hairs. Encyclopedia of Plant Anatomy, Band 4, Teil 5. Gebrüder Borntraeger, Berlin.

Utrilla, P., Montes, L. (2009) El Mesolítico geométrico en la Península Ibérica. Universidad de Zaragoza, Departamento de Ciencias de la Antigüedad, Zaragoza.

V

Valoch, K. (2007) Textile in the Upper Palaeolithic? Some notes on the matter. Archeologické rozhledy, 59: 143-154.

Van Bel, A.J.E., Gaupels, F. (2004) Pathogen-induced resistance and alarm signals in the phloem. Molecular Plant Pathology, 5: 495-504.

van der Knaap, E.O., van Leeuwen, J.F.N. (1995) Holocene vegetation succession and degradation as responses to climatic change and human activity in the Serra de Estrela, Portufal, Review of Palaeobotany and Palynology, 89: 153-211.

Vannière, B., Colombaroli, D., Chaprone, E., Leroux, A., Tinner, W., Magny, M. (2008) Climate versus human-driven fire regimes in Mediterranean landscapes: the Holocene record of Lago dell'Accesa (Tuscany, Italy). Quaternaty Sciences Reviews, 21: 1181-1196.

Veldmeijer, A.J. (2009) Cordage production. In Wendrich, W., Dieleman, J., Frood, E., Baines, J. (Eds.) UCLA Encyclopedia of Egiptology. Los Angeles.

Verde, A., Rivera, D., Obón, C. (1998) Etnobotánica en la sierras de Segura y Alcaraz: las plantas y el hombre. Instituto de Estudios Albacetenses. Albacete.

Vescovi, E., ammann, B., Ravazzi, C., Tinner, W. (2010) A new Late-glacial and Holocene record of vegetation and fire history from Lago del Greppo, northern Apennines, Italy. Vegetation History and Archaeobotany, 19: 219-233.

Vidal-Matutano, P., Palomo, A., Pardo-Gordó, S., Wojtczak, D., Rodríguez Rodríguez, A., Carballo-Pérez, J., Brito-Abrante, I., Melián, K. (2024) Shaping wood in the Canary Islands:

First experimental dataset focused on tool marks of Prehispanic wooden artifacts. Journal of Archaeological Science: Reports, 57: 104661.

Vilà Valentí, J. (1962) El campus spartarius. Homenaje al profesor Cayetano de Mergelina. Murcia, 196 1-62: 837-844.

Viotti, C., Albrecht, K., Amaducci, S., Bardos, P., Bertheau, C., Blaudez, D., Bothe, L., Cazaux, D., Ferrarini, A., Govilas, J., Gusovius, HJ., Jeannin, T., Lühr, C., Müssig, J., Pilla, M., Placet, V., Puschenreiter, M., Tognacchini, A., Yung, L., Chalot, M. (2022) Nettle, a Long-Known Fiber Plant with New Perspectives. Materials, 15: 4288.

Vydal, G., Hormazábal, S. (2016) Las fibras vegetales y sus aplicaciones. Innovación en su generación a partir de la depuración de agua. Grupo de Ingeniería y Biotecnología Ambiental (GIBA-UDE). Facultad de Ciencias Ambientales. Universidad de Concepción. Chile.

W

Walker, M.J. (1990) El Prado de Jumilla y el problema de la cerámica de cestería del Eneolítico del Sureste peninsular. In Homenaje a Jerónimo Molina García, Academia Alfonso X el Sabio, Caja Murcia, Murcia: 73-86.

Walker, M.J.C., Berkelhammer, M., Björck, S., Cwynar, L.C., Fisher, D.A., Long, A.J., Lowe, J.J., Newnham, R.M., Rasmussen, S.O., Weiss, H. (2012) Formal subdivision of the Holocene Series/Epoch: a Discussion Paper by a Working Group of INTIMATE (integration of ice-core, marine and terrestrial records) and the Subcomission on Quaternary Stratigraphy (International Commission on Stratigraphy). Journal of Quaternary Science, 27(7): 649-659.

Wallace, M., Jones, G., Charles, M., Fraser, R., Halstead, P., Heaton, T. H. E., Bogaard, A. (2013) Stable carbon isotope analysis as a direct means of inferring crop water status and water management practices. World Archaeology, 45: 388-409.

Wallace, M.P., Jones, G., Charles, M., Fraser, R., Heaton, T.H.E., Bogaard, A. (2015) Stable carbon isotope evidence for neolithic and bronze age crop water management in the eastern Mediterranean and southwest Asia. PLoS One, 10: 1-19.

Wang, C.G., Xi, X.Y. (1992) Structure of embryo sac before and after fertilization and distribution of transfer cells in ovules of green gram. Acta Botanica Sinica, 34: 496-501.

Wanner, H., Solomina, O., Grosjean, M., Ritz, S.P., Jetel, M. (2011) Structure and origin of Holocene cold events. Quaternary Science Reviews, 30: 3109-3123.

Warinner, C., Rodrigues, J.F., Vyas, R., Trachsel, C., Shved, N., Grossmann, J., Radini, A., Hancock, Y., Tito, R.Y., Fiddyment, S., Speller, C., Hendy, J., Charlton, S., Luder, H.U., Salazar-García, D.C., Eppler, E., Seiler, R., Hansen, L.H., Castruita, J.A., Barkow-Oesterreicher, S., Teoh, K.Y., Kelstrup, C.D., Olsen, J.V., Nanni, P., Kawai, T., Willerslev, E., von Mering, C., Lewis, C.M. Jr., Collins, M.J., Gilbert, M.T., Rühli, F., Cappellini, E. (2014)

Pathogens and host immunity in the ancient human oral cavity. Nature Genetics, 46(4): 336-44.

Watson, W. (1991) Pre-Tang Ceramics of China: Chinese Pottery from 4000 B.C. to 600 A.D. London, Faber and Faber. ISBN: 0571154336.

Wendrich, W. (1989) Preliminary report on the Amarna basketry and cordage. A: Kemp, B. K. (ed.). Amarna Reports V. Egypt exploration Society. Londres: 169-201.

Wendrich, W. (1991) Who is afraid of basketry? A guide to recording basketry and cordage for archaeologists and ethnographers. Centre of Non-Western Studies. Leiden University, Leiden.

Wendrich, W. (1999) The world according to basketry. An ethno-archaeological interpretation of basketry production in Egypt. The Cotsen Institute of Archaeology at UCLA. Los Angeles.

Wendrich, W. (2016) Basketry in Ancient Egypt. In Helaine, S. (Ed.) Encyclopaedia of the History of Science, Technology and Medicine in Non-Western Cultures.

Wendrich, W., Holdaway, S. (2018) Basket use, raw materials and arguments on early and Middle Holocene mobility in the Fayum, Egypt. Quaternary International, 468: 240-249.

Wendrich, W., Holdaway, S.J., Phillips, R., Emmitt, J.J. (2017) The K basin archaeological record. In Holdaway, S.J., Wendrich, W. (Eds.) The desert Fayum reinvestigated: the early to mid-Holocene landscape archaeology of the Fayum North Shore, Egypt. Monumenta Archaeologica 39. UCLA Cotsen Institute of Archaeology Press, Los Angeles: 99-164.

Wendrich, W., Ryan, P. (2012) Phytoliths and Basketry Materials at Çatalhöyük (Turkey): Timelines of growth, harvest and objects life histories. Paléorient, 38(1-2): 55-63.

Weninger, B., Alram, E., Bauer, E., Clare, L., Danzeglocke, U., Jöris, O., Kubatzki, C., Rollefson, G., Todorova, H., Andel, T. (2006) Climate Forcing Due to the 8200 Cal yr BP Event Observed at Early Neolithic Sites in the Eastern Mediterranean. Quaternary Research, 66: 401-420.

Weninger, B., Clare, L., Rohling, E., Bar-Yosef, O., Böhner, U., Budja, M., Bundschuh, M., Feurdean, A., Gebel, H., Jöris, O., Linstädter, J., Mayewski, P., Mühlenbruch, T., Reingruber, A., Rollefson, G., Schyle, D., Thissen, L., Todorova, H., Zielhofer, C. (2009) The Impact of Rapid Climate Change on Prehistoric Societies during the Holocene in the Eastern Mediterranean. Documenta Praehistorica, 902.

Wescott, D. (1999) Gathering and preparing plant fibers. In Wescott, D. (ed.) Primitive technology. A book of Earth Skills, from the Society of Primitive Technology. Gibbs Smith Publisher. Salt Lake City: 140143.

Whallon, R. (2006) Social networks and information: Non-“utilitarian” mobility among hunter-gatherers. Journal of Anthropological Archaeology, 25: 259-270.

White, J.W.C., Ciais, P., Figge, R.A., Kenny, R., Markgraf, V. (1994) A high resolution record of atmospheric CO2 content from carbon isotopes in peat. Nature, 367: 153-156.

Wigforss, E. (2014) Perished material-vanished people. Understanding variation in Upper Paleolithic/Mesolithic textiles technologies, Department of Archaeology and Ancient History, Lund Universitet.

Willman, J.C., Valera, A.C., Silva, A.M. (2021) The embodiment of craft production in Bronze Age Portugal: Exceptional dental wear grooves in an individual from Monte do Vale do Ouro 2 (Ferreira do Alentejo, Portugal). International Journal of Osteoarchaeology, 31(2): 252-262.

Wobst, H.M. (1974) Boundary conditions for Paleolithic social systems: a simulation approach. American Antiquity, 39: 147-178.

Woodbridge, J., Fyfe, R.M., Roberts, N., Downey, S., Edinborough, K., Shennan, S. (2012) The impact of the Neolithic agricultural transition in Britain: a comparison of pollen based land-cover and archaeological 14C date-inferred population change. Journal of Archaeological Sciences, 51: 216-224.

Wright, S.L., Dobney, K., Weyrich, L.S. (2021) Advancing and refining archaeological dental calculus research using multiomic frameworks. Science and Technology of Archaeological Research, 7: 13-30.

Y

Yll, E.I., Carrión, J.S., Pantaleón, J., Dupré, M., La Roca, N., Roure, J.M., Pérez, Obiol, R. (2003) Palinologia del Cuaternatio reciente en la Laguna de Villena (Alicante). Anales de Biología, 25: 65-72.

Yll, R., Roure, J.M., Pantaleóncano, J., Pérez Obiol, R. (1994) Análisis polínico de una secuencia holocénica en Roquetas de Mar (Almería). In M. Dupré, M.E. Burgaz, I. Mateu, J. Güemes (Coords.): Trabajos de palinología básica y aplicada. X Simposio de Palinología. Universitat de València, València: 189-198.

Z

Zhang, J., Lu, H., Sun, G., Flad, R., Wu, N., Huan, X., He, K., Wang, Y. (2016) Phytoliths reveal the earliest fine reedy textile in China at the Tianluoshan site. Scientific Reports, 6: 18664.

Zhushchikhovskaya, I. (2007) Jommon pottery: cord-imitating decoration. Documenta Praehistorica, 34: 21-29.

Zilhão, J. (2001) Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. Proceedings of the National Academy of Sciences, 98: 14180.

Zohary, D. (2020) Domestication of the Southwest Asian Neolithic crop assemblage of cereals, pulses, and flax: The evidence from the living plants. The Emergence of Agriculture. Routledge: 197-216.

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Romero-Brugués, S., Herrero-Otal, M., Piqué, R., Rosillo, R., Terradas, X., López-Bultó, O., Berrocal-Barberà, A., Palomo, A. (2021) “Los implementos elaborados con fibras vegetales del neolítico antiguo de Coves del Fem, Ulldemolins (Tarragona)”. Antropolgia-Arkeologia, 72: 43-56. DOI: 10.21630/maa.2021.72.14.