Journal of Archaeological Science 180 (2025) 106266

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: www.elsevier.com/locate/jas

Using intestinal parasites to identify the utilization of archaeological structures: A 12th-13th century sewer systems from an Islamic *funduq* (Murcia, Spain)

Ramón López-Gijón [a,b,*], Alicia Hernández-Robles [c,d,**], Salvatore Duras [a,e], Mireia Celma [c], Ana Curto [b,f], José Ángel González-Ballesteros [c], Benjamin Dufour [g], Matthieu Le Bailly [g], Jorge A. Eiroa [c]

[a] *Laboratory of Anthropology, Faculty of Medicine, University of Granada, Av. de la Investigación 11, 18071, Granada, Spain*
[b] *Hercules laboratory, University of Évora, Largo Marquês de Marialva 8, 7000-809, Évora, Portugal*
[c] *Department of Prehistory, Archaeology, Ancient History, Medieval History and Sciences and Historiographical Techniques, Faculty of Letters, University of Murcia, Campus de La Merced, 30001, Murcia, Spain*
[d] *Department of Medieval History and Sciences and Historiographical Techniques and Laboratory of Biocultural Archaeology, Faculty of Philosophy and Letters, University of Granada, Campus Universitario de Cartuja, 18071, Granada, Spain*
[e] *Faculty of Medicine, University of Sassari, Viale S. Pietro, 07100, Sassari, Italy*
[f] *IN2PAST, Associate Laboratory for Research and Innovation in Heritage, Arts, Sustainability and Territory, 7000-809, Évora, Portugal*
[g] *Université Marie & Louis Pasteur, CNRS UMR 6249 Chrono-Environment, 16 route de Gray, 25030, Besançon Cedex, France*

A R T I C L E I N F O

Keywords:
Bioarchaeology
Funduq
Sewer and drainage system
Islamic Europe
Paleoparasitology
Paleopathology

A B S T R A C T

The discovery of specific parasites in archaeological contexts provides unique insights into the hygiene, sanitation, and socioeconomic dynamics of ancient populations, as well as their patterns of mobility. Paleoparasitological evidence offers a window into the spread of infections across different regions and time periods. This investigation leveraged paleoparasitology to explore the utilization of archaeological structures, specifically the water drainage system of a 12th-13th century *funduq* in the ancient Islamic city of Murcia, Spain. Through a systematic analysis, parasitic findings were compared with archaeological evidence, revealing a strong correlation between the presence of roundworm and whipworm eggs in wastewater channels and their functional role. In contrast, the absence of parasitic eggs in the clean water system further confirmed the distinct purposes of the pipes. This approach confirms paleoparasitology as a powerful tool for interpreting the use of ancient infrastructure.

1. Introduction

The study of parasites in archaeological contexts offers important insights to the life conditions of past populations (Le Bailly et al., 2021; Mitchell, 2024). Data on their presence can shed light on hygienic-sanitary (Le Bailly et al., 2014; Rabinow et al., 2024) and socioeconomic (Trigg et al., 2017) conditions and yield evidence of population movements (Araújo et al., 2013; Slepchenko, 2020).

The number of paleoparasitological studies has increased over recent years (Gaeta and Fornaciari, 2022; Mitchell, 2023a) due to technological improvements and the development of paleoparasitology as a scientific discipline (Ferreira et al., 2014). Such studies include analyses of materials from individuals (Roche et al., 2021; López-Gijón, 2023) and archaeological structures (Mitchell, 2015a; Graff et al., 2020). Sediments that accumulate fecal remains have provided valuable evidence on specific parasites associated with archaeological structures (López-Gijón et al., 2024). Research to date has focused on latrines and cesspits in historical periods (e.g., Florenzano et al., 2012; Chessa et al., 2020; Ledger et al., 2021). However, fecal remains that accumulate in sanitary pipework can also be an important source of paleoparasitological information (Slepchenko et al., 2023), complementing systematic studies on the functionality of archaeological structures (Langgut

* Corresponding author. Laboratory of Anthropology, Faculty of Medicine, University of Granada, Av. de la Investigación 11, 18071, Granada, Spain.
** Corresponding author. Department of Medieval History and Sciences and Historiographical Techniques and Laboratory of Biocultural Archaeology, Faculty of Philosophy and Letters, University of Granada, Campus Universitario de Cartuja, 18071, Granada, Spain.
E-mail addresses: ramonlopez131094@correo.ugr.es (R. López-Gijón), ahernandezrobles@ugr.es (A. Hernández-Robles).

https://doi.org/10.1016/j.jas.2025.106266
Received 31 January 2025; Received in revised form 16 May 2025; Accepted 17 May 2025
Available online 26 May 2025

et al., 2016; Langgut, 2022; Marković et al., 2024).

Limited paleoparasitological research has been published from the historic period of Al-Andalus (Cunha et al., 2017; López-Gijón et al., 2023a), in particular in the case of archaeological structures (Knorr et al., 2019), on which extensive archaeological information is available for the contextualization of findings.

This study compares paleoparasitological findings in sediments from drainpipes found in a 12th-13th century *funduq* in Murcia with archaeological and documentary evidence of their function. By doing so, this research aims to confirm the potential of paleoparasitology as a valuable and underutilized tool in archaeological investigation (Reinhard, 1992). Our aim is to explore the usefulness of this type of study and the value of its systematic application in a multidisciplinary approach to archaeological research.

2. Material and methods

2.1. Archaeological site

The San Esteban archaeological site covers a large area (around 10,000 m2) of Arrixaca, the main extramural neighborhood of Medieval Murcia (Spain) (Fig. 1). Excavations and documentary sources reveal that Arrixaca was urbanized between the 11th and 13th c., growing to a size of around 30 ha, during a northern and western expansion of Murcia, which was established earlier, in the 9th century (Eiroa Rodríguez et al., 2021).

The site was first explored in 2009 during a rescue excavation in San Esteban Garden before the planned construction of an underground parking lot (Robles Fernández et al., 2011). This excavation revealed one of the most important archaeological discoveries of Islamic Murcia for its size and the number of spaces identified, including houses, a cemetery, commercial buildings, religious constructions, and a network of main and secondary streets (Eiroa Rodríguez et al., 2019; 2021; Robles Fernández et al., 2011). Consequently, the construction plan was rejected, and the area was classified in 2011 as a *Bien de Interés Cultural* (*BIC* in Spanish initials). Archaeological excavations resumed in 2018 for an interdisciplinary investigation of the structures at the site. Three excavation campaigns were carried out between 2018 and 2023, followed by months of laboratory work.

Besides the remains identified in the San Esteban archaeological site, the neighborhood had a surrounding wall and contains a minor palace (*Dār aṣ-Sugrà*) as a residential and power-projection space, the *Aljufía* acequia (uncovered water channel), and housing for foreigners, who may have been Italians, according to references in the poem *Qaṣīda Maqṣūra* by Ḥāzim al-Qarṭāŷannī (1211–1285) and in the *Cantigas* of Alfonso X (Eiroa Rodríguez et al., 2021). *Arrixaca* can be described socioeconomically as a central urban space, with all the usual contemporary urban elements.

Samples examined in this paleoparasitological study derive from the building designated "Building I" (Fig. 2). This is the largest documented construction in the San Esteban archaeological site (surface area of 410 m^2) and has been identified as a *funduq*, providing lodging for travelers and traders and space for their goods in the city of Murcia between the 12th and 13th c. (Hernández Robles, 2022; Eiroa Rodríguez et al., 2021). *Fanādiq* (plural of *funduq*) are typically large buildings of one or two floors arranged around a central patio (Torres Balbás, 1946; Constable, 2003). They have an entrance, patio, latrines, and rooms for lodging, storage, or office use, and they habitually possess structures for water supply and drainage. Other possible but not inevitable elements include kitchens, stables, and religious spaces (Hernández Robles, 2022). According to written sources, *fanādiq* were a common feature of Islamic cities between the 8th and 13th c. (Constable, 2003). As in the case of Arrixaca, they offered lodging and warehouse space to traders and travelers of any origin (Constable, 2003).

The *funduq* has a rectangular ground plan, with a central patio surrounded by four walkways and porticoed in the northeast area, where three perimetral corridors are found: a double corridor to the north, a single corridor to the east and another to the west. Excavations have revealed that the building was constructed in three phases between the 12th and 13th c. Residential areas have been identified in eastern and northern parts of the building and service areas (latrines and kitchen) in western and northwestern areas, which were more compartmentalized and had smaller rooms.

The water system observed in Building I is more complex than typically found in dwellings in Al-Andalus. It includes a well in the west corridor, a set of water drainage pipes for ground floor rooms and drainpipes within the walls of the building. In total, the western/northwestern part of the building contained a total of ten brick, and two ceramic, drainpipes (Fig. 3) (Hernández Robles, 2022).

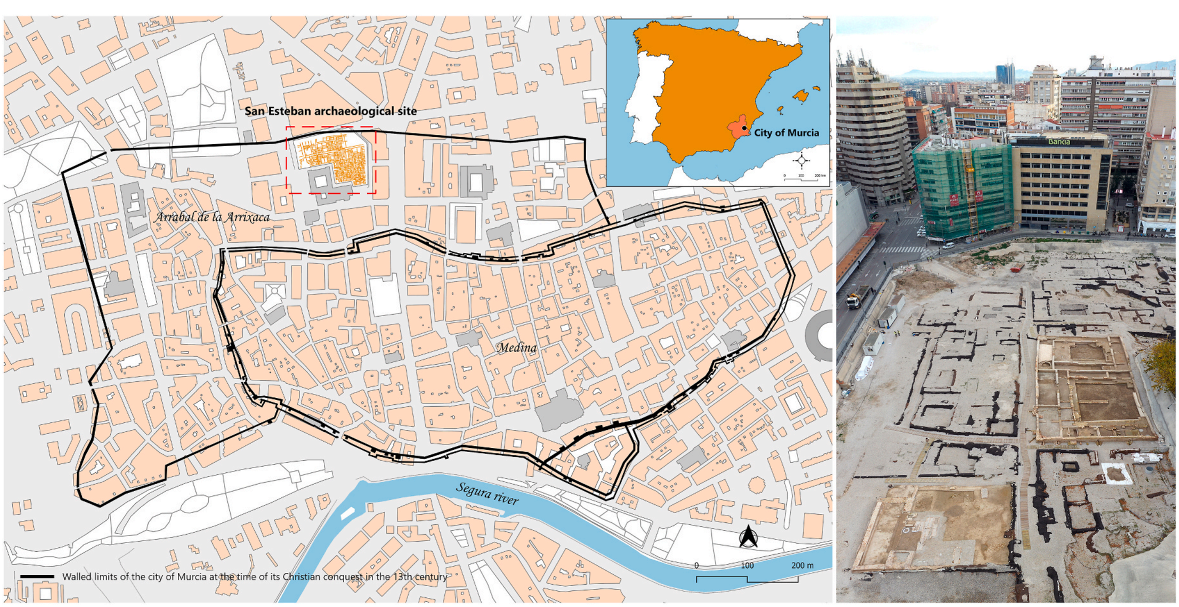

Fig. 1. Map of the San Esteban archaeological site and aerial photo of the area explored in this study. Author: San Esteban Project-UM ©

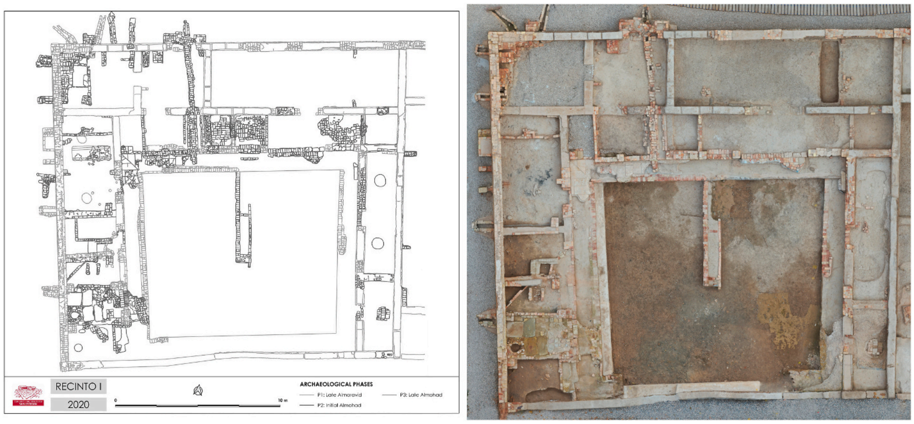

Fig. 2. Floor plan and photograph of Building 1. Author: San Esteban Project-UM ©

Fig. 3. At the top, photograph of Building I from the northwest, showing the drainpipes emerging from the building. At the bottom, detail photographs of the drainpipes (correspondence with D-9, D-8 and CP-1 in Fig. 5). Author: San Esteban Project-UM ©

2.2. Historical context

The political, socioeconomic, and demographic growth of Murcia during the 12th c. positioned it as one of the main capitals of Al-Andalus until its conquest by Castilian troops in 1243 (Jiménez Castillo, 2013). This conquest was followed by a reduction in the population of Murcia and the depopulation of some neighborhoods, including Arrixaca (Jiménez Castillo, 2013). There was a major boost to the urbanization of Arrixaca in the 12th c, when the city was controlled by the Almoravid dynasty, and later under the government of Ibn Mardanīš, when it became the capital of eastern Al-Andalus *(Šarq Al-Andalus)* (Eiroa Rodríguez and Gómez Ródenas, 2019). Ibn Mardanīš granted a *funduq* to Valencia in his 1149 treaty with Genoa and to Denia in his 1150 treaty with Pisa, underlining the connection of eastern Al-Andalus with Mediterranean commerce and Italian traders (Constable, 1997). Hence, Arrixaca was an urban space that was far from being peripheral or secondary and occupied a central commercial and economic position.

There is fragmentary documentary evidence on the presence of *fanādiq* in Al-Andalus (Constable, 2003; Hernández Robles, 2022). However, archaeological investigation of this type of building only started in the 1990s in the Iberian Peninsula. Researchers who studied the *al-funduq al-ŷadīd* of Granada (Fig. 4.) from the Nasrid period (14th and 15th c.), known as the *Corral del Carbón*, described it as the sole preserved Andalusi *funduq* (Hernández Robles, 2021; Torres Balbás, 1946).

Written sources refer to hundreds of *fanādiq* in the cities of Al-Andalus, which were commonly described as featuring “markets, baths, and a *funduq*” (Constable, 2003; Hernández Robles, 2022). The

Fig. 4. Example of *funduq*. *Funduq al-ŷadīd*, known as the *Corral del Carbón* (Granada, Spain). Author: Alicia Hernández Robles.

funduq was always in a strategic location on main streets or intersections and near the main market area, the *Aljama* mosque, baths, shops, or city gates (Constable, 2003; VV.AA, 2000; Hillenbrand, 1994). Four of the six buildings proposed as possible *fanādiq* in the city of Murcia, dated between the 11th and 13th c., were found near baths that may have been used by the travelers or traders from the *funduq* (Hernández Robles, 2021). At the San Esteban archaeological site, Building I is documented as being on the main street (street Ñ) at an intersection with a secondary street (street N).

Some excavated buildings interpreted as possible *fanādiq* in the Iberian Peninsula possess complex water supply and drainage systems, providing numerous points of access to water (e.g., wells, fountains, or basins) and multiple pipes/gutters for its drainage from latrines, patios and rooms, among other spaces (Reklaityte, 2012). The finding of downpipes that connected with ground floor drainpipes, as in the *funduq* of Corretgeria Street in Valencia (Martí Oltra and Burriel Alberich, 2008), suggests the possible presence of latrines on the top floor that had left no archaeological traces (Hernández Robles, 2021).

2.3. Method

During the archaeological campaigns of 2019 and 2020, sediment samples were systematically gathered from all structures (pipes, gutters) that comprised the water supply and drainage system in Building 1 (the *funduq*), totalizing 39 samples. Control samples of sediment (n = 4) were also taken from archaeological units outside the water system (Le Bailly et al., 2021). The sampling scheme was determined by the preserved archaeological deposits within the structures and their dimensions. In those structures where little archaeological deposit was preserved, only one sample per structure could be taken (contexts: D-2, D-3, CP-1). However, in other contexts, more samples could be taken due to the significant archaeological deposits found (contexts: D-6 and D-9) and the dimensions of the pipe, which had a long extension (context: D-1).

Each sample, weighing 2–5 g, was collected using a fresh pair of nitrile-free gloves (López-Gijón et al., 2024) and a disposable plastic spoon (Sianto et al., 2018) to avoid cross contamination. Samples were individually wrapped in aluminum foil, placed in a labeled zip seal plastic bag (López-Gijón, 2023), and stored in a Styrofoam box for insulation from the light and major changes in temperature (Haber-Uriarte et al., 2020). Samples were analyzed in the Physical Anthropology laboratory of the University of Granada (Spain) and a second analysis was conducted in the Chrono-environment laboratory of the University of Franche-Comté (France). Samples were treated using the standard rehydration, homogenization and micro-sieving (RHM) protocol used in Besançon laboratory (Dufour et al., 2013). Briefly, samples were rehydrated for seven days in aqueous solution of 50 % 0.5 % trisodium phosphate (Na_3PO_4) and 50 % 5 % glycerol ($C_3H_8O_3$), with drops of 10 % formaldehyde (CH_2O). The material was then ground in a porcelain mortar, immersed for 1 min in an ultrasound bath, and passed through 315 μm, 160 μm, 50 μm, and 25 μm micro-sieves under a constant stream of tap water. Material trapped on the 50 μm and 25 μm micro-sieves was collected and studied under light microscopy (Olympus CX43 and Leica DM, 2000 at 100, 400, and 600 M coupled to Olympus SC-50 camera and Leica ICC50HD camera), using Olympus CellSens software to process the images. Twelve slides were analyzed per sample, following the standard for this type of study. In total, 516 slides were used. Parasite eggs were identified by size and morphological characteristics, following reference manuals (Thienpont et al., 1986; Roberts and Janovy, 2008).

3. Results

Eggs of roundworm (n = 48) and whipworm (n = 20) were detected in this study. Roundworm eggs were identified by their characteristic mamillated shell (see Fig. 6a), ovoid/elliptic shape, and size (50.2–70.1 μm long, 42.3–50.2 wide), although decorticated *Ascaris* were also found (see Fig. 6b). Whipworm eggs were identified by their lemon shape, bipolar protuberances (polar plugs), smooth surface, thick shell, and size (49.8–57.6 μm long, 21.9–27.2 wide) (see Fig. 7). Due to the polymorphism of the shell, non-parasitic elements (artefacts) can be sometimes misidentified - and identification of artefacts (e.g. pollen, plant cells, psocid insects, etc.) is an integral part of the diagnostic process to avoid common misdiagnosis in the laboratory (see Reinhard, 2017).

Out of the total of 43 samples gathered for study, geohelminth eggs were observed in 12 samples (27.9 % of the total) (Table 1); specifically, roundworm eggs were found in 12 samples (27.9 %), whipworm eggs in 5 (11.6 %), and the eggs of both parasites in 5 (11.6 %) (Table 1).

Out of the 10 drainage pipes studied (Fig. 5), (50 %) were positive for parasites; specifically, roundworm eggs were found in 5 drainpipes (50 %) and whipworm eggs in 2 (20 %). In addition, a sample (UE40074) associated with to a latrine and the drainage pipe UE 3194 D-7 was positive. No control samples were positive for parasites, as well as the ceramic pipe sample.

These results have made it possible to distinguish the use of different hydraulic structures for the evacuation of dark water or clean water. By dark water it is understood wastewater containing urine and fecal remains, for example, collected from latrines to the public street sewer. Clear water means water free from contamination, for example, rainwater drained from roofs, terraces, or patios to the public street sewer (Reklaityte, 2012).

The drainage pipes hypothesized to contain wastewater have been confirmed with at least one positive result for parasites, except for D-5. However, in the case of D-5, its use for wastewater evacuation has been maintained based on the functional interpretation of spaces and phases in the building. The functional hypothesis of the structures studied was proposed based on the structures documented in the archaeological excavation, its location in the building and its relationship with other elements inside the spaces.

Of relevance are the results from the samples taken from drainpipes D-8 and D-9. The positive parasite results in these two drainpipes are significant because they were not connected to any interior space on the ground floor, and they indicate fecal contamination, therefore from an unpreserved upper floor in the three different phases of the building. This provides rare evidence for the existence of a latrine, or a wastewater evacuation point on the unpreserved upper floor, something previously proposed for a funduq but unconfirmed through archaeology alone (Martí Oltra and Burriel Alberich, 2008). Without this analysis, such an interpretation would remain purely hypothetical, as the absence of preserved upper-floor structures limits architectural interpretation

Table 1
Parasite egg findings and hypothetical functionality for each structure in the drainage system of the *funduq*.

Context	Phase of use	Hypothetical functionality	Sample	Parasite findings and number of eggs found	Type of drainpipe
D-1 Drainage UE 7045	II/ second half of the 12th c.	Clean water drainage from upper floor	E2 7045a (1)	–	Clean water
			E2 7045b (2)	–	
			E2 7045c (3)	–	
			E2 7045d (4)	–	
			E7 7045 (5)	–	
			E7 7045 (6)	–	
			E7 4045 (7)	–	
			E7 7045 H-2	–	
D-2 Drainage UE 3174	III/first half of the 13th c.	Clean water drainage	Street Ñ 3174 (1)	–	Clean water
D-3 Drainage UE 3172	III/first half of the 13th c.	Clean water drainage	Street Ñ 3172 (1)	–	Clean water
D-4 Drainage UE 3179	I and II/ 12th c.	Wastewater drainage	E1 3179 (1)	–	Dark water
			E1 3179 (2)	*Ascaris* sp. (2)	
D-5 Drainage UE 3184	I and II/ 12th c.	Wastewater drainage	Street Ñ 3184 (1)	–	Dark water
			Street Ñ 3184 (2)	–	
D-6 Drainage UE 3193	III/first half of the 13th c.	Wastewater drainage (latrine)	Street N 3193 (1)	*Ascaris* sp. (3)/ *Trichuris* sp. (4)	Dark water (latrine)
			Street N 3193 (2)	*Ascaris* sp. (4)/ *Trichuris* sp. (6)	
			Street N 3193 (3)	–	
			Street N 3193	*Ascaris* sp. (2)	
			Street N 3193a	*Ascaris* sp. (3)/ *Trichuris* sp. (4)	
			Street N 3193c	–	
D-6 Soil UE 40099	III/first half of the 13th c.	Deposit inside the wastewater drainage (latrine UE 3193)	Street N 40099 (1)	*Ascaris* sp. (6)	Dark water (latrine)
			Street N 40099 (2)	*Ascaris* sp. (7)/ *Trichuris* sp. (3)	
			Street N 40099b	–	
D-7 Drainage UE 3194	III/first half of the 13th c.	Wastewater drainage (latrine)	Street N 3194 (1)	*Ascaris* sp. (2)	Dark water (latrine)
			Street N 3194 (2)	*Ascaris* sp. (5)/ *Trichuris* sp. (3)	
			Street N 3194 (3)	–	
D-8 Drainage UE 3204	III/first half of the 13th c.	Wastewater drainage	Street N 3204 (1)	*Ascaris* sp. (5)	Dark water
			Street N 3204a	–	
D-9 Drainage UE 40088	I and II/ 12th c.	Wastewater drainage	Street N 40088 (1)	–	Dark water
			Street N 40088 (2)	–	
			Street N 40088 (3)	*Ascaris* sp. (6)	
			Street N 40088d	–	
D-10 Drainage UE 3195	I, II, and III/12th c. and first half of the 13th c.	Clean water drainage	Street N 3195 (1)	–	Clean water
			Street N 3195 (2)	–	
			Street N 3195 (3)	–	
CP-1 Ceramic pipe UE 40022	III/first half of the 13th c.	Clean water ceramic pipe	E16 40022	–	Clean water
S-1 Structure UE 40074	III/first half of the 13th c.	Wastewater drainage (latrine UE 3194)	E1 40074a (1)	–	Dark water (latrine)
			E1 40074b (2)	*Ascaris* sp. (3)	
UE 40128		Street level (street N)	Street N 40128 CS	–	Control sample
UE 40020		Organic soil with numerous charcoals (E1)	E1 40020 CS	–	Control sample
UE 40142		Soil beneath brick structure of latrine UE 3194	E1 40142 CS	–	Control sample
UE 40094		Clayey soil in E−3	E3 40094 CS	–	Control sample
UE 40332		Soil from ground associated with combustion structures E16 (phase II)	E16 40332	–	Other structure

relying on stratigraphy.

4. Discussion

In this analysis of a 12th-13th c. *funduq* in Murcia, only structures archaeologically designated as wastewater systems contained the eggs of intestinal parasites, namely roundworm and whipworm. In contrast, clean water systems were always free of these parasites (Table 1).

There is documentary and archaeological evidence of the wastewater and clean-water pipework in the building (see Table 1). The drainpipes in the northwest and in the corridor in the west suggest that this part of the building was used for supplies and services, including sanitation, with a room that served as latrine (Hernández Robles, 2022). The supply and drainage of water would be a major concern in the *funduq*, given the crucial importance of body hygiene in Islam (Reklaityte, 2012). *Fanādiq* frequently had at least one latrine, and some may have had collective latrines. Clean water would be available to travelers from a well or water tank for cleaning and washing as well as for drinking and cooking (Constable, 2003; Reklaityte, 2012). *Funduq* rental contracts underlined the obligation to clear human and animal waste (Hernández Robles, 2022), and rubbish disposal and pipe cleaning costs appear in the accounts of some *Fanādiq* (Constable, 2003; Goitein, 1983). Leo Africanus reported in his Description of Africa published in 1530 (translation by S. Fanjul, 1995) that the 200 inns of Fez had fountains, latrines, and drainpipes for waste removal and that the owners were responsible for their cleaning.

It has been verified trough the excavations that two structures in the same room on the ground floor were latrines. There is also evidence of a clean water system to drain and gather rainwater falling on the roof, patio, and perhaps terrace.

Until now, archaeological work had not been able to confirm the presence of latrines on upper floors in Andalusi buildings. Reklaityte (2012), who described the general characteristics of latrines in Al-Andalus (entrance, ventilation, location, paving, and decoration), could not confirm their presence. Drainpipes documented in houses from the Andalusi period (e.g., in Murcia [Guillermo, 1998; Navarro Palazón and Jiménez Castillo, 2010] and Córdoba [Aparicio Sánchez, 2008]), have been interpreted as serving to drain rainwater from roofs. In a study of the *funduq* in Corretgeria Street, Valencia, one drainpipe was documented in the patio and another within a room. The archaeologists suggested that it might have taken water from a sink or latrine on the upper floor, although they could not rule out that its function was to drain water from the roof (Martí Oltra and Burriel Alberich, 2008). The present work is an additional proof that paleoparasitological studies can help to settle these questions (Reinhard, 1992; Langgut et al., 2016). In our case study, samples were taken from three structures (two brick drainpipes and one ceramic pipe) that would allow water to be drained from the upper floor. Sediment samples from the drainpipes D-8 and D-9 (3204 [1] and 40088 [3]) contained several roundworm eggs, indicating the presence of fecal remains and suggesting a possible unpreserved upper floor latrine or wastewater drainage point. The fact that no parasites were detected in the sample from the ceramic pipe supports its role in the clean water system of the building.

Sample 40074b (2) was taken from a quadrangular brick structure (S-1 in Fig. 5) attached to a latrine and connected to its drainpipe (Fig. 8). The possible use of this structure could be a sewage disposal point.

Shortcomings of this type of study include the loss of parasitic evidence through taphonomic processes (Morrow et al., 2016), limiting the findings of parasitic dispersion phases to those with more resistant shells such as geohelminths (Wharton, 1980). Other parasitic species with lesser resistance capacity and fewer eggs have not been detected at archaeological sites in the southern Iberian Peninsula (López-Gijón et al., 2024). The preservation of parasitic evidence is less favorable under the conditions and temperatures that characterize semiarid areas (Rodrigo et al., 1999; Bouchet et al., 2003; Mitchell et al., 2022) compared with more humid climates, e.g., in the Northern Iberian Peninsula (Maicher et al., 2017; López-Gijón et al., 2023b; Revelles

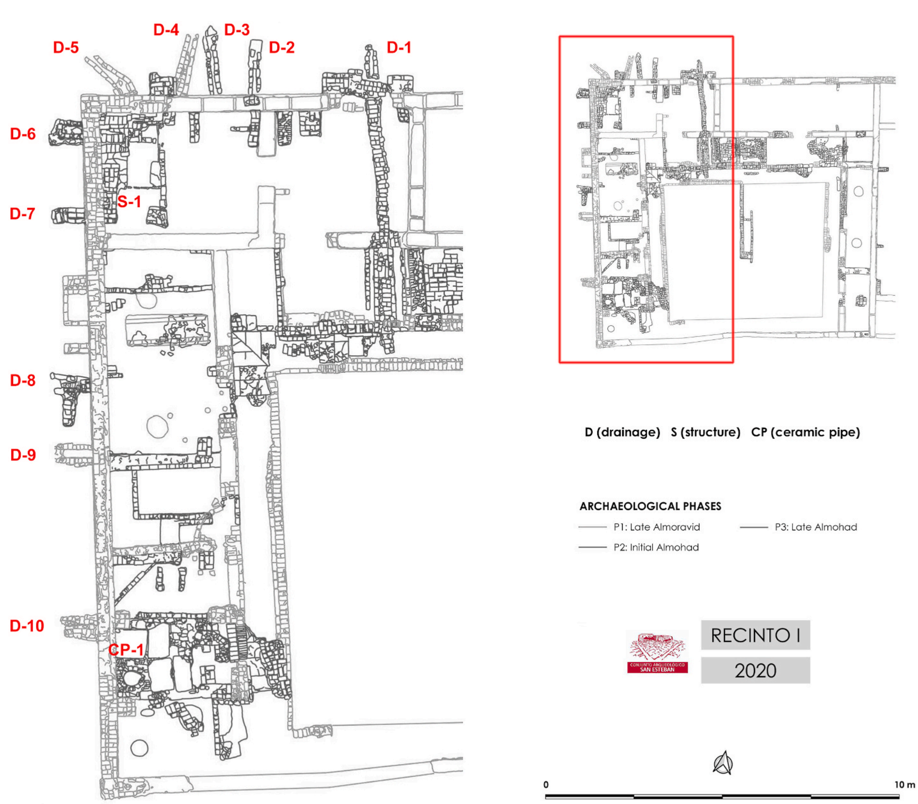

Fig. 5. Detail plan of the contexts sampled in Building 1. Author: San Esteban Project-UM ©

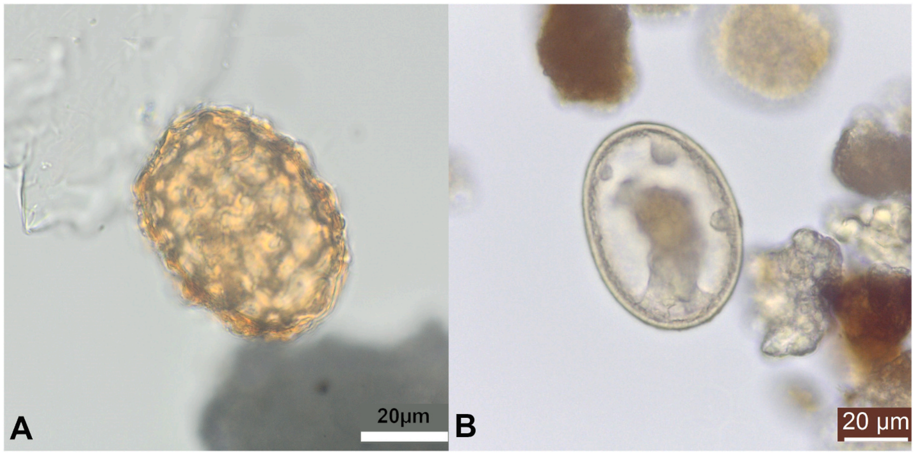

Fig. 6. A) Egg of *Ascaris* sp. with mamillated coat (70,1 x 49,07 μm); B) Decorticated egg of *Ascaris* sp. (66.35 × 48.03 μm).

Fig. 7. Egg of *Trichuris* sp. (52.80 × 25.71 μm).

Fig. 8. Photograph of the latrines of Building I. On the left, the latrine that connects with the D-7 drainage pipe and the quadrangular structure S-1. On the right, the latrine that connects with the D-6 drainage pipe. Author: San Esteban Project-UM ©

et al., 2017; Tejedor-Rodríguez et al., 2021). This effect is reflected in the small number of parasitic eggs found to date in the southern Iberian Peninsula (Knorr et al., 2019; López-Gijón et al., 2022, 2023c, 2024). Given the consequent possibility of false negative results, it is therefore important to take multiple sediment samples from each structure under study (López-Gijón, 2023).

It is almost impossible to distinguish morphologically between the species of roundworm (A. *lumbricoides* vs. A. *suum*) (Liu et al., 2012; Leles et al., 2012) and whipworm (T. *trichiura* vs. T. *suis*) (Betson et al., 2015) that infect humans *versus* pigs. Given that the infection of humans by pig parasites cannot be completely ruled out (Nejsum et al., 2012; Silva et al., 2021), the parasites are classified as either *Ascaris* sp. or *Trichuris* sp. in the present study. Although the archaeozoological study of the San Esteban archaeological site shows no evidence of pigs or wild boar (García-García, 2020, unpublished), contact with these animals may have occurred in other places, due to the mobility of travellers. It is possible that *funduq* users from Christian areas have been in contact with pigs (Banegas López, 2010), which also feature in the zooarchaeological record of Al-Andalus, although in small numbers (García-García, 2017; Grau-Sologestoa, 2023).

The health effects of these intestinal parasites on the host depend on their number and can include diarrhea, stomach cramps, anemia, malnutrition, stunted childhood growth, and cognitive impairment, while severe intestinal obstruction has been reported in severe cases of ascariasis (Jourdan et al., 2018).

Paleoparasitological research in Al-Andalus has been limited (Cunha et al., 2017; Knorr et al., 2019; López-Gijón et al., 2023a). Sediment samples evidenced the presence of roundworm eggs in Córdoba and Mértola (Knorr et al., 2019) and of roundworm and whipworm eggs in Silves (Cunha et al., 2017). These parasites have been associated with poor sanitation and water supply conditions, with the absence of handwashing, and with the intake of feces-contaminated food or water (Jourdan et al., 2018). Despite the religion-based focus on bodily hygiene in Al-Andalus (Knorr et al., 2019), the risk of parasitosis might have been increased by the utilization of human fecal remains to fertilize crops, as reported by Ibn Bassal (11th-12th c.), together with that of other fecal material of animal origin (Varisco, 2016; Watson, 2001; Knorr et al., 2019). These geohelminths have been the most frequently detected parasites in ancient European material (Gaeta and Fornaciari, 2022), due to the high resistance of their eggshells and their strong fecundity. Thus, up to 200,000 eggs/day are produced by a female of *Ascaris lumbricoides* and between 3000 and 20,000 eggs/day by a female of *Trichuris trichiura* (Roberts and Janovy, 2008).

The intestinal parasites observed in Al-Andalus are similar to those found in other medieval Islamic populations (Cunha et al., 2017; Knorr et al., 2019) and in contemporary Christian populations in the Iberian

Peninsula (Hidalgo-Argüello et al., 2003), as well as in the rest of Europe (Mitchell, 2015b, 2023b), including the Italian Peninsula (Chessa et al., 2020; Florenzano et al., 2012; Heirbaut et al., 2011; Ledger et al., 2021; Roche et al., 2019, 2021). Specifically, ascariasis is described in "Kitāb al Qānūn fi-l Tibb" by Avicenna (Canon Medicinae) (Hoeppli, 1956; Cordero del Campillo, 1980) and in other medieval medical texts from the Islamic world (Cox, 1990, 2002). Ascariasis is also mentioned by important physicians (Casal and Casal, 2004) such as Abulcasis in his *Altasrrif*, later known as *Metodus medendi* (Cordero del Campillo, 1980). However, there are no references to trichuriasis in the medical writings of Al-Andalus.

A key study limitation is the inability to associate the parasitic eggs with individuals, given that skeletal remains were not considered (López-Gijón et al., 2024). Paleoparasitological studies on infrastructures will have to be completed with paleoparasitological studies carried out on skeletal remains, which will allow us to approach the levels of prevalence of intestinal geohelminths in these populations.

It is therefore not possible to distinguish between Islamic and Christian populations or between locals and foreigners using the *funduq*, although the cultural material obtained and the sanitary conditions all point to its utilization by Muslims (Casal and Casal, 2004; Cordero del Campillo, 1980; Gutiérrez-Aroca, 2018; Savage-Smith, 2013). The fact that intestinal helminths can persist within humans without causing death (Goater et al., 2014) favors their geographic spread, and paleoparasitological research in human remains can yield evidence of population movements (Aagaard-Hansen et al., 2010; Yeh et al., 2016; Mitchell and Yeh, 2023). However, further research is required in material from individuals and other types of spaces to evaluate the prevalence of parasitosis in Arrixaca and to reveal any possible evidence of population movements, including the documented arrival of Italians in the neighborhood from the 12th c. (Eiroa Rodríguez and Gómez Ródenas, 2019; Constable, 1997).

5. Conclusion

This pioneering study of parasitic dispersal in the water drainage system of a 12th-13th century Islamic funduq has confirmed archaeological hypotheses regarding the functionality of the pipes at the site. Beyond providing insight into the prevalence of parasitic infections and population movements in ancient societies, paleoparasitology proves here again to be a valuable tool for interpreting the use of archaeological structures. In this case, it offered critical evidence on the function of water pipes and even provided clues about upper floors that left no physical remains. By systematically integrating paleoparasitological data into a multidisciplinary framework, this study underscores the broader importance of this approach, contributing significantly to our understanding of ancient infrastructure and sanitary practices. The results of this research demonstrate the potential of paleoparasitology to set new standards in archaeological investigation, enriching interpretations of both the social and structural aspects of past civilizations.

CRediT authorship contribution statement

Ramón López-Gijón: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Alicia Hernández-Robles:** Writing – original draft, Resources, Project administration, Conceptualization. **Salvatore Duras:** Writing – original draft. **Mireia Celma:** Writing – original draft, Resources, Methodology. **Ana Curto:** Writing – original draft. **José Ángel González-Ballesteros:** Writing – review & editing, Resources. **Benjamin Dufour:** Writing – review & editing. **Matthieu Le Bailly:** Writing – review & editing, Supervision. **Jorge A. Eiroa:** Writing – review & editing, Resources, Project administration, Funding acquisition.

Data availability statement

All data produced for this work are available in the main manuscript. The figures and tables provided in this paper are available through the following link: https://doi.org/10.5281/zenodo.15446020.

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.

Acknowledgments

This work was supported by Murcia City Council in agreement with the University of Murcia, in the *Proyecto de revisión y diagnóstico del estado de conservación, estudio pluridisciplinar, adopción de medidas de consolidación y exposición temporal en el yacimiento arqueológico de San Esteban* (2018–2023). RLG is currently supported by the InOsteo project (https://doi.org/10.54499/2022.03576.PTDC), funded by FCT (Portuguese Foundation for Science and Technology). AHR is supported by the Juan de la Cierva grant (JDC2022-049201-I) funded by MCIN/AEI/10.13039/501100011033 and by "European Union NextGenerationEU/PRTR". The authors acknowledge the use of Paleoparasitological laboratory in the University of Franche-Comté facilities during research stay by RLG. We would like to thank all the Bachelor's and Master's degree students from the University of Murcia who provided help during the sampling, inventory, and research processes. For further data concerning the site and the current research project, see https://sanesteban.um.es/.

References

Aagaard-Hansen, J., Nombela, N., Alvar, J., 2010. Population movement: a key factor in the epidemiology of neglected tropical diseases. Trop. Med. Int. Health 15 (11), 1281–1288. https://doi.org/10.1111/j.1365-3156.2010.02629.x.

Aparicio Sánchez, L., 2008. Redes de abastecimiento y evacuación de agua en los arrabales califales de Córdoba. Arte. Arqueología e Historia 15, 237–256.

Araújo, A., Reinhard, K., Ferreira, L.F., Pucu, E., Chieffi, P.P., 2013. Paleoparasitology: the origin of human parasites. Arq. Neuropsiquiatr. 71 (9), 722–726. https://doi.org/10.1590/0004-282X20130159.

Banegas López, R.A., 2010. Consumption of meat in Western European cities during the late middle ages: a comparative study. Food Hist. 8, 63–86. https://doi.org/10.1484/j.food.1.100974.

Betson, M., Søe, M.J., Nejsum, P., 2015. Human trichuriasis: whipworm genetics, phylogeny, transmission and future research directions. Curr. Trop. Med. Rep. 2, 209–217. https://doi.org/10.1007/s40475-015-0062-y.

Bouchet, F., Guidon, N., Dittmar, K., Harter, S., Ferreira, L.F., Chaves, S.M., Reinhard, K., Araújo, A., 2003. Parasite remains in archaeological sites. Mem. Inst. Oswaldo Cruz 98, 47–52. https://doi.org/10.1590/s0074-02762003000900009.

Casal, M.T., Casal, M., 2004. El tratamiento de las enfermedades infecciosas en Al-Andalus. Rev. Esp. Quim 17 (4), 350–356.

Chessa, D., Murgia, M., Sias, E., Deligios, M., Mazzarello, V., Fiamma, M., Rovina, D., Carenti, G., Ganau, G., Pintore, E., Fiori, M., Kay, G.L., Ponzeletti, A., Cappuccinelli, P., Kelvin, D.J., Wain, J., Rubino, S., 2020. Metagenomics and microscope revealed T. trichiura and other intestinal parasites in a cesspit of an Italian nineteenth century aristocratic palace. Sci. Rep. 10 (1), 12656. https://doi.org/10.1038/s41598-020-69497-8.

Constable, O.R., 1997. Comercio y comerciantes en la España musulmana: la reordenación comercial de la Península Ibérica del 900 al 1500. Omega. Barcelona.

Constable, O.R., 2003. Housing the Stranger in the Mediterranean World. Cambridge University Press, Cambridge.

Cordero del Campillo, M., 1980. Panorama de la Parasitología Española. Laboratorios Sobrino, S.A., Madrid. http://hdl.handle.net/10612/3575.

Cox, F.E., 1990. A History of Human Helminthology. CAB International, Wallingford.

Cox, F.E., 2002. History of human parasitology. Clin. Microbiol. Rev. 15 (4), 595–612. https://doi.org/10.1128/cmr.15.4.595-612.2002.

Cunha, D., Santos, A.L., Matias, A., Sianto, L., 2017. A novel approach: combining dental enamel hypoplasia and paleoparasitological analysis in medieval Islamic individuals buried in Santarém (Portugal). Antropol. Port. 34, 113–135. https://doi.org/10.14195/2182-7982_34_6.

Dufour, B., Le Bailly, M., 2013. Testing new parasite egg extraction methods in paleoparasitology and an attempt at quantification. Int. J. Paleopathol. 3, 199–203. https://doi.org/10.1016/j.ijpp.2013.03.008.

Eiroa Rodríguez, J., Haber Uriarte, M., Vallalta Martínez, P., González Ballesteros, J.A., Hernández Robles, A., Celma Martínez, M., Martínez Rodríguez, A.L., Muñoz

Espinosa, M.A., Salas Rocamora, S., Molina Campuzano, M.I., 2019. El conjunto arqueológico de San Esteban: aportaciones desde la investigación interdisciplinar. In: García Sandoval, J., Collado Espejo, P.E., Iniesta Sanmartin, A. (Eds.), XXV Jornadas de Patrimonio Cultural. Región de Murcia. Tres Fronteras Ediciones, Murcia, pp. 41–51. ISBN: 978-84-7564-768-5.
Eiroa Rodríguez, J.A., Gómez Ródenas, M., 2019. El emirato de Ibn Mardanīš: una breve síntesis interpretativa. In: Eiroa Rodríguez, J.A. (Ed.), Rey Lobo. El legado de Ibn Mardanīš (1147-1172). Comunidad Autónoma de la Región de Murcia, Murcia, pp. 16–41.
Eiroa Rodríguez, J.A., Haber, M., Vallalta, P., González, J.A., Hernández, A., Celma, M., Martínez, A.L., Molina, M.I., Muñoz, M.A., Salas, S., 2021. Nuevas investigaciones arqueológicas en el arrabal de la Arrixaca (Murcia): El conjunto arqueológico de San Esteban desde una disciplina interdisciplinar. In: Retuerce, M. (Ed.), Actas del VI Congreso de Arqueología Medieval (España-Portugal). Asociación Española de Arqueología Medieval, pp. 55–62. Alicante.
Fanjul, S., 1995. (translation of Leo Africanus 1530). Descripción general del África y de las cosas peregrinas que allí hay. Lunwerg Editores, Barcelona.
Ferreira, L.F., Reinhard, K.J., Araújo, A., 2014. Foundations of Paleoparasitology. Editora Fiocruz, Rio de Janeiro.
Florenzano, A., Mercuri, A.M., Pederzoli, A., Torri, P., Bosi, G., Olmi, L., Rinaldi, R., Bandini Mazzanti, M., 2012. The significance of intestinal parasite remains in pollen samples from medieval pits in the Piazza Garibaldi of Parma, Emilia Romagna, northern Italy. Geoarchaeology 27 (1), 34–47. https://doi.org/10.1002/gea.21390.
Gaeta, R., Fornaciari, G., 2022. Paleoparasitology of helminths. In: Bruschi, F. (Ed.), Helminth Infections and Their Impact on Global Public Health. Springer, Vienna, pp. 73–101. https://doi.org/10.1007/978-3-031-00303-5_3.
García-García, M., 2017. Some remarks on the provision of animal products to urban centres in medieval Islamic Iberia: the cases of Madinat Ilbirah (Granada) and Cercadilla (Cordova). Quater. Inter. 460. https://doi.org/10.1016/j.quaint.2016.06.021.
García-García, M., 2020. Informe arqueozoológico. Conjunto arqueológico de San Esteban (Murcia): Fases 01+03 unpublished.
Goater, T.M., Goater, C.P., Esch, G.W., 2014. Parasitism: the Diversity and Ecology of Animal Parasites. Cambridge University Press, Cambridge.
Goitein, S.D., 1983. A Mediterranean society. The Jewish Communities of the World as Portrayed in the Documents of the Cairo Geniza, IV. University of California Press, Berkeley, Los Angeles.
Graff, A., Bennion-Pedley, E., Jones, A.K., Ledger, M.L., Deforce, K., Degraeve, A., Byl, S., Mitchell, P.D., 2020. A comparative study of parasites in three latrines from Medieval and Renaissance Brussels, Belgium (14th–17th centuries). Parasitology 147 (13), 1443–1451. https://doi.org/10.1017/S0031182020001298.
Grau-Sologestoa, I., 2023. Food taboos in medieval Iberia: the zooarchaeology of socio-cultural differences. Anthropozoologica 58 (3), 23–33. https://doi.org/10.5252/anthropozoologica2023v58a3.
Guillermo, M., 1998. La casa islámica y el horno bajomedieval de la calle de La Manga 4 (Murcia). In: Memorias de Arqueología. Murcia: Dirección General de Cultura, Servicio de Patrimonio Histórico, pp. 451–475 (1992), 7.
Gutiérrez Aroca, J.B., 2018. Desarrollo de la ciencia y la medicina en Al-Andalus. Arte. Arqueología e Historia 25, 133–148.
Haber-Uriarte, M., Eiroa-Rodríguez, J.A., González-Ballesteros, J.Á., Hernández-Robles, A., Celma-Martínez, M., Gómez-Marín, J.G., 2020. Planificación y metodología de campo para una investigación interdisciplinar en la maqbara islámica del conjunto arqueológico de San Esteban (Murcia). Arkeogazte 10, 201–222.
Heirbaut, E., Jones, A.K.G., Wheeler, W., 2011. Archaeometry: methods and analysis. In: Jansen, G.C., Koloski-Ostrow, A., Moorman, E.M. (Eds.), Roman Toilets: Their Archaeology and Cultural History. Peeters, Leuven, pp. 7–20.
Hernández Robles, A., 2021. Comercio y alojamiento en Madīnat Mursiya. Estudio arqueológico de los fanādiq andalusíes en Murcia. Arqueología y Territorio Medieval 28, 125–152. https://doi.org/10.17561/aytm.v28.6186.
Hernández Robles, A., 2022. Comercio y alojamiento en las ciudades andalusíes. Estudio histórico-arqueológico del funduq (siglos VIII-XIII) (Doctoral dissertation. Universidad de Murcia). http://hdl.handle.net/10201/126028.
Hidalgo-Arguello, M.R., Díez Banos, N., Fregeneda Grandes, J., Prada Marcos, E., 2003. Parasitological analysis of Leonese royalty from Collegiate-Basilica of St. Isidoro, León (Spain): helminths, protozoa, and mites. J. Parasitol. 89 (4), 738–743. https://doi.org/10.1645/0022-3395(2003)089[0738:PAOLRF]2.0.CO;2.
Hillenbrand, R., 1994. Islamic Architecture: Form, Function and Meaning. Edinburgh University Press, Edinburgh.
Hoeppli, R., 1956. The knowledge of parasites and parasitic infections from ancient times to the 17th century. Exp. Parasitol. 5 (4), 398–419. https://doi.org/10.1016/0014-4894(56)90024-8.
Jiménez Castillo, P., 2013. Murcia. De la Antigüedad al Islam (Doctoral Dissertation. Universidad de Granada). http://hdl.handle.net/10261/95860.
Jourdan, P.M., Lamberton, P.H., Fenwick, A., Addiss, D.G., 2018. Soil-transmitted helminth infections. Lancet 391, 252–265. https://doi.org/10.1016/S0140-6736⟩(17)31930-X.
Knorr, D.A., Smith, W.P., Ledger, M.L., Peña-Chocarro, L., Pérez-Jordà, G., Clapés, R., Palma, M.F., Mitchell, P.D., 2019. Intestinal parasites in six Islamic medieval period latrines from 10th–11th century Córdoba (Spain) and 12th–13th century Mértola (Portugal). Int. J. Paleopathol. 26, 75–83. https://doi.org/10.1016/j.ijpp.2019.06.004.
Langgut, D., Shahack-Gross, R., Arie, E., Namdar, D., Amrani, A., Le Bailly, M., Finkelstein, I., 2016. Micro-archaeological indicators for identifying ancient cess deposits: an example from Late Bronze Age Megiddo, Israel. J. Archaeol. Sci. Rep 9, 375–385. https://doi.org/10.1016/j.jasrep.2016.08.013.
Langgut, D., 2022. Mid-7th century BC human parasite remains from Jerusalem. Int. J. Paleopathol. 36, 1–6. https://doi.org/10.1016/j.ijpp.2021.10.005.
Le Bailly, M., Landolt, M., Mauchamp, L., Dufour, B., 2014. Intestinal parasites in first world war German soldiers from "kilianstollen". Carspach, France. PLoS One 9 (10), e109543. https://doi.org/10.1371/journal.pone.0109543.
Le Bailly, M., Maicher, C., Roche, K., Dufour, B., 2021. Accessing ancient population lifeways through the study of gastrointestinal parasites: paleoparasitology. Appl. Sci. 11, 4868. https://doi.org/10.3390/app11114868.
Ledger, M.L., Micarelli, I., Ward, D., Prowse, T.L., Carroll, M., Killgrove, K., Rice, C., Franconi, T., Tafuri, M.A., Manzi, G., Mitchell, P.D., 2021. Gastrointestinal infection in Italy during the Roman Imperial and Longobard periods: a paleoparasitological analysis of sediment from skeletal remains and sewer drains. Int. J. Paleopathol. 33, 61–71. https://doi.org/10.1016/j.ijpp.2021.03.001.
Leles, D., Gardner, S.L., Reinhard, K., Iñiguez, A., Araújo, A., 2012. Are Ascaris lumbricoides and Ascaris suum a single species? Parasit. Vectors 5, 1–7. https://doi.org/10.1186/1756-3305-5-42.
Liu, G.H., Wu, C.Y., Song, H.Q., Wei, S.J., Xu, M.J., Lin, R.Q., Zhao, G., Huang, S., Zhu, X.Q., 2012. Comparative analyses of the complete mitochondrial genomes of Ascaris lumbricoides and Ascaris suum from humans and pigs. Gene (Amst.) 492, 110–116. https://doi.org/10.1016/j.gene.2011.10.043.
López-Gijón, R., Duras, S., Botella-López, M.C., Sentí-Ribes, M.A., Dufour, B., Le Bailly, M., 2022. Evidencia paleoparasitológica de Ascaris lumbricoides en restos esqueletizados de ́epoca romana de Dianium (Alicante, España). Munibe 73, 181–190. https://doi.org/10.21630/maa.2022.73.10.
López-Gijón, R., 2023. La salud y la enfermedad en las poblaciones del pasado a través de la Paleoparasitología (Doctoral dissertation. Universidad de Granada). https://hdl.handle.net/10481/88593.
López-Gijón, R., Duras, S., Maroto-Benavides, R., Mena-Sánchez, L.A., Camarós, E., Jiménez-Brobeil, S., 2023a. Two cases of cystic echinococcosis reported from Al-Andalus cemeteries (southern Iberia): insights into zoonotic diseases in Islamic Medieval Europe. Int. J. Osteoarchaeol. 33 (5), 910–919. https://doi.org/10.1002/oa.3253.
López-Gijón, R., Carnicero, S., Botella-López, M.C., Camarós, E., 2023b. Zoonotic parasite Infection from a funerary context: a Late Antique child case from Cantabrian Spain. Int. J. Paleopathol. 41, 55–58. https://doi.org/10.1016/j.ijpp.2023.03.003.
López-Gijón, R., Camarós, E., Rubio-Salvador, Á., Duras, S., Botella-López, M.C., Alemán-Aguilera, I., Rodríguez-Aguilera, Á., Bustamante-Álvarez, M., Sánchez-Barba, L.P., Dufour, B., Le Bailly, M., 2023c. Implications of the prevalence of *Ascaris* sp. in the funerary context of a Late Antique population (5^{th}-7^{th} c.) in Granada (Spain). Int. J. Paleopathol. 43, 45–50. https://doi.org/10.1016/j.ijpp.2023.09.002.
López-Gijón, R., Jiménez-Brobeil, S., Maroto-Benavides, R., Duras, S., Suliman, A., Fernández-Romero, P.L., Botella-López, M.C., Sánchez-Montes, F., Mitchell, P.D., 2024. Parasite eggs in 16th-18th century cesspits from Granada (Spain). J. Archaeol. Sci. Rep. 53, 104342. https://doi.org/10.1016/j.jasrep.2023.104342.
Maicher, C., Hoffmann, A., Côté, N.M., Palomo Pérez, A., Saña Segui, M., Le Bailly, M., 2017. Paleoparasitological investigations on the neolithic lakeside settlement of La Draga (lake Banyoles, Spain). Holocene 27 (11), 1659–1668. https://doi.org/10.1177/0959683617702236.
Marković, N., Raičković Savić, A., Mitić, A., Mitchell, P.D., 2024. Palaeoparasitological evidence for a possible sanitary stone vessel from the Roman city of Viminacium, Serbia. J. Archaeol. Sci. Rep 57, 104671. https://doi.org/10.1016/J.JASREP.2024.104671.
Martí Oltra, J., Burriel Alberich, J., 2008. Comerciar en tierra extraña. La alhóndiga musulmana de la calle Corretgeria de Valencia, en Historia de la ciudad V. Tradición y progreso. Colegio Oficial de Arquitectos de la Comunidad Valenciana y Colegio Territorial de Arquitectos de Valencia, Valencia, pp. 41–60.
Mitchell, P., 2015a. Sanitation, Latrines and Intestinal Parasites in Past Populations. Ashgate Publishing, Ltd, New York.
Mitchell, P.D., 2015b. Human parasites in medieval Europe: lifestyle, sanitation and medical treatment. Adv. Parasitol. 90, 389–420. https://doi.org/10.1016/bs.apar.2015.05.001.
Mitchell, P.D., Anastasiou, E., Whelton, H.L., Bull, I.D., Pearson, M.P., Shillito, L.M., 2022. Intestinal parasites in the neolithic population who built Stonehenge (Durrington walls, 2500 BCE). Parasitology 149, 1027–1033. https://doi.org/10.1017/S0031182022000476.
Mitchell, P.D., 2023a. Parasites in Past Civilizations and Their Impact upon Health. Cambridge University Press, Cambridge. https://doi.org/10.1017/9780511732386.
Mitchell, P.D., 2023b. Parasites in medieval Europe. In: Mitchell, P.D. (Ed.), Parasites in Past Civilizations and Their Impact upon Health. Cambridge University Press, Cambridge, pp. 65–79. https://doi.org/10.1017/9780511732386.005.
Mitchell, P.D., Yeh, H.Y., 2023. Intestinal parasites at the Xuanquanzhi relay station on the silk road 2000 Years ago. In: Infectious Diseases along the Silk Roads: the Spread of Parasitoses and Culture Past and Today. Springer International Publishing, Cham, pp. 131–139. https://doi.org/10.1007/978-3-031-35275-1_9.
Mitchell, P.D., 2024. Ancient parasite analysis: exploring infectious diseases in past societies. J. Archaeol. Sci. 170, 106067. https://doi.org/10.1016/j.jas.2024.106067.
Morrow, J.J., Newby, J., Piombino-Mascali, D., Reinhard, K.J., 2016. Taphonomic considerations for the analysis of parasites in archaeological materials. Int. J. Paleopathol. 13, 56–64. https://doi.org/10.1016/j.ijpp.2016.01.005.
Navarro Palazón, J., Jiménez Castillo, P., 2010. El agua en la ciudad andalusí, en Actas del II Coloquio Internacional Irrigación, Energía y Abastecimiento de Agua: La cultura del agua en el arco mediterráneo. Alcalá de Guadaria: Ayuntamiento de Alcalá de Guadaira, pp. 147–254.
Nejsum, P., Betson, M., Bendall, R.P., Thamsborg, S.M., Stothard, J.R., 2012. Assessing the zoonotic potential of Ascaris suum and Trichuris suis: looking to the future from

an analysis of the past. J. Helminthol. 86, 148–155. https://doi.org/10.1017/S0022149×12000193.
Rabinow, S., Wang, T., van Oosten, R., Meijer, Y., Mitchell, P.D., 2024. Intestinal parasite infection and sanitation in medieval Leiden, the Low Countries. Antiquity 98, 1–17. https://doi.org/10.15184/aqy.2024.72.
Reklaityte, I., 2012. Vivir en una ciudad de Al-Andalus. Hidráulica, saneamiento y condiciones de vida. Universidad de Zaragoza, Zaragoza.
Reinhard, K.J., 1992. Parasitology as an interpretive tool in archaeology. Am. Antiq. 57 (2), 231–245. https://doi.org/10.2307/280729.
Reinhard, K.J., 2017. Reestablishing rigor in archaeological parasitology. Int. J. Paleopathol. 19, 124–134. https://doi.org/10.1016/j.ijpp.2017.06.002.
Revelles, J., Burjachs, F., Morera, N., Barceló, J.A., Berrocal, A., López-Bultó, O., Maicher, C., Le Bailly, 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). J. Archaeol. Sci. 81, 101–115. https://doi.org/10.1016/j.jas.2017.04.001.
Roberts, L.S., Janovy Jr., J., 2008. Foundations of Parasitology, eighth ed. McGraw-Hill, New York.
Robles Fernández, A., Sánchez Pravia, J.A., Navarro Santa-Cruz, E., 2011. Arquitectura residencial andalusí y jardines en el arrabal de la Arrixaca. Breve síntesis de las excavaciones arqueológicas realizadas en el jardín de San Esteban, Murcia (2009). Verdolay 13, 205–219.
Roche, K., Pacciani, E., Bianucci, R., Le Bailly, M., 2019. Assessing the parasitic burden in a Late Antique Florentine emergency burial site. Korean J. Parasitol. 57 (6), 587. https://doi.org/10.3347/kjp.2019.57.6.587.
Roche, K., Capelli, N., Pacciani, E., Lelli, P., Pallecchi, P., Bianucci, R., Le Bailly, M., 2021. Gastrointestinal parasite burden in 4th-5th c. CE Florence highlighted by microscopy and paleogenetics. Infect. Genet. Evol. 90, 104713. https://doi.org/10.1016/j.meegid.2021.104713.
Rodrigo, F.S., Esteban-Parra, M.J., Pozo-Vázquez, D., Castro-Díez, Y., 1999. A 500-year precipitation record in Southern Spain. Int. J. Climatol. 19 (11), 1233–1253. https://doi.org/10.1002/(SICI)1097-0088(199909)19:11%3C1233::AID-JOC413%3E3.0.CO;2-L.
Savage-Smith, E., 2013. Medicine in medieval Islam. The Cambridge History of Science 2, 139–167.
Sianto, L., de Miranda Chaves, S.A., Teixeira-Santos, I., Pereira, P.A., Godinho, R.M., Gonçalves, D., Santos, A.L., 2018. Evidence of contact between new and old world: paleoparasitological and food remains study in the Tagus river population of Sarilhos Grandes (Montijo, Portugal). Archaeol. Anthropol. Sci. 10, 75–81. https://doi.org/10.1007/s12520-016-0337-9.
Silva, T.E. da, Barbosa, F.S., Magalhães, L.M.D., Gazzinelli-Guimarães, P.H., dos Santos, A.C., Nogueira, D.S., Resende, N.M., Amorim, C.C., Gazzinelli-Guimarães, A. C., Viana, A.G., Geiger, S.M., Bartholomeu, D.C., Fujiwara, R.T., Bueno, L.L., 2021. Unraveling *Ascaris suum* experimental infection in humans. Microbes Infect 23 (8), 104836. https://doi.org/10.1016/j.micinf.2021.104836.
Slepchenko, S., 2020. *Opisthorchis felineus* as the basis for the reconstruction of migrations using archaeoparasitological materials. J. Archaeol. Sci. Rep 33, 102548. https://doi.org/10.1016/j.jasrep.2020.102548.
Slepchenko, S.M., Ostapenko, S.N., Khrustalev, A.V., 2023. Archaeoparasitological characteristics of drains in the Phanagoria city of the Khazar period (VIII-IX centuries AD). J. Archaeol. Sci. Rep 47. https://doi.org/10.1016/j.jasrep.2022.103810.
Tejedor-Rodríguez, Cristina, Moreno-García, Marta, Tornero, Carlos, Hoffmann, Alizé, García-Martínez de Lagrán, Íñigo, Arcusa-Magallón, Héctor, Garrido-Pena, Rafael, Royo-Guillén, José I., Díaz-Navarro, S., Peña-Chocarro, Leonor, Alt, Kurt W., Rojo-Guerra, Manuel, 2021. Investigating neolithic caprine husbandry in the central Pyrenees: insights from a multi-proxy study at els Trocs cave (Bisaurri, Spain). PLoS One 16/1, e0244139. https://doi.org/10.1371/journal.pone.0244139.
Thienpont, D., Rochette, F., Vanparijs, O.F.J., 1986. Diagnosing Helminthiasis by Coprological Examination. Janssen Research Foundation Beerse, Belgium.
Torres Balbás, L., 1946. Las alhóndigas hispano-musulmanas y el corral del carbón de Granada. Al-Andalus 11, 446–480.
Trigg, H.B., Jacobucci, S.A., Mrozowski, S.A., Steinberg, J.M., 2017. Archaeological parasites as indicators of environmental change in urbanizing landscapes: implications for health and social status. Am. Antiq. 82 (3), 517–535. https://doi.org/10.1017/aaq.2017.6.
Varisco, D., 2016. Zibl and zirā'a: coming to terms with manure in Arab agriculture. In: Jones, R. (Ed.), Manure Matters: Historical, Archaeological and Ethnographic Perspectives. Routledge, New York, pp. 129–144.
VV.AA, 2000. Bilans. In: Garcin, J.C. (Ed.), Grandes villes méditerranéennes du monde musulman médiéval. École française de Rome, Rome, pp. 263–308.
Watson, A., 2001. Agricultural sciences. In: Al-Hassan, A. (Ed.), The Different Aspects of Islamic Culture. UNESCO, Paris, pp. 21–40.
Wharton, D., 1980. Nematode egg-shells. Parasitology 81 (2), 447–463. https://doi.org/10.1017/S003118200005616X.
Yeh, H.Y., Mao, R., Wang, H., Qi, W., Mitchell, P.D., 2016. Early evidence for travel with infectious diseases along the Silk Road: intestinal parasites from 2000 year-old personal hygiene sticks in a latrine at Xuanquanzhi Relay Station in China. J. Archaeol. Sci. Rep. 9, 758–764. https://doi.org/10.1016/j.jasrep.2016.05.010.