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Pyre wood fuel and food remains in a necropolis of Barcino (Barcelona, NE Iberian Peninsula): The case of Sant Antoni Market site (1st century CE)

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ABSTRACT

Funerary cremations in Roman times were important rites of passage that involved the use of fire to accompany the dead into the afterlife. In the present study, we investigated the wood fuel that was used to build cremation pyres and the foodstuffs involved in offerings and funerary feasts in a necropolis of Barcino (present-day Barcelona), dated to the 1st century CE and located at the Sant Antoni Market site. Our approach began with the analysis of wood charcoal and fruit/seed remains, which were preserved over time through carbonisation. These archaeobotanical remains offer valuable insights into the selection of woody species and the condition of wood logs used for cremations. Additionally, they shed light on the food composition of offerings and feasts in this area of the Mediterranean coast, where data on such practices are scarce.

The anthracological analysis of different combustion structures revealed that the principal taxon used for the stacks was evergreen oak, with deciduous oak playing a significant role during the initial use of the necropolis. Dendro-anthracological analysis indicated that medium to large diameters wood logs of deciduous oak obtained from mature individuals were commonly employed. Moreover, charcoal analysis suggested the use of pruning remains from fruit trees such as olive, grapevine, walnut, plums, and members of the apple family, providing evidence of arboriculture practices in the city. Additionally, various minor woody species (Aleppo and mountain pines, juniper, cypress, mastic, and rockroses) may have had several functions, including symbolic sensory aspects relating to smell and good flammability, the constitution of small objects or furniture placed on the stack (boxwood), and fire kindling or decoration (mastic, rockroses, honeysuckle, and laurustinus).

Carpological analysis indicated that the most abundant offerings and/or feast remains consisted primarily of cultivated fruits such as figs, walnuts, and grapes, while pulses and cereals were comparatively scarce or absent. Finally, a noteworthy quantity of *Arbutus* berry remains was recorded, marking the first occurrence of such findings in similar Roman contexts to date.

1. Introduction

Death represented a natural part of life in Roman times, and consequently, funerary rituals (defined as *funus* in Latin) implied specific

practices strongly related to cultural identity and beliefs associated with the deceased from the time of death to the burial (Hope, 2007). These ceremonies were essential to purify the individual's soul, which was polluted by the act of death, and to transfer it from the world of the

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living to the afterlife. Moreover, *funus* represented an important moment for the family of the deceased, who had the occasion to honour, mourn, commemorate him/her, and eventually display their wealth and social status (Cerezo-Román and Williams, 2014; Hope, 2007; Toynbee, 1971).

Up to the second half of the 2nd century CE, both inhumation, cremation, and, albeit rarely, embalment rites were carried out in the Italic peninsula and western provinces of the Roman Empire, apparently based on personal choice and economic possibilities. Thereafter, with the spread of Christianity, inhumation overtook other practices (Noy, 2000a; Toynbee, 1971).

Individual cremation was the most honourable burial ritual, though it was generally restricted to the wealthiest families, who could afford to pay for one of the most costly elements of the pyre: the wood fuel (Pearce et al., 2000). Cremation implied a long process that could last from sunrise to nightfall, according to the time necessary to reduce the human body to ashes and bone fragments. It was normally accompanied by a funerary feast (*silicernum*) attended by members of the family, during which food was offered to the gods, the dead, and the people thusly reunited (Livarda, 2013; Noy, 2000a, 2000b). Hence, these practices were imbued with symbolic meaning; the appearance, constituents, and size of the pyre were a sign of the deceased's wealth and status.

Written and iconographical evidence describing the performance of cremations in Classical Antiquity is abundant, though the details are often scant and/or refer primarily to exceptional events or prominent figures (Cenzon-Salvayre, 2014; Noy, 2000a; Toynbee, 1971). In this regard, the contribution of archaeology and physical anthropology (Duday and Masset, 1987) have proven crucial in increasing our understanding of these practices in different parts of the Empire. In particular, carbonised cremation remains have great potential for shedding light on the food and wood involved, as carbonisation ensures the preservation in sediment of such perishable organic material.

Despite the archaeobotanical richness of these contexts, however, studies of Roman necropolises are limited, and sampling protocols are not widely integrated in the archaeological practice. Nevertheless, recent years have seen a growing interest in bioarchaeological research on rituals and religion (Livarda and Madgwick, 2018; Lodwick and Rowan, 2022). For instance, there were case studies of funerary food and fuel in Italy (Caracuta and Fiorentino, 2018; Castiglioni et al., 1992; Riso, 2020, 2023; Rottoli and Castiglioni, 2011) and Pompeii (Coubay, 2013; Matteredne and Derreumaux, 2007); Croatia (Reed et al., 2019, 2019oštarić et al., 2006); Bulgaria (Hristova, 2015); France (Bouby and Marinval, 2004; Cenzon-Salvayre, 2014; Cenzon-Salvayre and Durand, 2017; Fabre et al., 2003; Figueiral et al., 2010b, 2017; Marinval, 1993; Preiss et al., 2005); Germany (Kreuz, 2000); Belgium (Cooremans, 2008; Deforce and Haneca, 2012); and Great Britain (Challinor, 2006). In the Iberian Peninsula, published archaeobotanical studies of Roman cremation sites are limited to Portugal (Costa Vaz et al., 2021), north-west Spain (Martín-Sejido and César Vila, 2019) and central Spain (Saelices, Cuenca; Cebrián Fernández and Hortelano, 2016), while in Barcelona, sporadic archaeobotanical studies were carried out in the necropolis located at Drassanes Reials (1st–2nd centuries CE; Piqué i Huerta and Ferré Trias, 2015) and Vila de Madrid Square (2nd–3rd centuries CE; Beltrán de Heredia Bercero et al., 2007). However, these have provided limited archaeobotanical data.

The present study aimed to improve our knowledge of pyre wood-fuel supplies and the foodstuffs involved in funerary practices in the Roman colony of *Barcino* (current Barcelona), beginning with the extensive archaeobotanical analysis of charcoal and seed/fruit remains sampled at the necropolis of Sant Antoni Market (Hinojo García, 2020, Figs. 1 and 2).

First, through the taxonomical identification of charcoal fragments, we aimed to examine the availability of regional wood and possible wood selection practices that may have been carried out for firing the

pyres, in comparison with the urban fuel used for productive and domestic activities at *Barcino* (Bianco et al., 2023). Secondly, we sought to gather other qualitative information about wood fuel remains (i.e., charcoal fragments), for example, the diameters of the logs and wood growing conditions (dry, green, debarked or not, and so on), to better understand the structuration of the pyres and wood gathering practices. Thirdly, we wished to shed light on the foodstuffs used in funerary feasts by analysing fruit/seed macro-remains carbonised during cremation, thereby providing valuable information about the socio-cultural dimension of food and particular customs in Mediterranean ritual contexts, a subject that has not been widely explored.

2. Geographic setting and archaeological context

The city of Barcelona is located on a littoral plain that extends from sea level to 125 m.a.s.l., between the Llobregat and Besòs rivers, on the central coast of Catalonia. The plain, formed during the Pleistocene and Holocene, is delimited in the north-east by a littoral mountain range constituted of a Paleozoic phyllite and granite outcrop (Serra de Collserola), which reaches its maximum altitude at 512 m.a.s.l. The maritime side of the Collserola range is characterised by several aligned calcareous elevations (*turons* in Catalan) of around 200 m.a.s.l., whereas the plain nearer to the coast is characterised by Miocene littoral hills such as Montjuïc and *Mons Taber* (Ventanyol, 2000; Riera Mora et al., 2020a).

The area presents a Meso-Mediterranean climate (Rivas-Martínez, 1982), with 620 mm of mean annual precipitation, 12–19 °C mean annual temperatures (AEMET – Barcelona Fabra station), and summer droughts. *Quercetum ilicis galloprovinciale* (holm oak woodland) is the principal plant community (*Quercus ilex*, *Arbutus unedo*, *Viburnum tinus*, *Lonicera implexa*, *Rhamnus alaternus*, *Phillyrea latifolia*, amongst others species), while in some areas in the northern shadowy valley of Collserola, a humid variant of holm oak woodland is present, with the presence of deciduous *Quercus pubescens* and *Quercus cerrioides* (the community of *Quercetum ilicis galloprovinciale* subsp. *Cerrioidetosum*; Fig. 1).

The Roman necropolis of Sant Antoni Market is located within the urban structure of the current city of Barcelona, in the Eixample neighbourhood. In Roman times, this space was a suburban area included in the territory (*ager centuriatus*) controlled by the colony of *Barcino*, which was founded between the years 15 and 9 BCE (Figs. 1 and 2; Granados, 1991).

The archaeological remains of this necropolis were documented as a result of an archaeological rescue intervention carried out on the occasion of the remodelling of works in the basement of the market (2012–2017; Hinojo García, 2020). This made it possible to detect, among others, Roman structures such as a water channel perpendicular to a 50 m section of a main road (*Via Augusta*) with 14 open-air quadrangular and rectangular funerary enclosures aligned along both sides (Fig. 3).

The necropolis had functioned since the beginning of the 1st century CE and it was later abandoned after a flood episode at the end of the same century. A total of 13 inhumations and seven cremation burials - in pit or urn - were identified in the excavated area. Archaeologists suggest that there must have been many more, as the funerary space seemed greater than the excavated area below the market (Hinojo García, 2020).

Cremations were generally carried out on pyres built in dedicated spaces inside enclosures. After each cremation, remains of bones, funerary goods, and some charcoal fragments were moved to a burial pit or urn (i.e., a secondary deposition). In certain rarer cases, the deceased was cremated and subsequently buried where the pyre was settled (i.e., a primary deposition). In the first case, the cremation area was called *ustrinum* and in the second one, *bustum* (Hinojo García, 2020; Miró Alaix and Hinojo García, 2021; Nadal Roma, 2015). Differentiation of

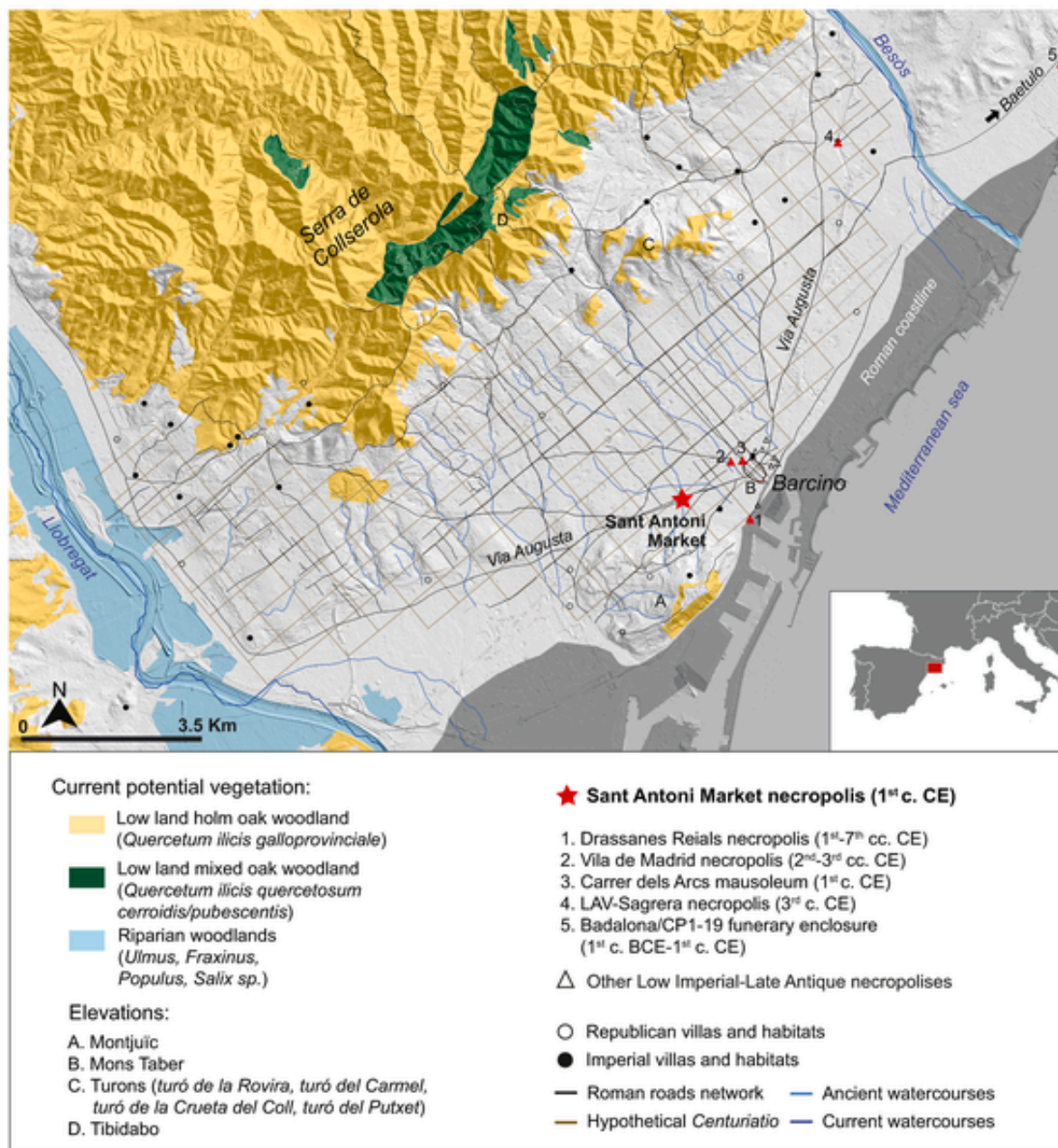


Fig. 1. The territory of Barcino, showing current potential vegetation associated with Roman settlements, funerary areas, roads, and watercourses (DTM base map obtained from <https://www.icgc.cat/>, Catalan Vegetation Map from Carrillo et al., 2018, archaeological data from Beltrán de Heredia Bercero, 2010a, 2007; Guasch Dalmau et al., 1996; Hinojo García, 2020; Miró and Ramos, 2013; Nadal Roma, 2015; Palet i Martínez, 1997; Palet i Martínez et al., 2021; Peña Cervantes and Miró Alaix, 2017; Soberón, 2020 and <http://cartaarqueologica.bcn.cat/>).

these two ritual practices is important to correctly interpret the archaeobotanical remains. In the case of *ustrinum*, charcoal and seed/fruits debris probably resulted from pyre cremations reiterated over time (see Angelucci, 2008), while in the case of *bustum*, remains may have resulted from a single pyre-burning event. At the Sant Antoni Market necropolis, nine *ustrina* (not to be confused with the cremation burials) and two *busta* were documented during the archaeological excavation (Fig. 4, Hinojo García, 2020).

Examples of Roman funerary cremations have also been found in the suburban area of Barcino, for example, at Dels Arcs Street (*ustrinum*; Beltrán de Heredia Bercero, 2010a, 2010b; Miró Alaix and Hinojo García, 2021) and Villa de Madrid Square (*busta*; Beltrán de Heredia

Bercero, 2007; Jordana Comín and Malgosa Morera, 2007), whereas at the necropolis of Drassanes Reials, only secondary deposition cremations (plausibly obtained through an *ustrinum*) were documented (Nadal Roma, 2015). Recently, a monumental *ustrinum* was identified in a necropolis in the nearby town of Baetulo (present-day Badalona; Soberón, 2020, pp. 38–43). However, up until now, archaeobotanical analyses have only been carried out at the Drassanes Reials site, considering a small assemblage of 63 charcoal fragments and 115 carpological remains proceeding from secondary depositions (funerary urns/pits; Piqué i Huerta and Ferré Trías, 2015), and at Vila de Madrid, from where 19 carpological remains and pollen samples from circulation lay-

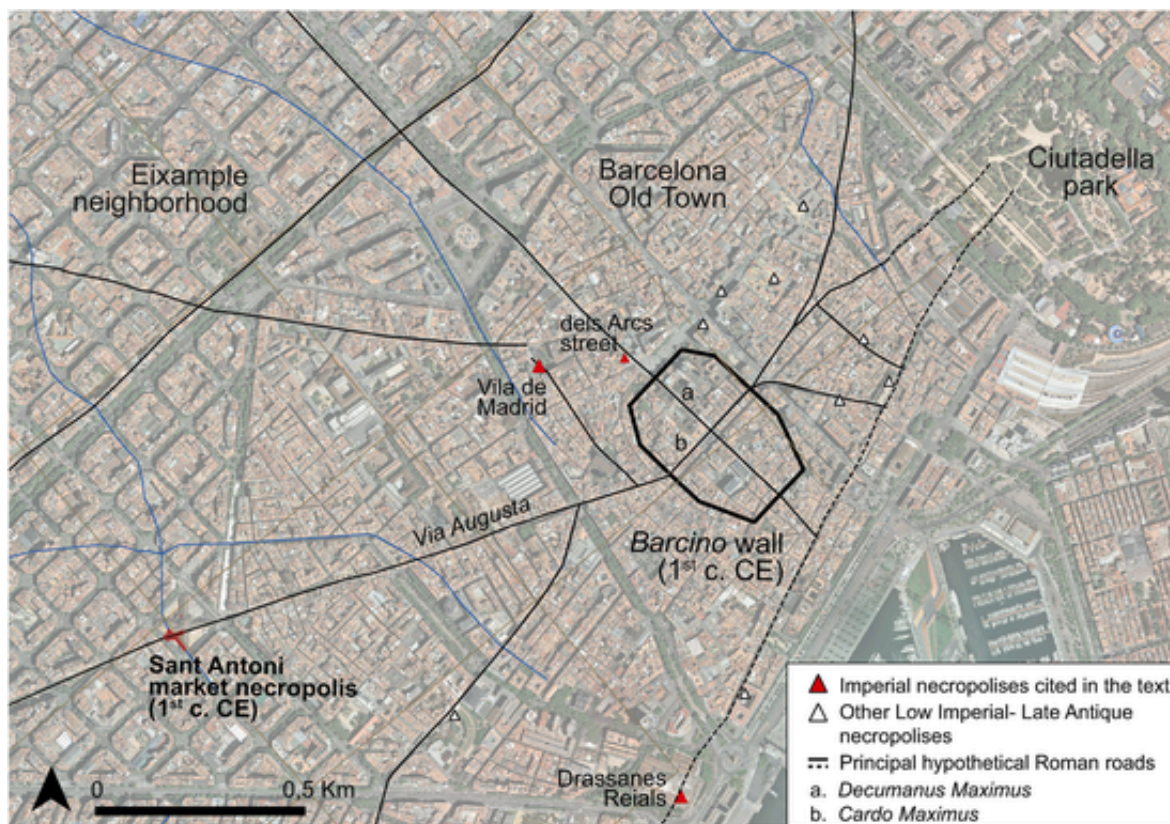


Fig. 2. Orthophoto of the current city of Barcelona (<https://www.icgc.cat/>), the perimeter of the Roman city of Barcino, the ancient road network and locations of the necropolis cited in the text.

ers of the funerary enclosure were analysed (Beltrán de Heredia Bercero et al., 2007, Fig. 1–2).

In this context, the present study provides a large set of new archaeobotanical data from *ustrina* and *busta* at the necropolis of Sant Antoni Market with the aim of improving our knowledge about the wood composition of pyres and the foodstuffs used in funerary rituals during the High-Imperial period in Barcino.

Furthermore, archaeological investigations of cremation structures at the Sant Antoni Market yielded fragments of at least eight funerary beds, (*lecti funebris*) bone decorations, and metallic elements (Hinojo García, 2020; Miró Alaix and Hinojo García, 2021; Pellejero, 2016). These pieces of furniture, probably composed of a wooden and metal core covered by lathe-worked and carved parts made of ivory or bone were used to publicly exhibit the deceased (*collocatio*) and transport the body to the necropolis (*funus traslaticium*), whereupon they were placed on the pyre for the cremation (*crematio*; Miró Alaix and Hinojo García, 2021; Pellejero, 2016). Funerary beds were frequent appanages of the Roman high-middle classes from the 2nd century BCE to the end of the 1st century CE, primarily produced and traded in and from the area of the central Italic peninsula (Bianchi, 2010). In Iberia, bone fragments of funerary beds were documented in several cities (e.g., Valencia, Tarragona, and Empúries; Lasheras González, 2015; Martínez Pérez, 2016). They have also been recorded at the necropolis of Drassanes Reials in the suburban area of Barcino (Nadal Roma and Pellejero, 2015). Nevertheless, the decorated bone fragments from Sant Antoni Market represent, up until now, the best assemblage in terms of abundance and variety of decorative motifs (Miró Alaix and Hinojo García, 2021).

It must, therefore, be borne in mind that charcoal debris from cremations might also include remains of wooden furniture along with fuel. Anthracological analysis may provide valuable data about the species used to elaborate the wooden sections of funerary beds.

3. Material and methods

Archaeobotanical analyses of macro-remains (i.e., charcoal and fruits/seeds) were carried out on samples obtained through water flotation of recovered archaeological sediments from different funerary enclosures (FEs). In particular, various quantities of sediment were collected by archaeologists during the excavation process and stored at the Archaeological Archive of the History Museum of Barcelona – Conservation and Restoration Centre (MUHBA, Zona Franca). In 2021, these samples were processed through manual bulk-water flotation and sieved through 2, 1, and 0.5 mm meshes column to extract charcoal and the seed/fruit remains. A total of 1199 L of sediment from 28 SU were processed (Table 1).

The chronology and phases of the macrobotanical remains were based on archaeological stratigraphic sequences and the material culture typology (Hinojo García, 2020). Three phases - Phase 1 (first half of the 1st century), Phase 2 (middle of the 1st century), and Phase 3 (second half of the 1st century) - are in line with successive remodelling processes archaeologically documented inside the necropolis.

The sector expanding southwards of the *Via Augusta* provided more sediment than the northern area. Archaeobotanical samples were obtained principally from concentrated deposits, namely, *in situ* organic material depositions in rectangular depressions, probably resulting from single (*bustum*) or multiple (*ustrinum*) cremation events. However, *ustrina* were probably cleaned of debris before the construction of new pyres, as documented at the necropolis of *Olisipo* (Lisbon, Portugal; Angelucci, 2008). Hence, establishing whether the anthracological and carpological assemblages were the result of a single or various cremation events was not possible without specific soil micromorphological analyses.

Despite these limitations, the analysis of chronologically different *ustrina* and *busta* from the same necropolis has allowed us to shed light

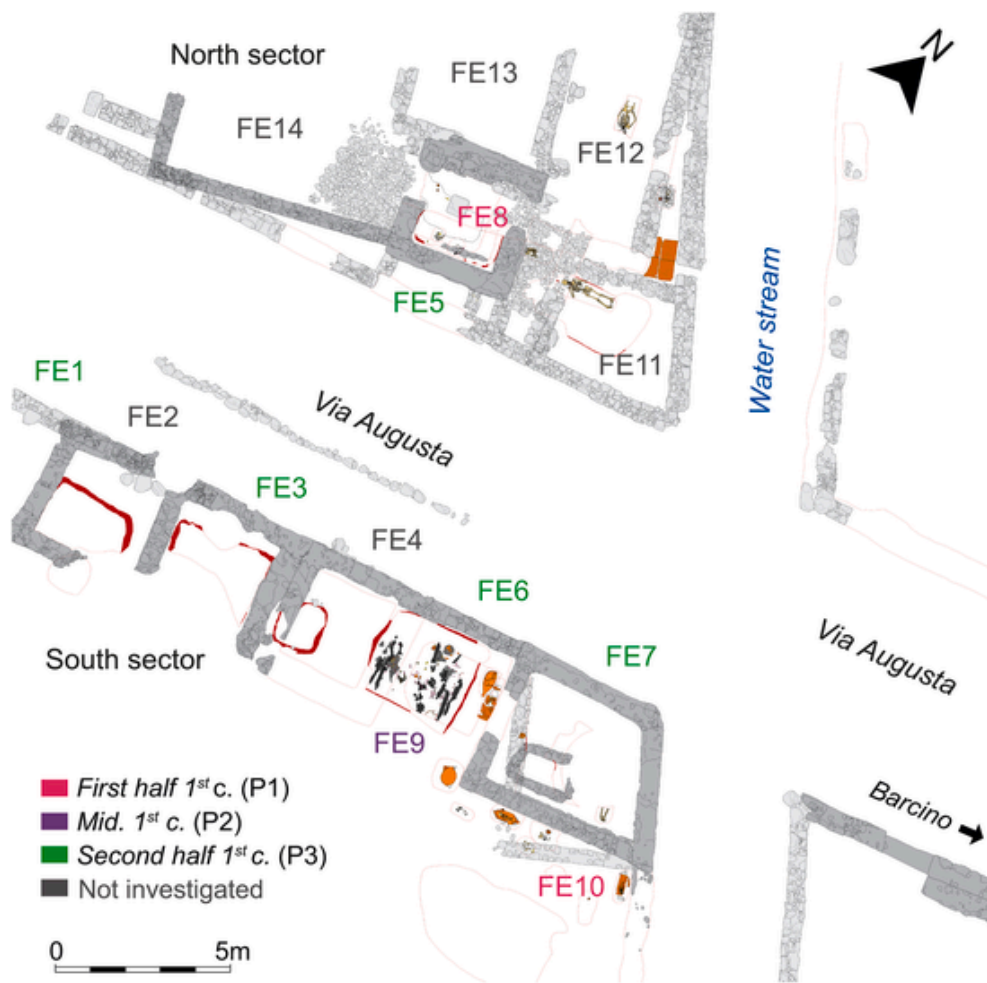


Fig. 3. Plan of the archaeological structures in the Roman necropolis of Sant Antoni Market (elaborated from Hinojo García, 2020). Funerary enclosures (FEs) are indicated with different colors on the basis of their chronology.

on the evolution of woody species and foodstuffs used in cremation rituals in the 1st century CE.

3.1. Anthracological analysis

3.1.1. Taxonomical determination

Anthracological analyses were carried out on 24 samples from eight *ustrina* out of nine (*Ustrinum*/20615, *Ustrinum*/20605, *Ustrinum*/20566, *Ustrinum*/20621, *Ustrinum*/2524, *Ustrinum*/2489, *Ustrinum*/2446, and *Ustrinum*/2463); two *busta* (*Bustum* UF16/2961–2962 and *Bustum* UF19/2542); a fireplace probably used to cook a funerary feast in FE9 (Fireplace/20560); the sediment from two infantile amphora inhumations (called *enchytrismos*; Amphora infill UF4/2604 and Amphora infill UF6/2954); a layer of dump probably resulting from *ustrinum* cleaning (*Ustrinum* dump/20538); and an infill layer of indeterminate structure (Indet. infill layer/20599; Table 1).

Charcoal fragments between 2 and 4 mm and, in some rarer cases, >4 mm in size were identified taxonomically using an optical reflected-light microscope (Olympus BX41) with bright-dark fields and $\times 50$, $\times 100$, $\times 200$, and $\times 500$ magnifications. Fragments were hand cut to expose the three anatomical sections of wood and comparative materials, including the reference collection of the Archaeobotanical Laboratory at the Institut Català de Paleocologia Humana i Evolució Social (IPHES-CERCA), wood anatomy atlases (Schweingruber, 1990), and the Insidewood database (InsideWood, 2004; Wheeler, 2011) were consulted. A minimum number of 100 fragments per SU, when available, were analysed (Table 1 in Supplementary Materials).

3.1.2. Dendro-anthracological analysis

To gather further information about pyre characteristics, as the calibres of the wood employed for the stack (original diameters), different dendro-anthracological methods were applied to the charcoal assemblage from the Sant Antoni Market necropolis.

Growth-ring curvatures of each charcoal fragment (>4 mm), were evaluated during the taxonomical determination phase (Table II, Fig. III in Supplementary Materials). The material was divided into groups according to the degree of ring curvature (RC). Weakly curved growth rings (RC1) referred to larger-diameter logs, while moderately curved growth rings (RC2) and strongly curved growth rings (RC3) indicated the presence of smaller logs or branches (Marguerie and Hunot, 2007).

Additionally, charcoal–pith distance was estimated for the *Quercus* sp. deciduous charcoal fragments, to obtain a more precise approximation of the (minimum) diameter of the raw wood before carbonisation. The measurements were carried out at the AASPE Laboratory (Archéozoologie, archéobotanique: sociétés, Pratiques et Environnements) at the Muséum National d’Histoire Naturelle (UMR7209, MNHN/CNRS, Paris) with a Nikon AZ100 multi-zoom macroscope with $\times 4$ to $\times 500$ magnifications and NIS-Element image analysis software, following the protocol established by Dufraisse et al. (2020).

As the majority of fragments had no conserved pith, the charcoal–pith distances were estimated using a trigonometric tool that starts from the angle and the distance between two ligneous rays in the transverse section to obtain the output value of *minimum radius*. Only those charcoal fragments with more than 2 mm distance between the two adjacent rays and presenting an angle $> 2^\circ$ were included, thus en-

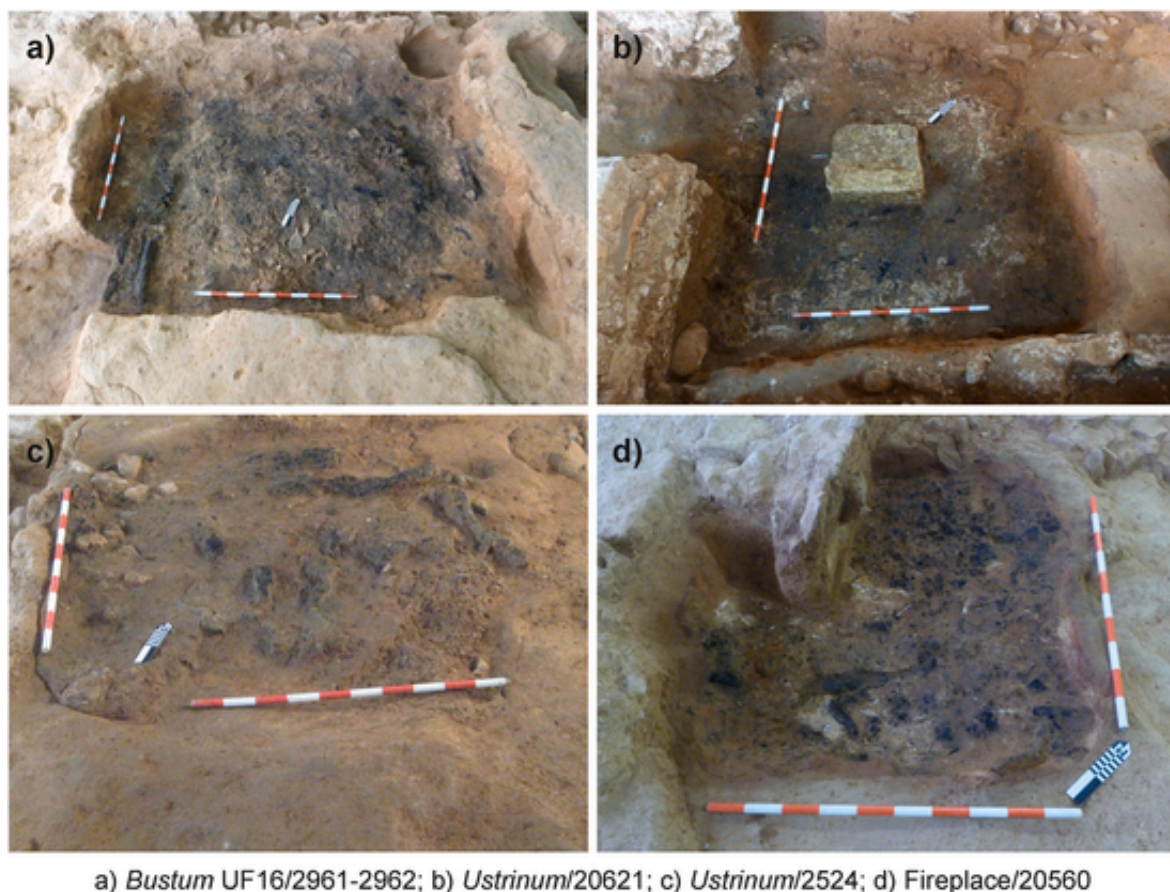


Fig. 4. Some of the combustion features in the necropolis of Sant Antoni Market (photos by E. Hinojo).

sureing that measurements were representative. The measurements were repeated five times for each sample, removing then the extreme values and calculating the average. The minimum diameter was therefore established (with a minimum radius $\times 2$) and 20% was added to the fragments with diameters between 5 and 10 cm as a corrective measure to the trigonometric tool. Afterwards, 20% was added to all samples to compensate for the shrinkage effect of carbonisation (Paradis-Grenouillet and Dufraisse, 2018). Finally, the results were grouped in diameter classes: [0–2[, [2–4[, [4–7[, [7–10[, [10–20[, and > 20 cm.

However, the calculated charcoal–pith distances (and consequently the minimum diameters) did not directly represent the original diameter of the unburnt raw wood, since during the combustion process, wood undergoes fragmentation and a loss of mass. To address this issue, the analysis diameter tool (ADmodel), developed by the DENDRAC project and freely accessible as an Excel macro (<https://dendrac.mnhn.fr/spip.php?article237>), was used to correct this bias. It is based on the premise that a tree trunk can be considered as a series of stacked cones and from here, the model corrects the distribution of data into diameter classes starting from theoretically unburnt wood diameters (Dufraisse, 2006; Picornell Gelabert et al., 2020; Table III, Fig. IV in Supplementary Materials).

3.1.3. Assessing the taphonomy and other characteristics of wood fuel

Further qualitative understanding of the wood fuel and appearance of a pyre can be assessed by observing other elements in wood charcoal fragments – either as alterations or particular characteristics of the microscopic wood anatomy resulting from taphonomic processes or burning conditions (Table IV, Fig. V in Supplementary Materials). Following the traditional anthracological method (Marguerie and Hunot, 2007; Théry-Parisot et al., 2010) we recorded the presence of the following during the taxonomical determination process:

- (a) **Vitrification features:** intended as a variable fusion of anatomical elements in wood, which, at its maximum degree, makes the charcoal a glassy-amorphous, dense, and refractive mass, and therefore impossible to identify. The different stages of fusion were classified into three groups: (1) low brilliance – refractivity and low fusion of anatomical elements; (2) strong brilliance – medium fusion of anatomical elements; and (3) total fusion – an (almost) indeterminate woody structure (Marguerie and Hunot, 2007). The causes of vitrification in archaeological charcoal fragments represent an ongoing debate in the literature (Théry-Parisot, 2001; Marguerie and Hunot, 2007; Henry, 2011; McParland et al., 2010; Vidal-Matutano et al., 2019; Courty et al., 2020), since many of the variables traditionally thought to influence the process (e.g., high heating rates, lengthy combustion times, or the use of green or unseasoned wood) have often been disproven in experiments (Henry, 2011; McParland et al., 2010). Recently, tree exposure to electrically charged aerosols and the presence of highly conductive impurities in the wood structure have been identified as possible key factors (Courty et al., 2020). However, these hypotheses and their archaeological implications need further examination.
- (b) **Radial cracks:** splits alongside rays are common in charcoal fragments, above all in dense and long-ray woods that are far from the pith (Marguerie and Hunot, 2007). It has been observed that these alterations are more prevalent in woods with high moisture content (Prior and Alvin, 1986) and as a consequence, radial cracks might suggest the use of unseasoned wood in combustion events (Marguerie and Hunot, 2007; Théry-Parisot, 2001; Théry-Parisot and Henry, 2012).

Table 1

List of the stratigraphic units (SU) from the archaeological intervention at Sant Antoni Market (Cod. 003/12) considered for the anthracological (A) and carpological (C) analyses. Chronology, phases, sector and funerary enclosure (FE) numbers and names of the structures are based on data from the archaeological report (Hinojo García, 2020). Litres of sampled sediment for each SU are also indicated.

Stratigraphic unit (SU)	Chronology (CE)	Phase	Sector/ funerary enclosure (FE)	Structure name	Litres of sampled sediment	A	C
20612	First half 1st c.	1	South/ FE10	<i>Ustrinum/</i> 20615	72	x	x
20606	First half 1st c.	1	South/ FE10	<i>Ustrinum/</i> 20605	30		x
20581	First half 1st c.	1	South/ FE10	<i>Ustrinum/</i> 20605	33	x	x
20586	First half 1st c.	1	South/ FE10	<i>Ustrinum/</i> 20605	180	x	x
20597	First half 1st c.	1	South/ FE10	Indeterminate (Ind.) infill layer/ 20599	5	x	x
20540	First half 1st c.	1	South/ FE10	<i>Ustrinum/</i> 20566	118	x	x
20558	First half 1st c.	1	South/ FE10	<i>Ustrinum/</i> 20566	17	x	x
2638	First half 1st c.	1	North/FE8	<i>Ustrinum/</i> 20621	62	x	x
2899	Mid 1st c.	2	South/FE9	<i>Bustum</i> UF16/ 2961–2962	118	x	x
2877	Mid 1st c.	2	South/FE9	<i>Bustum</i> UF16/ 2961–2962	13	x	x
2871	Mid 1st c.	2	South/FE9	<i>Bustum</i> UF16/ 2961–2962	12	x	x
20544	Mid 1st c.	2	South/FE9	Fireplace/ 20560	32	x	x
20556	Mid 1st c.	2	South/FE9	Fireplace/ 20560	18	x	x
20559	Mid 1st c.	2	South/FE9	Fireplace/ 20560	8		x
2955	Second half 1st c.	3	South/FE6	Amphora filling UF6/ 2954	32	x	x
2523	Second half 1st c.	3	South/FE6	<i>Ustrinum/</i> 2524	4	x	
2810	Second half 1st c.	3	South/FE6	Amphora filling UF4/ 2604	26	x	x
2501	Second half 1st c.	3	South/FE3	<i>Ustrinum/</i> 2489	26	x	x
2440	Second half 1st c.	3	South/FE3	<i>Ustrinum/</i> 2446	8	x	x
2463	Second half 1st c.	3	South/FE1	<i>Ustrinum/</i> 2463	2	x	x
20539	Second half 1st c.	3	South/FE7	<i>Ustrinum</i> dump/20538	28		x
20538	Second half 1st c.	3	South/FE7	<i>Ustrinum</i> dump/20538	178	x	x
20510	Second half 1st c.	3	South/FE7	<i>Ustrinum</i> dump/20538	112	x	x
20522	Second half 1st c.	3	South/FE7	<i>Ustrinum</i> dump/20538	36	x	x
2564	Beginning 2nd c.	3	South/FE7	<i>Cupa structilis</i> UF17/2546	16		x
2562	Second half 1st c.	3	North/FE5	<i>Bustum</i> UF19/ 2542	6	x	x
2536	Second half 1st c.	3	North/FE5	<i>Bustum</i> UF19/ 2542	3	x	x
2557	Second half 1st c.	3	North/FE5	<i>Bustum</i> UF19/ 2542	4	x	x
Total SU: 28				Total litres:	1199		

- (c) **Reaction wood:** the thickening of tracheid walls and the emergence of radial grooves on their internal surfaces are identifiable as parallel striations in longitudinal charcoal sections. They represent the reaction of the wood to structural tension, for instance, a tree leaning to one side on a slope or, more often, branches subjected to the weight of snow, wind force, or their own canopy (Marguerie and Hunot, 2007).
- (d) **Fungal hyphae:** thread-like structures produced by fungi/microbes within dead or dying and debarked wood, contributing to its decomposition and decay. In charcoal fragments, fungal hyphae are visible as brown filaments inside the longitudinal section of vessels; their presence could suggest the collection of degraded or dead wood for fire (Marguerie and Hunot, 2007; Moskal-del Hoyo et al., 2010).
- (e) **Traces of insect degradation:** large circular holes with irregular patterns resulting from the activity of wood-boring insects or woodworms. In some cases, the shape and dimension of the tunnels can provide information on the species of insect responsible (Toriti et al., 2021).
- (f) **Wood knot:** circular or irregular growth in the wood anatomy related to the insertion of branches or limbs in the tree trunk. High frequencies of knots in the charcoal assemblage suggest the use of irregular or crooked logs in the fire (Schweingruber, 2007).
- (g) **Tyloses:** parenchymatic cells outgrowths with irregular prismatic shapes that block or partially fill the vessel lumens of certain tree species. They form more frequently in the heartwood with the ageing of the tree (in deciduous oaks after 20–25 years; Dufraisse et al., 2018) and help protect the wood from decay and attacks by microorganisms. Tyloses also represent a tree's response to injury or stress. In charcoal fragments, these features are refractive and easily visible and in certain species, as the case of deciduous oak, they could be an indicator that the fragment was derived from the heartwood of mature tree (Dufraisse et al., 2018; Marguerie and Hunot, 2007).
- (h) **Bark:** the presence of bark, both in association with recognisable wood structure and cambium (bark + wood) and as undeterminable fragments (bark only). In particular, bark in the Sant Antoni Market charcoal assemblage offers a useful clue regarding the appearance of the pyre wood stacks (debarked wood or not); when it is found in combination with the cambium, it indicates the tree's cutting season.

3.2. Carpological analysis

The carpological remains of 27 samples (collected in 15 structures) were analysed. The samples were roughly the same as those in the charcoal analysis (except for *Ustrinum/2524* in FE6 and the addition of a sample from the infill layer of a *Cupa structilis* UF17/2546, a funerary pit where cremated remains were disposed after the pyre-burning [i.e., a secondary deposition]). Taxonomical determination was based on the morphological and biometrical criteria typical of each species. The remains were compared with the reference collection available at the Laboratory of Bioarchaeology of the University of Lleida, and several determination atlases were consulted (Brouwer and Stählin, 1975; Cappiers et al., 2012; Jacquat, 1988; Montegut, 1970; Renfrew, 1973; Sabato and Peña-Chocarro, 2021). The results are presented in Table V in Supplementary Materials.

According to archaeobotanical procedure, subsampling was necessary in the case of samples with large volumes of macro-remains. This facilitated identification. The results were multiplied by the subsampling dividend (i.e., 1/2 SU, 20538, 1/4 SU20586, and 1/8 SU20510, amongst others; Table V in Supplementary Materials)

Most of the fruit remains corresponded to endocarp fragments, none of which were found to be complete. Because it was impossible to assess

the total number of fruits, quantification was based on the number of identified fragments. In the case of *Ficus carica* (fig), most of the identified remains corresponded to fragments of infructescence, so the quantification referred to these rather than the achenes, which were scarce. The quantification of *Vitis vinifera* (grape) was based on seeds, even if in some cases parts of the fruit were preserved. For the remaining species, quantification was based on the number of seeds, except for peas (for which only cotyledons were documented) and the Brassicaceae family (for which capsule fragments were recovered). Quantification was carried out on the number of fragments/infructescence/seeds for each taxon and their ubiquity, to assess the presence/absence of each taxa in the different samples examined (Fig. VI in Supplementary Materials).

4. Results

4.1. Anthracological analysis

4.1.1. Taxonomical determination

Taxonomical determination of 1935 fragments from 15 structures (principally *ustrina* and *busta*) were carried out and 21 taxa were identified (Fig. 5 and Table I in Supplementary Materials). Amongst these, the most abundant taxon was *Quercus* sp. evergreen, most probably *Quercus ilex*, given the potential vegetation of the area (Carrillo et al., 2018), representing 46,5% of the analysed charcoal fragments. Next, *Quercus* sp. deciduous (*Quercus pubescens* or *Quercus cerroides*, grouped as deciduous oaks) represented 12,9% of the total assemblage, followed by *Erica t. arborea/Erica* sp. (6,4%) and *Arbutus unedo* (5,7%), which grow in the Holm oak woodland understorey (Ericaceae scrubs).

Less abundant species (<3,9%) were also present; these included heliophilous maquis shrubs such as *Pistacia lentiscus*, *Rhamnus alaternus/Phillyrea* sp., *Cistus* sp., and *Juniperus* sp., plants that are present in humid evergreen oak or mixed deciduous oak underwood such as *Lonicera* sp., *Viburnum* sp., Caprifoliaceae, and *Cornus* sp. In addition, we observed species that compose the middle mountain evergreen oak underwood, such as *Buxus sempervirens*, the Mediterranean and Mountain pines (*Pinus halepensis* and *Pinus sylvestris/nigra*), and trees such as *Juniperus/Cupressus* sp., *Juglans regia*, Maloideae, *Olea europaea*, *Prunus* sp., and *Vitis vinifera* that had been cultivated or introduced (De Bolós, 1962; Folch i Guillèn, 1981; Carrillo et al., 2018).

Quercus sp. evergreen and *Quercus* sp. deciduous were the most common taxa, being present in 15 and 12 of the 15 total structures, respectively (Fig. I in Supplementary Materials). *Arbutus unedo* was ubiquitous in nine structures and *Olea europaea* in six, while *Erica* sp.,

Pinus halepensis, and *Pinus sylvestris/nigra* were found in five. Other taxa were less common.

Despite their scarcity in the assemblage as a whole, some taxa (e.g., *Viburnum* sp., *Pinus halepensis*, *Olea europaea*, and *Pinus sylvestris/nigra*) were abundant in some structures, indicating their circumstantial use in the necropolis. This was the case in *Ustrinum/20615*, where *Viburnum* sp. reached 29%, Amphora infill UF4/2604, containing 49% of *Pinus halepensis*, Amphora infill UF6/2954, with 20% of *Olea europaea*, and *Bustum* UF19/2542, where *Pinus sylvestris/nigra* reached 11,8%.

In some combustion structures, *Quercus* sp. deciduous, Ericaceae shrubs, and *Viburnum* sp., prevailed upon *Quercus ilex*, as documented in *Ustrinum/20605*, Fireplace/20560, and *Ustrinum/20615*, respectively.

Finally, it is worth noting that deciduous oak, which was well represented in the cremation pyres during the first half of the 1st century CE, radically decreased in the following phase. Likewise, Ericaceae shrubs, in particular *Erica* sp., almost disappeared from charcoal assemblages dated to the second half of the century.

Hence, the relationship between the number of fragments analysed and the number of taxa identified (Fig. II in Supplementary Materials) indicates that structures dated to the first half of the 1st century CE (P1) appeared slightly richer in taxa than the structures from the subsequent phase (P2), which in turn, included more taxa than Phase 3. This falling trend in taxa diversity was, in most cases, independent of the number of fragments analysed. Furthermore, no particular tendency in taxa diversity was documented on the basis of the structure type (*ustrinum*, *bustum*, or others), because diverse results obtained within the same category.

4.1.2. Dendro-anthracological analysis

Growth-ring curvatures were observed in 299 charcoal fragments out of the total assemblage (Table II, Fig. III in Supplementary Materials). Estimations were not possible for the majority of fragments because of the poor preservation or absence of visible growth rings. Some species do not develop clear growth-rings boundaries, for example, *Quercus* sp. evergreen. Only *Quercus* sp. deciduous, *Arbutus unedo*, *Erica t. arborea/Erica* sp., *Viburnum* sp., *Pinus halepensis*, and *Rhamnus alaternus/Phillyrea* sp. presented at least 10 charcoal fragments with observable growth rings, which allowed us to discuss their calibre composition. Dendro-anthracological measurements were applied on 129 *Quercus* sp. deciduous charcoal fragments, which presented mostly weakly curved growth rings (RC1), suggesting the use of large calibre oak woods in the construction of the pyres. On the same line, also *Pinus halepensis* presented the greatest number of weakly curved growth rings

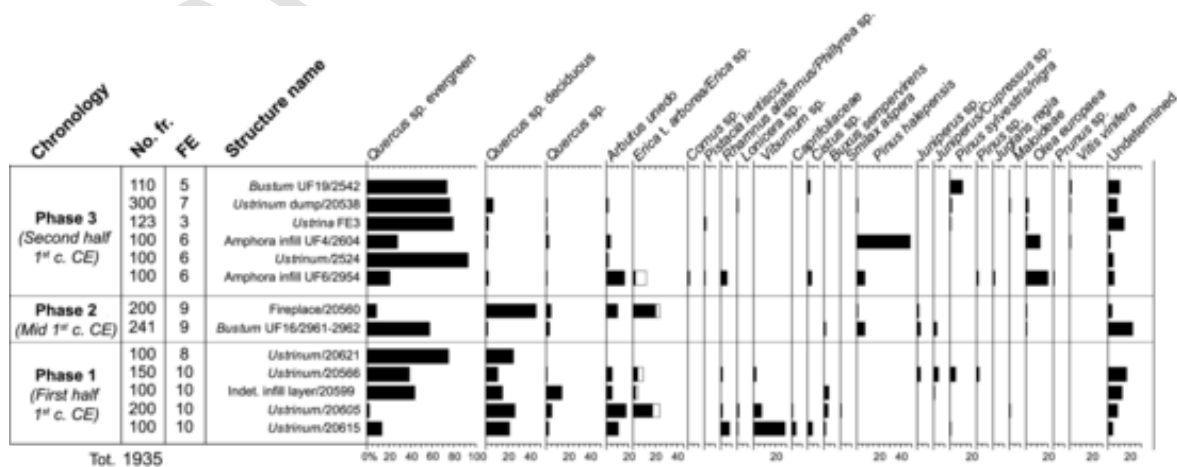


Fig. 5. Anthracological diagram of the Sant Antoni Market necropolis, which summarises data from the same archaeological structure. Note that the bar's sequence has to be considered as broadly indicative because some structures within the same time frame were functioning more or less simultaneously in different areas of the necropolis.

(15 out of 18). Meanwhile, *Arbutus unedo* and *Erica t. arborea*/*Erica* sp. (Ericaceae) were found in RC1, RC2, and RC3 in approximately the same proportions, indicating the use of small-, medium-, and large-calibre woods. Finally, *Viburnum* sp. and *Rhamnus alaternus*/*Phillyrea* sp. accounted for a greater number of RC2 than RC1 fragments, suggesting that medium calibres of these taxa were used in cremations.

While this qualitative proxy may be taken as indicative—given the relative subjectivity of Marguerie and Hunot's (2007) method and taking into account that ring curvature can vary in a single ring/stem due to pith decentralisation (e.g., after mechanical alterations of wood anatomy to orientate the plant towards the light)—it is nevertheless possible to conclude that most of the taxa that accounted more than 10 charcoal fragments presented mostly weakly and moderately curved growth rings.

Charcoal–pith distance estimations for *Quercus* sp. deciduous charcoal fragments were performed to estimate the diameter composition of the oak wood assemblage in the necropolis. However, because of size limitations on the applicability of the reconstruction tool and the fact that many fragments did not preserve complete growth rings, analysis was only carried out on 57 charcoal fragments from the different SUs. The results, which were corrected based on the ADmodel, showed that the diameter classes 4 [7–10 cm] and 5 [10–20 cm] were the best represented in the total assemblage, indicating that medium-large calibre oak wood pieces were employed in pyre construction (Table III, Fig. IV in Supplementary Materials).

4.1.3. Assessing the taphonomy of and alterations in the wood charcoal assemblage

The taphonomic features and alterations in the charcoal fragments were grouped according to their cause or moment of occurrence. For instance, compressions/tension wood, knots, and tyloses occurred during plant growth; the presence or absence of fungal hyphae or bark resulted from wood deposition or gathering practices; and the degree of vitrification and the presence of radial cracks were the consequence of combustion (Table IV, Fig. V in Supplementary Materials).

Notably, an important feature observed in deciduous oak charcoal fragments was the presence of tyloses, which appeared in all FEs (except FE5 and FE10; Fig. Va in Supplementary Materials), suggesting the use, among others, of mature oak trees. Moreover, the lack of many wood knots in the overall charcoal assemblage indicates that the woods used for the pyres were tendentially straight.

Regarding the condition of the wood at the moment of collection (Fig. Vb in Supplementary Materials), it seems that logs were mostly barked because of the frequent presence of bark fragments in the charcoal assemblage (4,4% of the total). We cannot exclude the regular use of dead wood, as suggested by the presence of fungal hyphae inside the charcoal microscopic structures, especially in FE8. However, no traces of other types of degradation (e.g., woodworm tunnels) were observed.

Finally, observing the alterations derived from combustion (Fig. Vc in Supplementary Materials), vitrification and radial cracks were recorded in all FEs (except FE1). In particular, vitrification Degree 1 was the most common feature, although several charcoal fragments in FE10 presented vitrification Degrees 2–3. Numerous charcoal fragments displaying radial cracks were observed in different taxa, suggesting the employment of green or not-well-seasoned wood for pyre-building.

4.2. Fruit/seed analysis

The analysis of 4257 carpological remains in 15 archaeological structures from the necropolis revealed 20 different taxa (Figs. 6 and 7 and Table V in Supplementary Materials) and some less precise identifications at family and genus level (Amaranthaceae, Papilionaceae, and *Rumex* sp.) that cannot be considered as taxa.

Cultivated fruit and nut trees represented the majority of the carpological remains. Figs (*Ficus carica*) infructescence (syconia) were the most abundant elements in all FEs except FE5 and FE8, accounting for a total of 1712 remains (4,22% of the total carpological assemblage). Furthermore, 135 walnut (*Juglans regia*) shell fragments were recovered (3,17% of the total assemblage and 18,5% of ubiquity). This species was concentrated in four structures from FE10 and FE3 (*Ustrinum*/20615 above all, and Indet. infill layer/20599, *Ustrinum*/20566, and *Ustrinum*/2446).

Although grape remains (*Vitis vinifera*) were not very abundant (36 remains), their ubiquity was notable, as they appeared in 40,7% of the samples and seven out of 15 archaeological structures, indicating their recurrent use in funerary rituals (as was the case with figs). Other fruit taxa such as olive trees (*Olea europaea*) and plum species (*Prunus* sp.) were less abundant; they were recovered in fewer than 10 remains, though they were present in 14,8% and 7,4% of the samples, respectively.

Fruits and nuts that were most probably gathered from wild vegetation were also present. Of these, the most abundant species were the *Arbutus* berries (*Arbutus unedo*), which comprised 49 fruit remains (1,15% of the assemblage and 14,8% of ubiquity). Other species were more sporadic, as hazelnuts (*Corylus avellana*) and stone pine nuts (*Pinus pinea*), which accounted six remains in two samples (<0.15% of the total assemblage). Moreover, only two fragments of Cornelian cherries (*Cornus mas*) were found in one sample.

The second most abundant plant category comprised adventitious or ruderal plants (Fig. 6), which were more abundant in FE10, FE7, and FE6 (nearer to the water stream). *Rumex acetosella*, *Echinochloa crus-galli*, *Cheopodium album*, and *Polygonum convolvulus* were the most common, though they are prolific seed producers. Their ubiquity ranged from 11% to 25%, depending on the taxon. Other herbaceous plants such as common fumitory (*Fumaria officinalis*) and vegetables such as beet (*Beta* sp.) and the amaranth and cabbage family (Amaranthaceae, Brassicaceae) were also recorded. Finally, shrubs such as the rose (*Rosa* sp.) and probably the rockrose genus (cf. *Cistus* sp.) were more scarce.

No cereals and few legumes were recovered. Only eight cotyledons of pea (*Pisum sativum*) were present in *Ustrinum* dump/20538. Moreover, a large proportion of undetermined charred fragments were recorded (41,04% of the total remains), above all in FE5 and FE8, where they represented 100% of the remains.

No noteworthy differences were observed between the different chronological phases, though comparisons were not reliable because of the low amount of FEs sampled in Phases 1 and 2.

5. Discussion

5.1. Principal woods used in pyre construction

The present study's primary purpose was to determine the woody species used in funerary practices in the city of Barcino in Roman times. Fuel selected for cremations has been explored in previous studies (Cenzon-Salvayre, 2014; Costa Vaz et al., 2021; Coubray, 2013; Deforce and Haneca, 2012; Fabre et al., 2003; Figueiral et al., 2010b; Martín-Seijo and César Vila, 2019). These have suggested that choices depended generally more on species availability in the surrounding woodlands than their symbolic significance, although the richness of taxa varied from case to case and different strategies were adopted. At Pompeii, for example, no substantial divergence was noted between domestic and funerary fuel (Coubray, 2013), while in northern Belgium, fewer taxa were detected in cremations than in domestic refuse, likely reflecting the functional purpose of pyres (Deforce and Haneca, 2012). The heterogeneous results of charcoal analyses reinforce the need for local studies in order to enrich our overall knowledge of wood uses and strategies in cremation practices during Roman times.

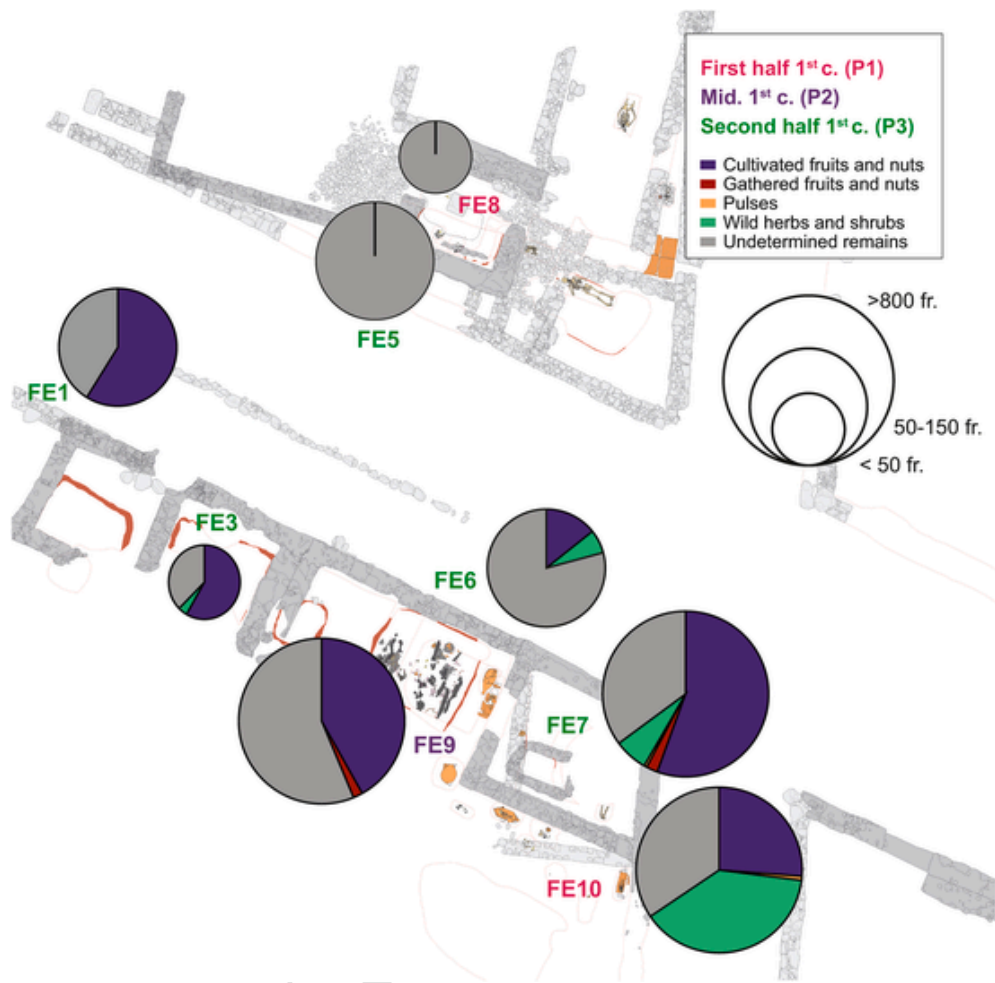


Fig. 6. Overall representation of the fruit/seed results for each funerary enclosure (FE). The pie charts represent the percentage of the different vegetation categories within the total fragments analysed. The dimensions of each pie chart are based on the number of fragments analysed for each FE. Letter colors indicate the archaeological phase of each structure.

Analysis carried out in different combustion features at the Sant Antoni Market necropolis, above all in the cremation areas, indicate that evergreen oak (*Quercus ilex*) was the most widely used species. This accords with the idea that selection was driven principally by local availability since evergreen woodlands are the most widespread plant formations in the surrounding area. These were also exploited to meet the fuel demands of the nearby city of Barcino (Bianco et al., 2023).

Deciduous oaks (*Quercus* sp. deciduous), Ericaceae (*Arbutus unedo* and *Erica* sp.), and laurustinus (*Viburnum* sp.) assumed a more important role in pyre construction in the first half of the 1st century. In the second part of the century, the presence of these species drastically declined in favour of an increased use of evergreen oak. Moreover, less taxonomical diversity was documented in the overall charcoal assemblage of this last phase, suggesting that evergreen oak wood gained a dominant importance, compared to other taxa, in the cremation rituals.

The use of deciduous oak for funerary rituals during the initial phase of the necropolis is worthy of note because it contrasts with the relatively lower percentages of this taxon in the urban fuel waste produced from Barcino (Bianco et al., 2023). This could be due to the fact that deciduous oak wood was intended for other uses rather than fuel, such as construction material - see e.g. the wooden elements at Villa de La Sagrera, in the Barcelona Plain (López Bultó, 2017) - and for the construction of funeral pyres, according to the present study.

The greater occurrence of evergreen and deciduous oak in the necropolis suggests that fuel procurement took place primarily in mixed oak forests, which probably occupied the most humid and shadowy ar-

eas of the nearby Collserola mountain range (according to Carrillo et al., 2018, Fig. 1), and that—during the first half of the 1st century CE—deciduous oaks were selected for building pyres rather than serving as firewood for the city.

De facto, deciduous oak charcoal fragments were documented in the cremation urns at the necropolis of Drassanes Reials (Barcelona), contemporaneous with Sant Antoni Market (Piqué i Huerta and Ferré Trías, 2015). Additionally, the use of deciduous oak has been attested to in other Roman cremation contexts, both in the north-western areas of Iberia, for example, Bracara Augusta (Costa Vaz et al., 2021) and Reza Vella (Martín-Sejjo and César Vila, 2019) and on the Mediterranean side, where the use of deciduous and evergreen oak woods have been recorded at Mas Delfau (Perpignan; Cençon-Salvayre, 2014, pp. 259–260), Soumaltre and Ambrussum (Hérault; Cençon-Salvayre and Durand, 2012; Fabre et al., 2003) and Nîmes (Figueiral et al., 2017) in southern France; in the Pompeian necropolis of Porta Nocera (Coubray, 2013); and in the Puglia region of southern Italy (Caracuta and Fiorentino, 2018).

The choice of oaks may be attributed not only to their abundance but also to their combustive and structural properties. Our dendro-anthracological analysis of deciduous oak shows that logs of medium-to-large diameter (i.e., between 7 and 20 cm) were used for pyre construction. Moreover, the presence of tyloses recorded in the deciduous *Quercus* charcoal fragments may indicate the selection of mature trees for cremation purposes (Dufraisse et al., 2018). These results are reliable, given that deciduous and evergreen oaks are dense woods that of-

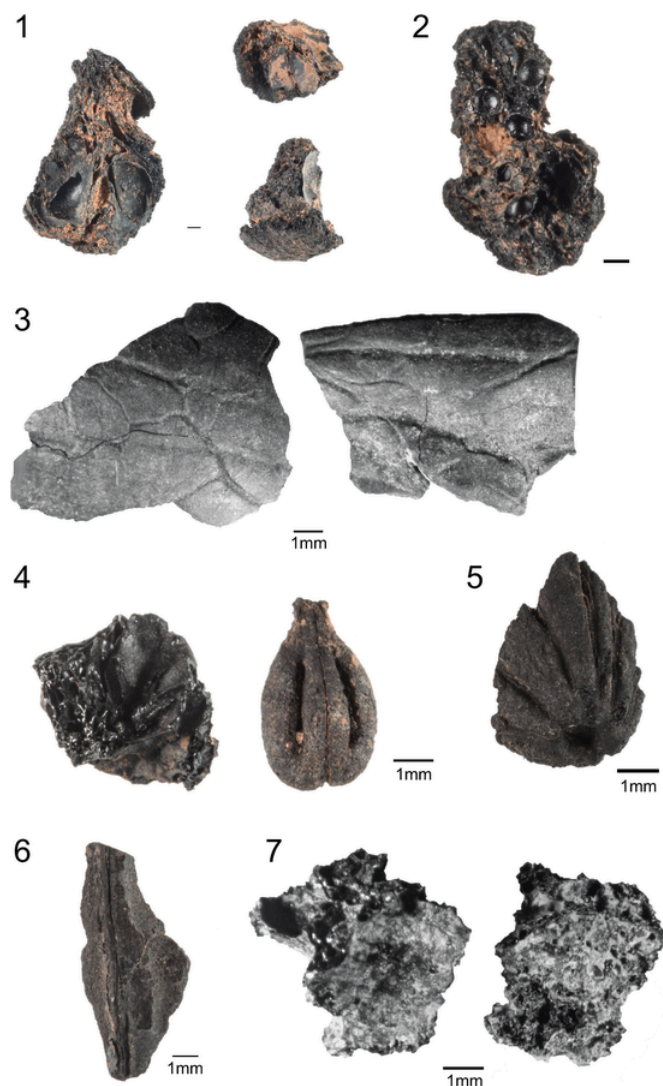


Fig. 7. Fruit/seed remains from Sant Antoni Market. 1. *Arbutus unedo*; 2. *Ficus carica*; 3. *Juglans regia*; 4. *Vitis vinifera*; 5. *Olea europaea*; 6. *Prunus* sp.; 7. Undeterminable.

for low flammability and slow combustion when used as large logs (Théry-Parisot, 2001). Such characteristics are highly effective in helping to reduce the human body to ashes (Fabre et al., 2003; Costa Vaz et al., 2021).

In addition, pyres had to have a well-designed and stable structure to visually impact the assistants and generate full combustion, as a partial cremation was considered a very serious outrage to the deceased (Noy, 2000b). Indeed, several Classical iconographical and written sources exhaustively examined by Cenzon-Salvayre (2014) indicate that pyres were likely composed of stacked layers of straight logs arranged in an alternating fashion, forming a rectangular structure. It is probably for this reason that large logs of deciduous oak were intended for the necropolis at the beginning of the 1st century CE.

Furthermore, the significant presence of bark in the charcoal assemblages indicates that the logs were not previously debarked, while the absence of signs of taphonomic degradation, such as fungal hyphae or tunnels made by xylophagous insects, suggests a systematic approach to wood-cutting, contrasting with opportunistic deadwood collection. Finally, the frequent presence of radial cracks might suggest that wood was not well dried in some cremations, which would have affected the efficiency of the fire. To solve this problem, written sources cite the use

of wax to increase flammability (Noy, 2000a), albeit this practice is difficult to detect from the archaeological and archaeobotanical records.

5.2. Wood selection or vegetation dynamics

The results of the present study show the decline of deciduous oak from charcoal assemblages during the second half of the first century. However, due to the very nature of the cremation wood remains - strongly affected by human selection - and because the number of the studied contexts is relatively small, we need to be cautious in interpreting this trend as a direct reflection of the regional vegetation dynamics. Nevertheless, it is still possible to formulate hypotheses, taking some factors into consideration.

First, progressive climate aridification in the north-west Mediterranean basin since the Late Holocene and the increasing impact of human activities—which in combination led to the expansion of sclerophyllous vegetation (i.e., evergreen oak) at the expense of Meso-Mediterranean deciduous species (i.e., deciduous oak)—is a well-known ecologic dynamic documented and discussed in an extensive literature (Allué et al., 2009; Azuara et al., 2015; Jalut et al., 2000, 2009; Mariotti Lippi et al., 2020; Pérez-Obiol et al., 2011; Reille and Pons, 1992; Revelles et al., 2022; Riera Mora and Esteban-Amat, 1994). In particular, the process had been ongoing on the Barcelona plain since the middle Bronze Age (approximately 3250 cal BP), according to the pollen sequence from Besos (Riera Mora and Esteban-Amat, 1994). We may assume that during the 1st century CE, the ecological niche of deciduous oaks was already limited to more humid areas in the hinterland hills (Carrillo et al., 2018), an idea that is in line with results obtained from the Roman pollen sequence from the moat of Barcino that suggest a scarcity of deciduous oak after the foundation of the colony (Bianco et al., 2023).

On the one hand, the exploitation of large wood logs of deciduous oak from mature trees (already threatened by a drier environment) for pyres for half a century may have helped deal the final blow to this species, triggering a change in the composition of the forest and favouring the expansion of *Quercus ilex*, which has higher resprouting capacities and greater resilience to disturbances in comparison with deciduous oak (Espelta et al., 1999). A similar woodland dynamic has been reported for the Tuscany region of Italy (amongst others) between the Roman and Middle Ages, (Buonincontri et al., 2013; Mariotti Lippi et al., 2020).

On the other hand, there are some aspects regarding wood procurement and purchase processes in Roman times that are difficult to assess. In particular, certain written and iconographic sources have reported that the *funus* were managed by funerary enterprises (Hinard and Dumont, 2003). It appears that specialists called *ustores* were in charge of the pyres since wood assemblage and combustion procedures required technical competence to ensure an effective and complete cremation (Noy, 2000a; Cenzon-Salvayre, 2014; Costa Vaz et al., 2021). However, we cannot be absolutely sure that this was valid everywhere in the Roman Empire.

Classical sources are scant in details regarding wood procurement, so it is difficult to know whether the wood intended for funerary rituals was collected or purchased directly by *ustores* from dedicated forests, or provided by the family of the deceased (Cenzon-Salvayre, 2014; Costa Vaz et al., 2021). The most important Barcino families managed land properties (*fundi*) across a wide area, from the Llobregat to the Vallés and even outside the territory controlled by the city (Olesti Vila and Carreras Monfort, 2013). Therefore, if they were supplying wood for the pyres from their various forests, taxa trends may have been affected consequently. In the case of Rome, it seems that the wood for cremations was procured from particular woodlands by those in charge of providing fuel for public baths (Noy, 2000b). Nevertheless, we cannot be sure that the same practice pertained in Barcino.

Further considerations relating to selection patterns concern the fuel used for the pyres and fuel debris in Barcino (Bianco et al., 2023). Twenty different wood taxa were identified at the Sant Antoni Market necropolis, which suggests a high taxonomic diversity covering natural oak woodlands and maquis, as well as species cultivated in urban and suburban gardens. This exploitation pattern is in keeping with practices observed in other necropolises located in Meso-Mediterranean environments, for instance, Soumaltra (Fabre et al., 2003), Richeaume (Cenzon-Salvayre, 2014), and Nîmes (Figueiral et al., 2017) in southern France.

We observed a slightly lower taxa diversity in pyre remains than in the urban fuel examined near the city's wall, where we found 27 taxa from the 1st century CE (Bianco et al., 2023). Riparian species such as alder, ash, poplar, willow or elm, which, according to pollen analysis, were likely to have grown near the abundant water streams of the Barcelona plain, were not identified in the wood used for pyre construction, despite their presence in urban fuel waste.

This might indicate, on one hand, the need for a more accurate fuel selection within the necropolis because of the significant solemn and symbolic connotations. Results for the second half of the 1st century CE, which point to the extensive use of evergreen oak woods for pyre construction, are similar to the composition of wood fuel observed in the city. This might suggest a common tradition in areas where fuel (evergreen oak) for the necropolis and the city tended to be acquired. These spaces were probably coppice-managed, allowing for sustainable and continuous exploitation over centuries; the analysis of urban fuel debris, which highlighted a homogeneous trend of oak woodland exploitation from the 1st to the 6th century CE, supports such a hypothesis (Bianco et al., 2023).

5.3. Symbolism or functionality of woody species

During Antiquity, plants were often charged with symbolic, superstitious, or religious meanings, representing in some cases a direct link with the deities or a particular sensorial function (i.e., odour or embellishment). From an archaeobotanical perspective, deciding how plants may have been used presents a challenge (Livarda and Madgwick, 2018; Rovira and Chabal, 2008). However, the few archaeobotanical studies existent play a crucial role in comparing plant-use patterns across different regions and proposing more solid assumptions. In the case of wood for the pyres, the presence of certain taxa in the charcoal assemblages may indicate conscious cultural and sensorial choices.

In particular, the presence of Aleppo and mountain pines (*Pinus halepensis* and *Pinus sylvestris/nigra*), which represent rare and minor taxa in the urban fuel waste (Bianco et al., 2023), and juniper or cypress (*Juniperus* sp., *Juniperus/Cupressus* sp.), may be connected to their scented properties. Burning their resin might have helped to mitigate the odour generated by decomposing flesh and to create a particular sensorial experience (Dixon, 2021; Martín-Seijo and César Vila, 2019; Moskal-del Hoyo, 2012; Picornell-Gelabert et al., 2018). These taxa also have good flammability and may have been used to light the pyre (Cenzon-Salvayre, 2014, p. 83; Noy, 2000a, p. 37). It is perhaps for this reason that pine was considered to be a mediator between the living and the dead (Rovira and Chabal, 2008). Nevertheless, we cannot discount the possibility that pinewoods fulfilled a more utilitarian purpose, for example, as beams to transport the deceased onto the pyre, as is shown in the *Amiternum* relief (Masséglià, 2016), or as wooden cores for the funerary beds, as is illustrated by the illustration engraved on the Sijpeldeld sarcophagus (Rijksmuseum, Amsterdam).

Studies of the woody species used to build funerary beds in the Roman world are scarce. In The Netherlands, at Valkenburg-Weerdkampen (Loopik, 2021), the lower part of a turned oakwood bed leg and a turned boxwood ornament (possibly placed on the corner of a bed frame) were identified. The oakwood element was, however, more likely to have been part of a bed in a private bedroom, and the boxwood

ornament might have originated from a *kline* in a dining room (T. Vermimmen, pers. comm.). The taxonomical identification of charred wood from furniture and construction elements has been conducted at the Herculaneum site, but no information about beds is currently available (Moser et al., 2018; Sirano and Siano, 2022). A lack of wood technology studies and no clear signs of woodworking in the charcoal assemblages from the Sant Antoni Market necropolis means that it is difficult to distinguish the wood for funerary beds from that of pyre fuel.

Moreover, the presence of boxwood (*Buxus sempervirens*) in the charcoal assemblages may be symbolically connected to immortality and liberty (Rovira and Chabal, 2008). Besides, the boxwood might have derived from personal objects placed on the funerary stack (e.g., combs, boxes, tool handles, or furniture) because it was commonly used for carving and hand-working, as documented by several examples in similar or waterlogged contexts (Chabal, 2005; Costa Vaz et al., 2016, 2021; Piqué et al., 2021; Rovira and Chabal, 2008), though the absence of working traces on our charcoal fragments makes this hypothesis difficult to confirm.

Other maquis shrubs such as mastic (*Pistacia lentiscus*) and rockroses (*Cistus* sp.) might have been used for fire kindling bundles, as documented in necropolises in southern France (Cenzon-Salvayre, 2014; Fabre et al., 2003), though we may also consider that they were selected for their odour, in the same way as conifer, as suggested in a prehistoric funerary context on the island of Mallorca (Picornell-Gelabert et al., 2018). Additionally, honeysuckle (*Lonicera* sp.) and laurustinus (*Viburnum* sp.), which grow in the underwood of humid and mixed oak forests (and which were represented in the gardens of Roman Pompeii; Gleason, 2019), may have been chosen to embellish the pyre with their flowers, which flourish during winter.

Finally, charcoal fragments originating from fruit trees such as olive (*Olea europaea*), grapevine (*Vitis vinifera*), and, to a lesser extent walnut (*Juglans regia*), plums (*Prunus* sp.), and the apple family (Maloideae) could possibly indicate the use of pruning leftovers for pyre fuel, even though no direct evidences of this practices were identified on charred remains. These taxa were also identified within the urban fuel debris, confirming the widespread practice of arboriculture in Barcino (Bianco et al., 2023). Olive wood had also several symbolic meanings (e.g., chastity, virtue, hopefulness, and eternal peace), while grapevine was associated with longevity and immortality (Rovira and Chabal, 2008; Segura Munguía and Torres Ripa, 2009). Their selection for funeral rites on such grounds cannot, therefore, be ruled out.

5.4. Food for the dead

The charred remains of fruits and seeds found at the Sant Antoni Market necropolis may have been food offerings intentionally placed on the stack to accompany the deceased into the afterlife, or refuses from funerary feasts (*silicernia*) thrown in the flames during the funeral ritual (Costa Vaz et al., 2021; Preiss et al., 2005). Investigating these remains is crucial for understanding the type of food involved in funerary practices along the western Mediterranean coast. Moreover, the combination of anthracological and carpological analysis helped to establish that the fruit and nut remains, whether cultivated or wild, were intentionally disposed of on the pyre or consumed during the accompanying feast rather than being accidentally transported with the wood fuel. In fact, fruits and nuts were not associated with wood of the same taxon in the same structure; and in the case of figs and hazelnuts, no wood charcoal fragments were identified at all.

5.4.1. Arboriculture

Fruit and seed analysis revealed that figs, grapes, walnuts and, to a lesser extent, olives and plums were the most common at the Sant Antoni Market necropolis. The results suggest that fruits were collected both from well-known-cultivated trees (e.g., vine, fig, or olive) and

from species such as walnut and some species of *Prunus* sp., which were introduced to Catalonia after the Roman colonisation (Buxó, 2005a).

Walnut shells and grape pips have been documented in other Roman necropolises of Barcelona, as at Drassanes Reials (Piqué i Huerta and Ferré Trías, 2015) and at Vila de Madrid sites (Beltrán de Heredia Bercero et al., 2007), despite the limited number of carpological remains analysed. This preference for fruits accords with several archaeobotanical studies conducted in Roman cremation contexts in southern Europe, for instance, in Portugal (Costa Vaz et al., 2021) and the Italian Peninsula (Caracuta and Fiorentino, 2018; Mattered and Derreumaux, 2007; Robinson, 2002; Rottoli and Castiglioni, 2011). It differs, however, from data obtained in funerary contexts in Gaul (France and Belgium; Cooremans, 2008; Marinval, 1993), and Pannonia inferior (Croatia; Reed et al., 2019), where fruit tree remains were scarce or were not identified at all (Bouby and Marinval, 2004).

Additionally, high presence of fig, grape, and walnut remains has been attested at the necropolis of Porta Nocera at Pompeii (Mattered and Derreumaux, 2007) and in northern Italy (Rottoli and Castiglioni, 2011). Evidence of unconsumed charred figs and the fleshy parts of grapes suggests that they were more likely to have been placed on pyres as offerings to the dead, whereas walnut shells may have been banquet leftovers (Costa Vaz et al., 2021).

Each of these fruits bore particular cultural significance in Roman times. Figs and grapes were sacred to Bacchus and closely associated with Roman banquets. Figs were reported to symbolise fecundity, fertility, and richness, while grapes represented immortality, hopefulness, and resurrection (Rovira and Chabal, 2008). Walnuts, sacred to Jupiter and Proserpina, may have symbolised childhood/youth and the transition from childhood not only to adult life but also death. They were also usually associated with weddings, during which the husband cracked them open as a symbolic act (Costa Suárez-Torga et al., 2021; Rovira and Chabal, 2008; Serrano Cueto, 2014).

Plum genus remains, indistinguishable at a species level due to their high fragmentary status (Fig. 7), were identified in two structures of the necropolis. They were probably sweet/sour cherries (*Prunus avium/cerasus*), plums (*Prunus domestica*), or blackthorn (*Prunus spinosa*); peaches (*Prunus persica*) and almonds (*Prunus amygdalus*) were less likely (because of their morphology). All these species (except for blackthorn), were cultivated—and in the case of peach, plums, and cherries, introduced—post-Roman colonisation (Buxó, 2005a; Peña-Chocarro et al., 2019; Peña-Chocarro and Pérez Jordá, 2018; Sadori et al., 2009), as reported by Pliny the Elder (Plin. *Nat. His.* 15, 30). These fruits have also been found at other Roman cremation sites (Bouby et al., 2011; Caracuta and Fiorentino, 2018; Cooremans, 2008; Costa Vaz et al., 2021; Kreuz, 2000; Rottoli and Castiglioni, 2011, 2011oštarić et al., 2006; Zach, 2002). Conversely, numerous peach endocarps were recovered from the coeval necropolis of Drassanes Reials in Barcelona (Fig. 2) (Piqué i Huerta and Ferré Trías, 2015), suggesting their significant role as a foodstuff in Roman funerary feasts and offerings.

Despite their strong connection with Roman culture as symbols of virtue and hopefulness (Rovira and Chabal, 2008), olives were relatively scarce in the carpological assemblage of Sant Antoni Market. Olive remains were also absent from the archaeobotanical assemblage in the other two necropolises of *Barcino* (Drassanes Reials and Vila de Madrid; Beltrán de Heredia Bercero et al., 2007; Piqué i Huerta and Ferré Trías, 2015). Given that olive tree wood was very scarce in the city's fuel debris (Bianco et al., 2023) and has been thus in archaeobotanical assemblages up until now, it seems probable that olive tree cultivation was not widespread on the Barcelona plain.

5.4.2. Gathered fruits and nuts

The abundance of *Arbutus* berries at the Sant Antoni Market necropolis is a very specific data. The strawberry tree was part of the natural Mediterranean holm oak woodlands in the area and its wood served as fuel both for the city (Bianco et al., 2023) and for the necropolis in par-

ticular, as recorded in the present study. Its berries are edible, although they are sandy in texture, bland in taste, and slightly alcoholic.

Arbutus berries have been previously documented in the area of Barcelona, at the Iberian settlement of Turo de la Rovira (3rd–2nd centuries BCE; Riera Mora et al., 2020b). However, archaeobotanical studies in other *Barcino* funerary contexts (Beltrán de Heredia Bercero et al., 2007; Piqué i Huerta and Ferré Trías, 2015) and non-ritual contexts (Ravotto et al., 2016; Livarda, *pers. comm.*) have not identified this species.

Generally, *Arbutus* berries are absent from the carpological assemblages of funerary or ritual contexts in Europe (Bouby et al., 2011; Bouby and Marinval, 2004; Caracuta and Fiorentino, 2018; Costa Vaz et al., 2021; Marinval, 1993; Mattered and Derreumaux, 2007; Megaloudi, 2005; Reed et al., 2019; Robinson, 2002; Rottoli and Castiglioni, 2011; Rovira and Chabal, 2008) and non-ritual contexts in Italy (Bosi et al., 2011, 2015, 2020; Ciaraldi and Richardson, 2000; Mariotti Lippi et al., 2015, 2020), southern France (Alonso and Rovira, 2016; Buxó, 2005b; Figueiral et al., 2010a; Figueiral and Séjalón, 2014), and Catalonia (Alonso, 2005; Buxó, 2005a; Peña-Chocarro et al., 2019). Indeed, it has appeared in only two Roman contexts on the Iberian Peninsula (Peña-Chocarro et al., 2019), namely, at Irún (Peña-Chocarro and Zapata Peña, 1996) and Sagres (Queiroz, 2010), where the remains were discovered in an oven also containing charcoal fragments of strawberry tree wood.

Hence, we may assume that the raw *Arbutus* berry was not a feature of the Roman diet; indeed, Pliny the Elder observed that it was not esteemed and that the species name *unedo* derived from *unum edo*, that is, “I eat but one” (Plin. *Nat. Hist.* 15, 28). Possibly, as happens nowadays in some Mediterranean regions, it was used in jams or liqueurs, though these have left no trace in archaeobotanical assemblages (Alarcão-E-Silva et al., 2001; Soufleros et al., 2005).

The unusual occurrence of charred remains of *Arbutus* berries at the Sant Antoni Market could be attributed to the use of firewood to which the fruit was still attached. In fact, in contrast with other fruit or nut remains documented in the carpological assemblage, *Arbutus* berries were found in structures where its wood charcoal remains were also present (*Ustrinum*/20615, *Ustrinum*/20605, Indet. infill layer/20599, Fireplace/20560). Given that the strawberry tree was a decorative tree in Roman gardens (Gleason, 2019; Miró i Alaix et al., 2020), we may assume that its branches might have had an aesthetic/decorative function on pyres. Following this hypothesis, we would argue that cremations took place in autumn or later, according to the maturation phase of the tree's berries (Alarcão-E-Silva et al., 2001; Soufleros et al., 2005). However, it is also possible that deliberate food offerings of *Arbutus* berries (which were abundant in the Mediterranean environment) were placed on the funerary stacks at the Sant Antoni Market necropolis, representing a particular tradition of the area and a *unicum* that had never previously been documented in other similar sites.

Cornelian cherry and hazelnut were also documented, though to a lesser extent and in one structure only, confirming that they played a part in funeral rites – as in similar contexts elsewhere (Caracuta and Fiorentino, 2018; Filipović et al., 2020; Marinval, 1993). They may have been gathered from the natural riparian woodland on the Barcelona plain and ranges (Bianco et al., 2023), though it is also plausible that they were planted in gardens or cultivated, especially in the case of hazelnuts (Bouby et al., 2022; Mariotti Lippi et al., 2020).

Finally, six pine nuts were identified at the necropolis. In general, stone pine cones and nuts played a role in rituals during the Classical period, particularly during sacrifices associated with the cults of Mithras, Bacchus, Cybele, and Silvanus (Bakels and Jacomet, 2003; D'Auria and Di Pasquale, 2020; Livarda, 2008; Lodwick, 2015; Mariotti Lippi et al., 2020; Megaloudi, 2005; Rovira and Chabal, 2008; van der Veen et al., 2008) but also in burials and cremations, for example, in northern Italy, France, and in the necropolises of Drassanes Reials and Vila de Madrid (Fig. 2; Beltrán de Heredia Bercero et al., 2007; Bouby et

al., 2011; Marinval, 1993; Piqué i Huerta and Ferré Trías, 2015; Rottoli and Castiglioni, 2011). Stone pine grows in Mediterranean vegetation, and we cannot rule out the possibility that it was spread in Roman times for specific purposes (Sadori et al., 2015). It often graced Roman gardens as a decorative tree (D'Auria and Di Pasquale, 2020; Gleason, 2019), and its pine nuts were traded between the Mediterranean and Britain and central Europe (Bakels and Jacomet, 2003; Lodwick, 2015). Hence, their relative scarcity in the present funerary context is somewhat surprising.

5.4.3. Cereals

The absence of cereals in the Sant Antoni Market necropolis is also worthy of note because it accords with other Roman funerary contexts in the Iberian peninsula (Costa Vaz et al., 2021; Piqué i Huerta and Ferré Trías, 2015). Scarce cereal remains have also been observed in the Italian peninsula (Caracuta and Fiorentino, 2018; Castiglioni et al., 1992; Mattered and Derreumaux, 2007; Rottoli and Castiglioni, 2011). By contrast, they were abundant in Roman necropolises in Gaul (France and Belgium; Bouby and Marinval, 2004; Cooremans, 2008; Marinval, 1993; Preiss et al., 2005) and the Pannonia inferior (Croatia; Reed et al., 2019) and ritual pits in Germania (Germany; Zach, 2002). In short, notwithstanding the lacunose archaeobotanical data for the Roman period, variations in funerary practices may have existed between the Mediterranean and other continental regions.

5.4.4. Pulses

Pulses played a significant ritual role for Romans. According to Pliny the Elder, beans were thought to encase the soul at death and were consequently often used in the funerary feasts of *Parentalia*. The author added that “bean pottages” were usually offered to the gods during religious rituals and that these foods “dull the senses and provoke sleepless night attended with dreams” (Plin. *Nat. Hist.* 18, 30). Legumes such as lentils, peas, broad beans, and vetches were found in abundance in necropolises in Gaul (Bouby and Marinval, 2004; Cooremans, 2008; Marinval, 1993) and to a lesser extent at *Bracara Augusta* in present-day Portugal (lentils, peas, and broad beans; Costa Vaz et al., 2021), the Pannonia inferior (lentils and grass peas; Reed et al., 2019), northern Italy (lentils, peas, lupins, vetches, and broad beans; Rottoli and Castiglioni, 2011), and Pompeii (lentils, chickpeas, peas, and bitter vetches; Mattered and Derreumaux, 2007; Robinson, 2002).

However, legumes are often underrepresented in the archaeobotanical record for various reasons, including their lower resistance to high temperatures and post-depositional taphonomic processes (Tarongi Chavarri, 2022; Tarongi et al., 2020). No legumes have been documented in the necropolis analysed in southern Italy (Caracuta and Fiorentino, 2018); at the Sant Antoni Market necropolis, only eight cotyledons of peas were identified in the entire carpological assemblage.

5.4.5. Wild herbs and shrubs

Various wild herb seeds from local vegetation, which probably grew in the enclosures, were documented. According to their seasonality, these species provide an approximative indication of the moment of the year when cremations took place. On the one hand, the presence of *Chenopodium album*, *Echinochloa crus-galli*, *Rumex acetosella*, and *Polygonum convolvulus*, which were abundant in *Ustrinum* dump/20538 (FE7) and *Ustrinum*/20566 (FE10), respectively, suggest that cremation rituals occurred in late summer/early autumn because almost all these species bear fruit towards the end of the summer season (except for *Chenopodium album*, which matures slightly later). On the other hand, in *Ustrinum*/20605 (FE10), lower quantities of *Rumex acetosella* and *Echinochloa crus-galli*, the absence of *Polygonum convolvulus*, and the presence of *Arbutus* berry may indicate a late-autumn–winter season cremation.

5.4.6. Undetermined remains

Finally, a large number of undetermined remains, representing 38,5% of the total, were reported in the present study. Such charred amorphous fragments may have derived from the fleshy parts of seedless fruits or the remnants of dough-based food such as bread (which was a common offering in Roman cremations and rituals; Bouby and Marinval, 2004; Costa Vaz et al., 2021; Preiss et al., 2005). However, further chemical analyses and environmental scanning electron microscope (ESEM) observations of the assemblage will be needed to validate this hypothesis.

6. Conclusions

The analysis of archaeobotanical macro-remains such as wood charcoals and seed/fruits at the necropolis of Sant Antoni Market on the Barcelona plain has allowed us to shed light on the wood fuel and foodstuffs associated with Early Imperial funerary cremations on the north-western Mediterranean coast. This is a topic that has been under-researched.

The principal wood used for pyre construction was holm oak, a common tree in the local vegetation. Moreover, during the initial phase of use of the necropolis (i.e., the first half of the 1st century CE), deciduous oaks and, to a lesser extent, Ericaceae (strawberry tree and tree heather) and laurustinus were exploited for cremation purposes, though they sharply decreased in subsequent phases. At that time, deciduous oak, not very common within the urban fuel debris of Barcino, was probably forming limited mixed oak forests in the humid and shady areas of the inland hills behind the city (Serra de Collserola). Medium/large diameters of deciduous oak wood, proceeding from mature individuals, were exploited principally for cremation practices, according to dendro-anthracological analysis and the presence of tyloses. These results appear to be in line with Classical iconographic representations of pyre structures comprising alternating layers of straight and consistent logs that were designed to efficiently reduce the deceased to ashes. Moreover, the presence of bark in the anthracological assemblage and frequent radial cracks on transverse sections of the charcoal fragments may indicate that the logs were not debarked and in some cases were not well-dried.

Hence, we hypothesise that the decrease of deciduous oak in the anthracological spectra reflects a change in the composition of the surrounding forest consequent upon human agency and climate variability. Given that deciduous oaks were already threatened and limited in expansion by the drier environment during Roman times, the exploitation of mature oak trees for cremations may have ensured their reduction in favour of holm oak, which was more resistant and resprouted more rapidly after disturbances. This assumption could be reliable, in the case that wood procurement for cremations were carried out by funerary enterprises and took place in the same well-defined areas throughout the century in question. However, this topic is very difficult to validate in lack of further information on a local scale. Moreover, if fuel provisioning was carried out by the deceased family in their own lands - at least for the wealthiest that has this privilege- or if wood was bought at the market from different providers, such a trend would not necessarily be related to vegetation dynamics.

Some woody species may have played a symbolic or sensorial function in cremation rituals or have been part of objects or furniture placed on pyres. Aleppo and mountain pines, and to a lesser extent, juniper and cypress may have been included for their scented properties or their good flammability. Pines were considered intercessors between the living and the dead and may have been used as beams or components of funerary beds to transport the deceased to the pyre, though this is difficult to assess absent comparative examples and a lack of wood technology studies on other areas of the Empire. Boxwood, a symbol of immortality and liberty, may have been used in the construction of objects placed on the stack or, again, as a component of funerary beds.

Mastic and rockroses may have served as fire kindling or used for their odour, while honeysuckle and laurustinus may have been used as an embellishment on account of the attractiveness of their flowers. Finally, pruning leftovers from fruit trees (olive, grapevine, walnut, plums, and the apple family)—whether their use was symbolic or functional—confirm the presence of arboriculture in Barcino.

In the present study, a high diversity of woody species was documented in the fuel used for cremation and ritual purposes. However, the number of taxa was lower than that for the urban fuel waste produced in the vicinity of Barcino; this was probably an indication of the selectivity required when building the pyres and the concentrated nature of the charcoal fragments analysed.

Cultivated fruits such as figs, walnuts, and grapes were the most abundant offerings and/or feast remains at the Sant Antoni Market necropolis; by contrast, pulses were scarce and cereals were absent. These findings align with similar patterns observed in other regions of southern Europe, where generally fruits were more relevant than cereals in funerary practices. Finally, a noticeable amount of *Arbutus* berry remains was recorded, representing a unique and unusual case up to date in similar Roman contexts. It may be that their presence was attributable to the use of firewood containing still-attached fruits, though it seems more plausible that they were placed intentionally on the pyre as offerings, as seemed to be the case with cornelian cherries, hazelnuts, and pine nuts.

In conclusion, the present study provides valuable insights into the behaviour of Romans towards plant resources on the western Mediterranean coast, demonstrating the importance of the integration of this type of analysis in Classical archaeology in deepening our knowledge of local and regional traditions.

Author contributions

S. Bianco took charge of sediment flotation, charcoal analysis, the anthracological and dendro-anthracological method, main conceptualization, figures creation and main data curation, interpretation and writing the original draft. M. Tarongi was responsible of fruits/seeds analysis, carpological method and carpological data curation. E. Allué; and Ll. Picornell-Gelabert supervised respectively the anthracological and the dendro-anthracological data acquisition and provided the main revisions of the draft. E. Hinojo was the director of the archaeological intervention at Sant Antoni Market site, responsible of archaeological interpretations and sediment samplings collection. A. Dufraisse supervised the dendro-anthracological method. C. Miró; coordinated the Pla Bàrcino project, facilitating the collection and study of samples. Finally, S. Riera is the PaleoBarcino project P.I., thanks to which the present study was conceptualized and realized. He was responsible for the project administration, funding acquisition and provided a main revision of the draft.

Data availability

Datasets related to this article can be found as Supplementary Materials.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quaint.2023.10.008>.

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