



Entomological analysis for archeological reconstruction and conservation strategies design: the mummies of Cerreto di Spoleto (Central Italy)

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Abstract

Insects found in archeological contexts provide useful information for reconstructing past events. In the context of funerary archeology, insects may help in reconstructing funerary practices or rituals, and in the understanding of the taphonomic processes. Furthermore, studying these insects is fundamental for developing effective conservation strategies for cultural heritage. This article focuses on the entomological investigation of four mummies (nineteenth century) discovered in the church of Santa Maria Annunziata (Cerreto di Spoleto, Central Italy). The research aimed to verify and eventually support archeological hypotheses about the four bodies and to plan an effective conservation strategy. The predominant findings were Diptera puparia and adult Coleoptera. Alongside, common species typical of the hypogean burial, such as *Hydrotaea capensis* and several mycetophilous (mold feeder) species were also collected. The presence of blowfly remains (Calliphoridae) would suggest that the bodies were exposed before burial.

Keywords Natural mummies · Italian church mummies · Funerary archaeoentomology · Necrophagous insects

Agata Lunardini and Giuseppina Carta contributed equally.

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Introduction

Funerary archaeoentomology, as defined by Huchet (1996), is the “application of the medico-legal forensic entomology to the study and interpretation of insect remains associated with graves in archaeological contexts.” Although funerary archaeoentomology and medico-legal forensic entomology differ in their timelines and purposes (legal in one case, historical in the other one), they share the same approach in collecting, analyzing, preserving, and, for some aspects, interpreting the entomological evidence (Huchet 2014; Giordani et al. 2018b). Both disciplines primarily focus on insects and other arthropods associated with human and animal bodies after their death. Funerary archaeoentomology takes also into account ectoparasites (e.g., lice, fleas) and other insects associated with burial environments and with funeral offerings.

The analysis of insects from mummified bodies was one of the initial pillars of what can be defined as “cadaver entomology,” encompassing both humans and non-humans, and forensic and funerary aspects. Two very first examples of the study of insects from mummified bodies are mentioned by Hope (1842) about a mummified ibis, and by Benecke

(2001) about the interest of Bergeret d'Arbois at the end of the nineteenth century for the Palermo Capuchin cemetery where more than 1200 mummies are stored. The ibis analysis allowed the first reconstruction of the diet of the bird when alive, while Bergeret's observations contributed to the development of forensic entomology.

Since the sixteenth century, several mummies (natural or artificial) have been discovered in Italy (Aufderheide 2003; Fornaciari 1997 1998). Some of these mummies have undergone entomological analysis, yielding interesting results regarding the interpretation of the funerary practices and the description of the past insect biodiversity as summarized in Tuccia et al. (2022). However, due to the geographic and climatic differences of the Italian territory, any additional information about insects associated with

bodies plays a significant role in both current and archeological cases, as in a communicating vessel system, and enhances the knowledge about past fauna, human behaviors, and activities.

In this article, the entomofauna associated with the mummified human bodies recovered in 2001, in the church of Santa Maria Annunziata, Cerreto di Spoleto (Perugia), is reported. The village is located in the Valnerina Valley, a mountainous area in Central Italy (Fig. 1). The burials took place, according to the preliminary analysis of the funerary material and clothes, in the nineteenth century.

The aim of this work is to gain insight into funerary practices through entomological analysis and to plan an effective conservation strategy of the mummified bodies. For this purpose, research addressed the following questions:

Fig. 1 Location of Cerreto di Spoleto (Umbria, Italy) (42°49'13"N 12°55'02"E) (© 2007–2018 d-maps.com)



- 1) Is it possible to distinguish, among the entomofauna associated with these bodies, species typical of specific environments or ecological conditions?
- 2) Does the entomological evidence reveal differences in the corpses' treatment?
- 3) Is it possible to distinguish between the fauna associated with initial body decomposition/transformation and secondary contaminants (museophagous insects)?

Geographical and historical context

Umbria is among the Italian regions with a high number of natural and artificial mummified human bodies. The Valnerina Valley is home to three important sites: Ferentillo, Borgo Cerreto (Aufderheide 2003; Costantini et al. 2013; Fornaciari 1998), and Cerreto di Spoleto. The mummies from Cerreto di Spoleto are the topic of this article. While the Borgo Cerreto and Ferentillo mummies were recovered inside a crypt, the Cerreto di Spoleto mummies were found beneath the floor of the church of Santa Maria Annunziata.

Cerreto di Spoleto is a medieval hilltop village characterized by a fortress structure dominated by a slender bell tower on the top. The town is located on the top of the hill of Saint Sebastiano, overlooking the Valnerina Valley at the confluence of the Vigi and Nera rivers (Costantini et al. 2013; Piccolpasso 1963). The church of Santa Maria Annunziata is the result of the architectural fusion, made in 1517, of two previous religious buildings: the church of Santa Maria di Piazza and the chapel of Santa Maria Nova (Fabbi 1976). The church is located in the South corner of the main square of the town. The building is a single-nave church with the main entrance on the left side; it is characterized by four arched lateral niches and a semicircular apse with an altar (Fig. 2).

The church suffered significant damage in the 1997 earthquake and remained closed to the public for several years. During the subsequent seismic improvements and building repairs, it was necessary to remove the floor of the church for a functional restoration and for the replacement of the marble elements. Excavations within the church focused solely on seismic improvements with no attention to any archaeological aspect. As a result, excavation beneath the church floor was not conducted systematically and scientifically.

In 2001, when the church recovery project started, the floor was completely removed revealing two burial areas: an ossuary along the right wall and a group of four partially mummified bodies, near the limit of the apse, a prime position close to the main altar (Fig. 3). The ossuary contained disarticulated bones, likely removed from primary burial graves, making it a secondary deposition grave. No diagnostic artifacts were found in the ossuary. The four bodies were found in their primary deposition, dressed in their original clothes and lying in wooden coffins with funerary equipment.

After their discovery, the mummies were temporarily stocked inside new wooden coffins, in a room in the local cemetery until 2018. They were then relocated to the “Mummies Museum of Borgo Cerreto” located in the same municipality, where the Baronio Vincenzi Documentation Center laboratory for the study of ancient human remains is active. A multidisciplinary study of the bodies began in 2021.

The Cerreto di Spoleto mummies are the result of a natural mummification process due to local micro-climatic conditions. This peculiar microclimate facilitates rapid natural dehydration of biological tissues leading to mummification.

In this region, as in many other Italian areas, the burial of deceased individuals under church floors was a common practice. Initially reserved for priests and churchmen, church spaces became more accessible to other classes of people between the seventeenth and the eighteenth centuries (Mytum 2017).

During these two centuries, aristocrats and wealthy people were the prime candidates for church burial, and their bodies were buried in “favored” positions, such as close to the main altar, or in assigned places when members of a specific brotherhood. Commoners were usually buried in simple wooden coffins either in collective burial chambers or in crypts located beneath the church floor or in the local parish churchyard, which were considered less sacred than the church itself. This practice continued until the early nineteenth century, and it gradually ended when the Edict of Saint-Cloud (Décret impérial sur les sépultures, 12 juin 1804) forbade burial within the city walls.

Fig. 2 The church of Santa Maria Annunziata (Cerreto di Spoleto, Italy). **a** General plan of the church; **b** historic stone entrance portal from 1592 (North wall). * indicates the position of the historic portal

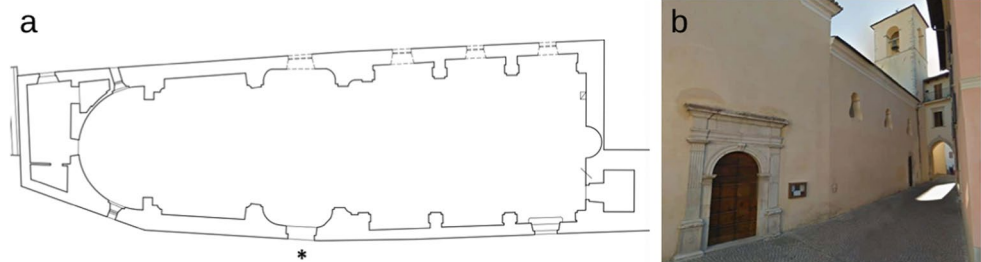
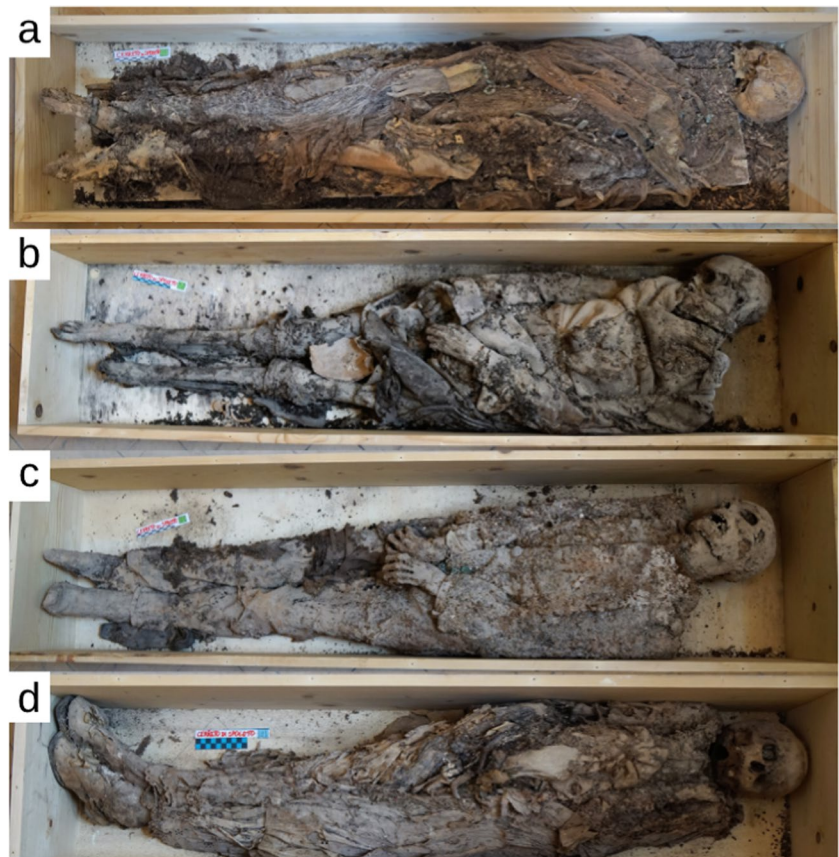


Fig. 3 The four mummies of Cerreto di Spoleto as they appear in the wooden coffins where they were stored after the restoration work. Anthropological data are reported in Table 1 (a CS01; b CS02; c CS03; d CS04)



Material and methods

The anthropological and paleopathological studies were carried out by the Division of Paleopathology of the University of Pisa. Macroscopic observations and radiological examinations were performed including conventional X-ray and computed tomography (CT) at the Radiological Service of the Hospital of Norcia. Sex determination was made by evaluating the external appearance and the genital organs. Age at death was determined based on the degree of dental wear (Miles 1963, 2001), and evaluating degenerative bone alteration related to age, which were assessed through CT scan, such as osteoarthritis and rarefaction of the spongy bone. The age of the non-adult mummy was determined by dental and bone growth rate (AlQahtani et al. 2010). Stature was directly measured on the bodies following the slight flexion of the spine and lower limbs.

Entomological studies, after the sampling *in situ*, were performed at the Forensic Lab for Entomology and Archaeology (FLEA) at the University of Genoa. An initial sampling was performed using tweezers and paintbrushes to carefully collect the specimens directly from the mummies. Then, sediments, dust, and other debris removed during the cleaning process were collected and sieved at three different resolutions (2 mm, 1 mm, and 355 μ m), to recover all

entomological elements of interest. Puparia were carefully cleaned with a small, wet paintbrush to allow for the observation of the diagnostic features (Pradelli et al. 2021).

The diagnostic features were photographed using a stereomicroscope Leica S9i with LAS EZ v3.4.0 software as described in Giordani et al. (2018a). Identification of the specimens was performed using specific identification keys and descriptions (Domínguez and Pont 2014; Giordani et al. 2018a; Grzywacz et al. 2017; Lyneborg 1970; Skidmore 1985). Comparison with a reference modern collection (SV) of previously identified specimens was also conducted.

The study was carried out on the dressed mummies in order to preserve the global integrity of these valuable biological archives.

Results and discussion

Anthropological study

The four mummies, consisting of three adult individuals (one female and two males) and one juvenile female (Table 1), are in a poor state of preservation. Signs of decomposition are visible on the skin surface in the sloping regions and the

Table 1 Anthropological data of the Cerreto di Spoleto mummies

Individual	Sex	Estimated age at the death (years)	Estimated stature (cm)
CS01	Female	40–50	150 ± 3
CS02	Male	45–55	154.5 ± 3
CS03	Male	55–65	154 ± 3
CS04	Female	11–13	128 ± 3

internal organs are collapsed and almost completely decomposed, as confirmed by the radiological study.

The overall preservation of the clothes is also poor, but preliminary observations revealed the good quality and preciousness of the original fabrics.

The radiological and paleopathological studies did not uncover any evidence of trauma or fractures in the individuals. However, signs of diffuse osteoarthritis (spondylarthrosis, coxarthrosis, and gonarthrosis) were observed in the two males. These degenerative changes were particularly pronounced in individual CS03. Furthermore, a complex pathological condition was identified in CS04 individual. The specific nature of this condition is still under investigation.

Entomological study

The amounts of sediment/dust analyzed per each mummy were as follows: CS01, 1016.5 g; CS02, 215 g; CS03, 110 g; and CS04, 67 g. Due to the differences in sample sizes, statistical analysis was not performed to avoid any interpretation error associated with the sampling bias. For this reason, a qualitative interpretation is provided.

Several thousands of arthropod fragments were recovered directly from the mummies or through sieving the associated sediments, dust, and debris. The sample is mainly composed by Diptera and Lepidoptera remains, while other arthropods were collected only in a small number. Summaries of the findings are presented in Table 2 and illustrated in Figs. 4, 5, 6, 7, 8, and 9.

Diptera

A large number of puparia (Fig. 4) was found among the analyzed material but the proportion of different taxa varied depending on the mummy.

In all mummies, the most abundant puparia belong to the species *Hydrotaea capensis* (Wiedemann, 1818) (Diptera: Muscidae). Species identification was performed analyzing the posterior spiracle and the anal plate as reported by Giordani et al. (2018a). *Hydrotaea capensis* is a cosmopolitan synanthropic species widely distributed except in very dry habitats. The larvae of this species develop in

the presence of high bacteria fermentation, often alongside saprophagous larvae of other families such as Calliphoridae, Sarcophagidae, Muscidae, Fanniidae, and Phoridae. As reported by Smith (1986) and Huchet and Greenberg (2010), the species of the genus *Hydrotaea* Robineau-Desvoidy, 1830, are specialized in colonizing buried bodies, where they can represent the totality of the flies with few other taxa. This point was clearly discussed by Pradelli et al (2019) analyzing the entomofauna of a putridarium.

Diptera capable of colonizing buried bodies, such as Phoridae and Fanniidae, were also sampled.

Phoridae are commonly known as “scuttle flies” and/or “coffin flies” for their ability of colonizing underground bodies. Puparia of two species of this family were sampled, *Conicera tibialis* Schmitz 1925 and *Megaselia scalaris* (Loew, 1866). The latter was collected only in a few specimens. These flies are mainly active during warmer seasons but, due to their synanthropic habit, can be active indoors or in urban environments throughout the year.

Puparia of *Fannia scalaris* (Fabricius, 1794) and *Fannia canicularis* Linnaeus, 1761 were also recovered. These species, one considered more synanthropic, and the other asynanthropic, are known to colonize bodies in a colliquative phase of decomposition. The structure of the villages in the past, where vegetation and buildings were in a continuum, but also the presence of space for the livestock in the same buildings inhabited by human may explain the copresence of these two species with different habitat preference. The effect of mixed environments (urban-rural) was also described for Calliphoridae (Vanin et al. 2008).

A few puparia of *Calliphora vomitoria* (Linnaeus, 1758) (Diptera: Calliphoridae) were also found. Calliphoridae are known as first colonizers of exposed bodies and their presence, due to the small number of specimens, may be related to a short exposition prior to burial. Another hypothesis, more difficult to be verified, is the potential presence of openings between the outdoor environment and the place where the bodies were found, allowing initial access to the bodies as potentially happened in the Roccapelago context (Vanin 2016; Vanin et al. 2020).

Coleoptera

Adult beetles belonging to Ptinidae, Cleridae, Histeridae (Fig. 5), Cryptophagidae, Latridiidae, and Mycetidae (Fig. 6) were also recovered.

Most of the specimens belonged to *Anobium punctatum* (De Geer, 1774) (Ptinidae: Anobiinae) (Fig. 5a) commonly known as the “furniture beetle” or “woodworm.” Some specimens were still active and other dead specimens were in perfect preservation conditions. Holes and wood dust (frass) were also observed (Fig. 7). These findings indicated an active infestation of the new made coffins used to store the

Table 2 Summary of the taxa collected from the mummified bodies found during the restoration work of the church of Santa Maria Annunziata of Cerreto di Spoleto (Umbria, Central Italy) (A adult; C cocoon; Pu puparia; x= 1 specimen; xx= 2–10 specimen; xxx= 11–100 specimens; xxxx= > 100 specimens)

Taxon		CS01	CS02	CS03	CS04
Diptera					
Calliphoridae	<i>Calliphora vomitoria</i>	Pu xx	Pu xx	Pu xx	Pu xx
Muscidae	<i>Hydrotaea capensis</i>	Pu xxxxx	Pu xxxx	Pu xxxx	Pu xxxx
Fanniidae	<i>Fannia scalaris</i>		Pu xxx	Pu xxx	Pu xx
	<i>Fannia canicularis</i>		Pu xx	Pu xx	
Phoridae	<i>Conicera</i> cfr <i>tibialis</i>	Pu xx	Pu xxx	Pu xxx	Pu xx
	<i>Megaselia</i> sp.		Pu xx	Pu xx	
Coleoptera					
Ptinidae	<i>Anobium punctatum</i>	A xxx	A xxxx	A xxxx	A xxx
	<i>Ptinus fur</i>	A xx	A xx	A xx	
Cryptophagidae	<i>Cryptophagus</i> cfr <i>montanus</i>	A xx	A xxx	A xx	
Cleridae	<i>Necrobia violacea</i>	A xx	A xx	A xxx	A xx
Mycetaeidae	<i>Mycetaea subterranea</i>	A x	A xx	A x	
Histeridae	<i>Saprinus semistriatus</i>		A x		
	<i>Gnathoncus rotundatus</i>	A x			
	Gen. sp.	A x	A xx	A x	
Latridiidae	<i>Dienerella filum/costolata</i>	A xx	A xxx		
	<i>Corticaria</i> sp.	A xx	A xx		
Lepidoptera					
Tineidae	Gen. sp.	C xxx	C xxx	C xxxx	C xx
Hymenoptera					
Parasitoid wasps	Fam. Gen. spp		A xx	A xx	
Formicidae	Gen. spp	A xx	A xx	A xx	
Arachnida					
Acarina	Gen. spp	A xxx	A xxx	A xxxx	A xxx
Pseudoscorpionida	Gen. spp	A xx	A xx	A xxx	A xx
Araneae	Gen. spp	A xx		A x	
Isopoda					
Oniscidae	Gen. spp	A x	A x		

bodies (Vanin et al. 2021). *Anobium punctatum* is specialized in infesting the sapwood of temperate softwoods and hardwoods that have been dead for at least 5 years but may also infect the heartwood of timbers such as beech, birch, cherry, alder and spruce, or timbers that have been modified

by fungal attack. Egg eclosion and adult emergence require a relative humidity (HR) of above 60%. The species has never been reported from animal tissues and, to authors' knowledge, it cannot be considered a pest for fabrics of plant origin.

Fig. 4 Diptera puparia collected from the Cerreto di Spoleto mummies (**a** *Megaselia scalaris*; **b** *Conicera* cfr *tibialis* (Phoridae); **c** *Hydrotaea capensis* (Muscidae); **d** *Fannia canicularis* (Fanniidae); **e** *Calliphora vomitoria* (Calliphoridae) (scale bar 1 mm)

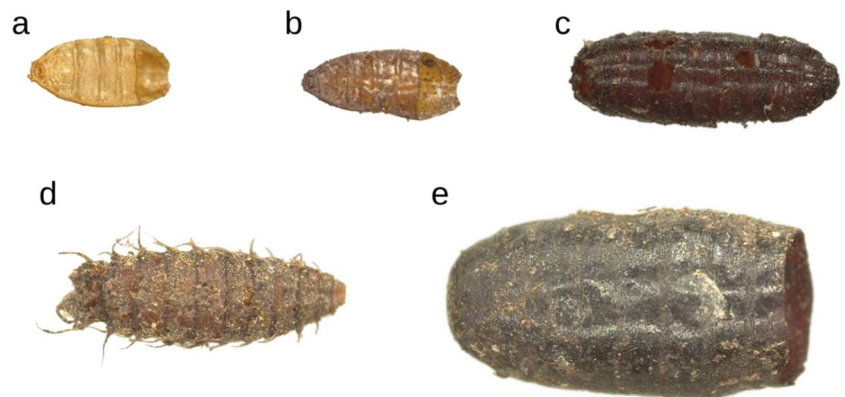


Fig. 5 Coleoptera collected from the Cerreto di Spoleto mummies (**a** *Anobium punctatum*; **b** *Ptinus fur* (Ptinidae); **c** *Necrobia violacea* (Cleridae); **d** *Saprinus semistriatus* (Histeridae) (scale bar 1 mm)

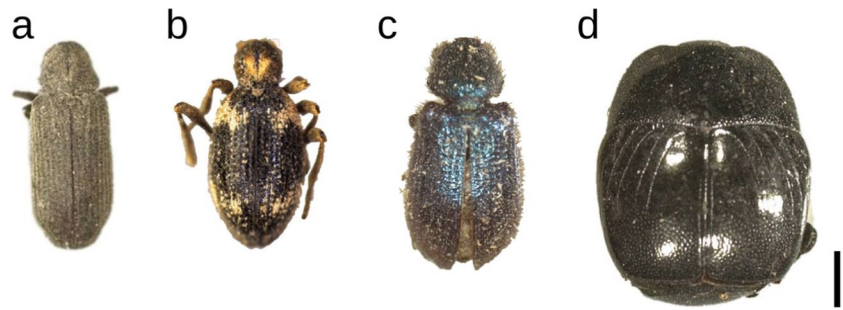


Fig. 6 Coleoptera collected from the Cerreto di Spoleto mummies (**a** *Mycetaea subterranea* (Mycetaeidae); **b** *Cryptophagus* cfr *montanus* (Cryptophagidae); **c** *Dienerella* sp.; **d** *Corticaria* sp. (Latridiidae) (scale bar 1 mm)

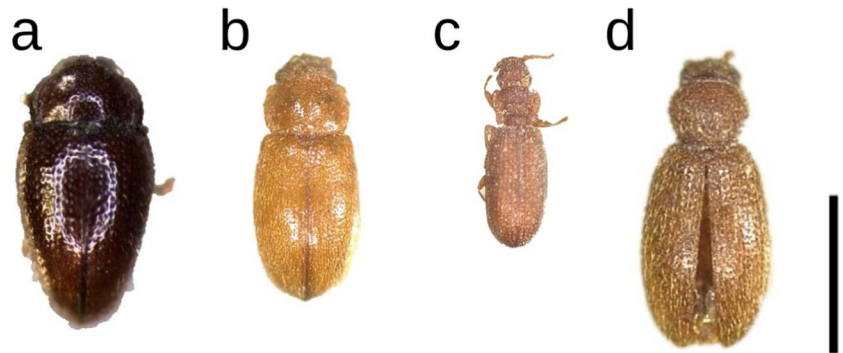


Fig. 7 *Anobium*'s frass falling from the wood coffin on the floor where also death and living beetle specimens are present

Specimens of *Ptinus fur* (Linnaeus, 1758) (Ptinidae: Ptininae) (Fig. 5b) were also collected although in a small number and partially broken. This species is known as a museophagous species but, their presence, given their conservation state (broken specimens, some of them without legs) and the small number, cannot be considered a problem for the conservation of the mummies and can be considered part of an ancient colonization.

Necrobia violacea (Linnaeus, 1758) (Cleridae) (Fig. 5c) specimens were found; some of them were still in their pupal chamber, potentially indicating a change in the environmental condition that stopped their development. Several hypotheses— insect repellent treatment, water level change, anoxic conditions, etc. —can be made but no one can be verified nowadays.

As in other Italian archeological contexts, *Mycetaea subterranea* (Fabricius) (Mycetaeidae, former Endomychidae) (Fig. 6a) and *Cryptophagus* cfr *montanus* Brisout, 1863 (Cryptophagidae) (Fig. 6b) were sampled in a small number.

Beetles belonging to this latter family are widespread in temperate regions where adults and larvae feed on fungal ifae, but also on rotten wood and on animal fur or feeders, showing a wide range in their food preferences.

Mycetaea subterranea was collected from barns feeding on mold, but also from hypogean habitats (Panagiotakopulu and Buckland 2012), and it was reported from bones (Aitken 1975) and from partially mummified bodies also in Italy (Vanin et al. 2022).



Fig. 8 Exuviae of Tineidae from the clothes of the mummy CS03



Fig. 9 Exuvia of a clothes moth (Tineidae) extracted from the mummy CS03 (scale bar 1 mm)

Among the mold feeders, some specimens of Latridiidae were found and here reported from mummified bodies for the first time. *Dienerella filum* (Aubé, 1850)/*D. costulata* (Reitter, 1877) (Fig. 6c), and a species in the genus *Corticaria* Marsham, 1802 (Fig. 6d) were collected only from the mummified bodies CS01 and CS02.

Histeridae beetles were identified as *Saprinus semistriatus* (Scriba 1790) (Fig. 5d) and *Gnathoncus rotundatus* (Kugelann, 1792) species. These beetles are mainly predators of dipteran maggots and are active mainly in the warmer seasons of the year (Vanin et al. 2013). *Saprinus semistriatus* has been reported as active on exposed cadavers for a short time, mainly during the active decay (Szelecz et al. 2018); however, its arrival requires the accessibility of the bodies from the external environment.

Lepidoptera

Cocoons and exuviae of clothes moths (Tineidae) were sampled in high numbers, especially from the clothes of CS03, where clear signs of their feeding activity were also detectable (Fig. 8). Given their abundance and conservation

status, their presence can be attributed to the initial stages of the mummification process, with the infestation no longer considered active. However, for future preservation of the mummy's clothes, an effective conservation strategy (low humidity, low temperature) should be considered.

Other taxa

Other taxa of insects included some ant heads and a few parasitoid wasps (Hymenoptera). Several mites, a few spider exuviae, and pseudoscorpions (Arachnida) were also collected. All of them can be associated with the location where the mummies were found except for the parasitoid wasps attracted by the fly maggots feeding on the bodies and the phoretic mites carried on the bodies by the saprophagous insects. It is worth mentioning that only *Hydrotaea capensis* puparia show signs of parasitoid attack, whereas the few puparia belonging to Calliphoridae do not exhibit any evidence of parasitism (Fig. 4c).

Conclusions

The archaeoentomological study of the insect's remains offers valuable data to reconstruct the after-death history of the Cerreto di Spoleto individuals.

Diptera puparia are the most important taxon. Among the flies, Calliphoridae are associated with the pre-depositional phase with exposed bodies prior to burial. On the other hand, the presence of the other taxa, such as *Necrobia* and *Ptinus* beetles, is related to the later decomposition phases of the bodies. In addition, cocoons and exuviae of clothes moths can be linked to the colonization of the bodies' dry tissues or their clothes.

Species associated with body tissues, fabric, but also keratinized tissues, as well as predators and parasites and mold feeders were collected from the bodies. The difference in environmental preferences suggests an initial colonization of the bodies prior to burial by calliphorid flies which, despite their low number, are present in all the bodies. This entomological evidence is linked with the usual Italian funerary practices. The body of the deceased was exposed to the family and to the local community for the last farewell and only subsequently buried in a wooden coffin. This practice is still followed in several Italian regions.

The environment structure at the time of the death characterized by a continuum between urban and rural areas with the presence of livestock does not allow speculation about the transfer of the bodies after death.

Living and well-preserved beetles of the genus *Anobium* were found among the bodies, but they were associated with the degradation of the wooden coffin, as confirmed by the presence of emergence holes and wood dust on the

new coffins. The finding of mold feeders is interesting, but it requires a deeper investigation and comparisons with the entomofauna associated with other mummified or partially mummified bodies to understand the importance, the dynamics, and the effect of this ecological group on the cadaver taphonomic process.

The four bodies shared the majority of taxa, suggesting no major differences in the bodies' treatments. However, the absence of mold feeders in CS04 and a reduced number of them in CS03 could indicate differences in the taphonomic processes of the bodies potentially associated with the coffins or their original positions under the church floor. No active infestation of the bodies appears to be present, but all the bodies show past infestations on the clothes that do not seem to have affected the human tissues.

In conclusion, the entomological study provided additional information useful for reconstructing the funerary practices of the four mummies which were not documented, and will enable the development of preservation strategies against future damage.

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Author contribution SV and AL conceived and planned the project. SV, GC, and AL wrote the paper. SV, AL, and MS collected the samples. GC, GG, and SV studied the entomological specimens. LC provided the archeological and historical information. VG and GG critically reviewed a first draft of the manuscript. All authors read and approved the final manuscript.

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Data availability The authors declare that the data supporting the findings of this study are available within the paper. Should any raw data files be needed in another format, they are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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References

- Aitken AD (1975) Insect travellers: a survey of the beetles recorded from imported cargoes, vol I. Coleoptera. Her Majesty's Stationery Office, London
- AlQahtani SJ, Hector MP, Liversidge HM (2010) Brief communication: the London atlas of human tooth development and eruption. *Am J Phys Anthropol* 142:481–490. <https://doi.org/10.1002/ajpa.21258>
- Aufderheide AC (2003) The scientific study of the mummies. Cambridge University Press, Cambridge, pp 192–206
- Benecke M (2001) A brief history of forensic entomology. *Forensic Sci Int* 120(1–2):2–14. [https://doi.org/10.1016/s0379-0738\(01\)00409-1](https://doi.org/10.1016/s0379-0738(01)00409-1)
- Costantini L, Costantini Biasini L, Fornaciari G, Lunardini A (2013) Baronio Vincenzi e le mummie di Borgo Cerreto in Valnerina. Speddy Press Spoleto, Perugia
- Domínguez MC, Pont AC (2014) Fanniidae (Insecta: Diptera), Fauna of New Zealand 71. <https://doi.org/10.7931/J2/FNZ.71>
- Fabbi A (1976) Storia dei Comuni della Valnerina. Fabbi e Abeto Editore, Perugia
- Fornaciari G (1997) The mummies of the Basilica of San Francesco in Arezzo. *Paleopathol Newsl* 97:13–14
- Fornaciari G (1998) Italian mummies. In: Cockburn A, Cockburn E, Reyman TA Mummies, Disease and Ancient Cultures, Second Edition, Cambridge University Press, Cambridge, pp 266–281
- Giordani G, Grzywacz A, Vanin S (2018a) Characterization and identification of puparia of *Hydrotaea* Robineau-Desvoidy, 1830 (Diptera: Muscidae) from forensic and archaeological contexts. *J Med Entomol* 56(1):45–54. <https://doi.org/10.1093/jme/tjy142>
- Giordani G, Tuccia F, Floris I, Vanin S (2018) First record of *Phormia regina* (Meigen, 1826) (Diptera: Calliphoridae) from mummies at the Sant'Antonio Abate Cathedral of Castelsardo, Sardinia, Italy. *PeerJ* 6:e4176. <https://doi.org/10.7717/peerj.4176>
- Grzywacz A, Hall MJ, Pape T, Szpila K (2017) Muscidae (Diptera) of forensic importance—an identification key to third instar larvae of the Western Palaearctic region and a catalogue of the muscid carrion community. *Int J Legal Med* 131:855–866. <https://doi.org/10.1007/s00414-016-1495-0>
- Hope FW (1842) Observation on some mummied beetles taken from the inside a mummied ibis. *Trans Ent Soc Lond* 3:191–193
- Huchet JB (1996) L'Archéontologie funéraire: une approche originale dans l'interprétation des sépultures. *Bull Mem Soc Anthropol Paris* 3–4:299–311. <https://doi.org/10.3406/bmsap.1996.2450>
- Huchet JB (2014) L'archéontologie funéraire. (chap. 15), p. 201–224. In: Charabidze D, Gosselin M (eds) Insectes, cadavres et scènes de crime, Principes et applications de l'entomologie médico-légale. Editions De Boeck, pp 280
- Huchet JB, Greenberg B (2010) Flies, Mochicas and burial practices: a case study from Huaca de la Luna, Peru. *J Archaeol Sci* 37:2846–2856. <https://doi.org/10.1016/j.jas.2010.06.025>
- Lyneborg L (1970) Taxonomy of european *Fannia* larvae (Diptera, Fanniidae). Staatliches Museum für Naturkunde, Karlsruhe
- Miles AEW (1963) Dentition in the estimation of age. *J Dent Res* 42:255–263. <https://doi.org/10.1177/00220345630420012701>
- Miles AEW (2001) The Miles method of assessing age from tooth wear revisited. *J Archaeol Sci* 28:973–982. <https://doi.org/10.1006/jasc.2000.0652>
- Mytum H (2017) Mortuary Culture. In: Richardson C, Hamling T, Gaimster D (eds) The Routledge handbook of material culture in early modern Europe. Routledge, London, pp 154–167

- Panagiotakopulu E, Buckland P (2012) Forensic archaeoentomology - an insect fauna from a burial in York Minster. *Forensic Sci Int* 221:125–130. <https://doi.org/10.1016/j.forsciint.2012.04.020>
- Piccolpasso C (1963) Le piante et i ritratti delle città e terre dell'Umbria sottoposte al governo di Perugia. Istituto Nazionale d'Archeologia e Storia dell'Arte, Roma
- Pradelli J, Rossetti C, Tuccia F, Giordani G, Licata M, Birkhoffc JM, Verzeletti A, Vanin S (2019) Environmental necrophagous fauna selection in a funerary hypogeal context: the putridarium of the Franciscan monastery of Azzio (Northern Italy). *J Archaeol Sci Rep* 24:683–692. <https://doi.org/10.1016/j.jasrep.2019.02.028>
- Pradelli J, Tuccia F, Giordani G, Vanin S (2021) Puparia cleaning techniques for forensic and archaeo-funerary studies. *Insects* 12:104. <https://doi.org/10.3390/insects12020104>
- Skidmore P (1985) *The biology of the Muscidae of the world*. Springer Netherlands, Dordrecht
- Smith KGV (1986) *A Manual of Forensic Entomology*. Cornell University Press, Ithaca
- Szelecz I, Feddern N, Seppay C, Amendt J, Mitchell E (2018) The importance of *Saprinus semistriatus* (Coleoptera: Histeridae) for estimating the minimum post-mortem interval. *Leg Med* 30:21–27. <https://doi.org/10.1016/j.legalmed.2017.10.011>
- Tuccia F, Giordani G, Vanin S (2022) State of the art of the funerary archaeoentomological investigations in Italy. *Archaeol Anthropol Sci* 14(4):1–10. <https://doi.org/10.1007/s12520-022-01524-3>
- Vanin S, Tasinato P, Ducolin G, Terranova C, Zancaner S, Montisci M, Ferrara P, Turchetto M (2008) Use of *Lucilia* species (Diptera: Calliphoridae) for forensic investigations in Southern Europe. *Forensic Sci Int* 177:37–41. <https://doi.org/10.1016/j.forsciint.2007.10.006>
- Vanin S, Zanotti E, Gibelli D, Taborelli A, Andreola S, Cattaneo C (2013) Decomposition and entomological colonization of charred bodies - a pilot study. *Croat Med J* 54:387–393. <https://doi.org/10.3325/cmj.2013.54.387>
- Vanin S (2016) Archeoentomologia funeraria: risultati e prospettive dallo studio delle mummie di Roccapelago. In: Roccapelago e le sue mummie: studio integrato della vita di una piccola comunità dell'Appennino tra XVI e XVIII secolo. Atti dei convegni del 24 settembre 2011 e del 22 settembre 2012, Roccapelago (Modena) pp 225–229
- Vanin S, Bortolini S, Giordani G, Tuccia F (2020) Indagine morfologica e molecolare sui reperti entomologici di Roccapelago. In: Benazzi S, Gruppioni G, Traversari M Atti convegno Le Mummie di Roccapelago 3.0 La rinascita degli antichi abitanti attraverso cinque anni di studi - Ravenna 24 marzo 2017, Università di Bologna-Campus di Ravenna pp 168–173
- Vanin S, Azzoni M, Giordani G, Belcastro MG (2021) Bias and potential misinterpretations in the analysis of insects collected from human remains of archaeological interest. *Archaeol Anthropol Sci* 13(11):201. <https://doi.org/10.1007/s12520-021-01458-2>
- Vanin S, Boano R, Giordani G, Carta G, Fulcheri E (2022) Description of the entomofauna associated with the remains of the cistercian nun Angela Veronica Bava (1591–1637). *Medicina Hist* 6(1):e2022006

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