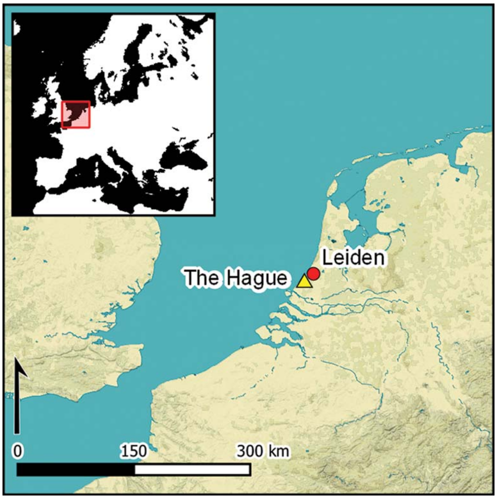
Antiquity 2024 Vol. 98 (400): 1006–1022
https://doi.org/10.15184/aqy.2024.72

Research Article

Intestinal parasite infection and sanitation in medieval Leiden, the Low Countries

Sophie Rabinow[1], Tianyi Wang[1], Roos van Oosten[2], Yolande Meijer[3] & Piers D. Mitchell[1,*]

[1] Department of Archaeology, University of Cambridge, UK
[2] Faculty of Archaeology, Leiden University, The Netherlands
[3] IDDS Archeologie, Noordwijk, The Netherlands
* Author for correspondence ✉ pdm39@cam.ac.uk



In the absence of written records, disease and parasite loads are often used as indicators of sanitation in past populations. Here, the authors adopt the novel approach of integrating the bioarchaeological analysis of cesspits in an area of medieval Leiden (the Netherlands) with historical property records to explore living conditions. Using light microscopy and enzyme-linked immunosorbent assays (ELISA) they identify evidence of parasites associated with ineffective sanitation (whipworm, roundworm and the protozoan *Giardia duodenalis*)—at residences of all social levels—and the consumption of infected livestock and freshwater fish (Diphyllobothriidae, cf. *Echinostoma* sp., cf. *Fasciola hepatica* and *Dicrocoelium* sp.).

Keywords: Netherlands, medieval, palaeoparasitology, ELISA, cesspits, diarrhoea, *Echinostoma*, fish tapeworm

Introduction

In the Low Countries, many artefacts are recovered from cesspits (Hupperetz 2010: 279; van Oosten 2016a: 41, 49), but the archaeological value of the material (the cess) that these pits contain is often underestimated. This article examines material from six medieval cesspits in a Low Countries town, integrating analysis of organic remains with textual records relating to town regulations and to the households within which the cesspits were located. Leiden was selected due to its promising archaeological record and the survival of documents detailing medieval street plans and inhabitants.

Received: 3 March 2023; Revised: 19 October 2023; Accepted: 6 November 2023

Eggs from a broad range of endoparasites have been identified in soil samples from cesspits in other regions of the Low Countries (Rocha *et al.* 2006; Appelt *et al.* 2014; Deforce *et al.* 2015; Rácz *et al.* 2015; Graff *et al.* 2020; De Cupere *et al.* 2021; Rabinow *et al.* 2023). The presence of these eggs—and the attendant infection by genera or species of parasites that may be identified—can help us to create a picture of parasitic infection and its interplay with social practices such as diet and sanitation in past populations (Mitchell 2015a, 2023). The nematodes *Ascaris* (roundworm) and *Trichuris* (whipworm), for example, can trigger such symptoms as abdominal cramps, diarrhoea, anorexia, nausea and vomiting (Stephenson *et al.* 2000). Certain species of protozoa, including *Entamoeba histolytica*, *Giardia* sp. and *Cryptosporidium* sp., can also cause diarrhoea and dysentery. *Ascaris, Trichuris* and these protozoa are therefore generally considered to be indicators of sanitation conditions. Species of the genera *Taenia* (pork and beef tapeworm), *Echinostoma* (intestinal flukes) and *Dibothriocephalus* (fish tapeworm) are zoonotic parasites, which can be transferred from non-human animals to humans by eating raw or undercooked meat and fish (Ledger & Mitchell 2022). By assessing cesspit contents and determining the types of parasites present in the medieval population of Leiden, we can improve our understanding of the health and lifestyle of the city's inhabitants. We can also address the question of whether households with indicators of more costly or poorer diet (potentially indicators of income or status) were infected by the same parasites, or if differences in infection might exist between these two groups.

Leiden

The town of Leiden (Figure 1), known primarily for its textile industry, was home to approximately 13 000 inhabitants at around AD 1500 (Brand 2008: 96; van Steensel 2020: 372), making it one of the larger urban centres of the Northern Netherlands at this time (van Oosten 2015: 28). In the later Middle Ages (up to AD 1500), textile production was already significantly higher than in other Dutch cities (Posthumus 1908: 368–9) and by the seventeenth century Leiden became known as the largest textile producer in Europe (de Vries *et al.* 2003: 88). From the last quarter of the sixteenth century, Leiden grew at a

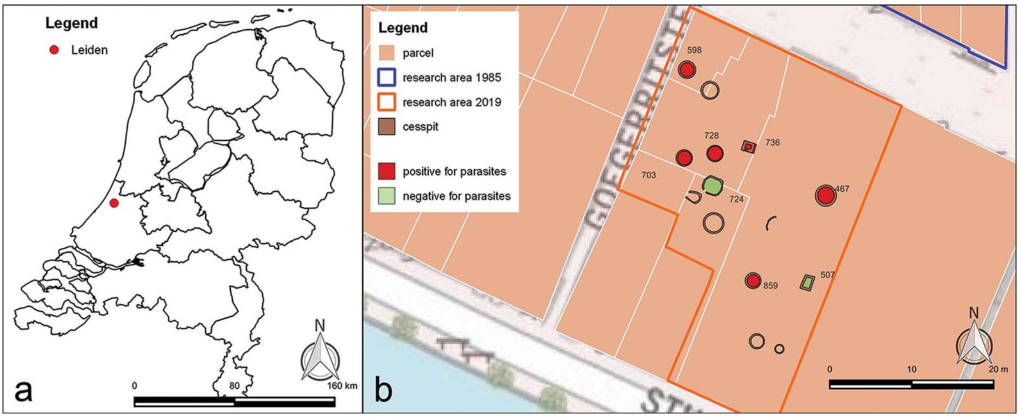


Figure 1. a) location of Leiden within the Netherlands; b) a site plan of locations of pits excavated (figure by authors).

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

rapid pace and the city welcomed thousands of religious refugees, mostly textile workers from what is now Belgium. A significant increase in the number and sizes of houses in the city and an expansion in its territory is therefore seen in the seventeenth century. During the early modern period (*c*. AD 1500–1800) for which significantly more detailed written records are available than for the Middle Ages, it has been estimated that two-thirds of the population was involved in the textile industry (de Vries *et al.* 2003: 88).

Materials

In 2019 an area in Leiden demarked by the present-day Haarlemmerstraat to the north and the Stille Rijn to the south was excavated (administratively known as Haarlemmerstraat 101–111/Stille Rijn 8–9). The Rhine, running on the other side of the Stille Rijn, was an important transport route in the Middle Ages and the Haarlemmerstraat, then called Marendorp, was a key street connecting the Zijlpoort in the east of the city to the Rijnsburgerpoort in the west.

Thanks to the ongoing project *Historisch Leiden in Kaart* (Mapping Historical Leiden), which provides access to historical data via a website, it is possible to look up the owners of properties that stood on the excavated site during the period *c*. 1550–1606. Map 28 from the so-called *Stratenboek* (Book of streets) (Figure 2) presents a good starting point, as it shows that in 1591 the excavated area was occupied by one large square 'plot' and two smaller ones. The purpose of this map was not, however, to accurately depict the contours of each plot but to record façade width, presumably to determine a proportional cost for street maintenance paid by the owners (de Baar 1985). As a result, adjacent plots owned by the same individual were schematically drawn as one 'plot'. Figure 2 shows the number of houses occupying the block for three sample years (1561, 1581 and 1606). While in 1561 the block consisted of only five properties (two of which were rented), this had increased to seven in 1581 and to 26 (including 12 rentals) in 1606. This increase in property numbers, and particularly in the number of rental properties, is a development that is also observed elsewhere in Leiden as population density increases significantly in the last quarter of the sixteenth century (van Oosten 2016b: 715, fig. 8).

There is a remarkable difference in social status between the residents of this block. Most were middle-class or poor residents: they rented instead of owning (hence their occupations were not recorded), the size of each plot was small and the tax they paid was low. In contrast, the largest plot was occupied from at least 1498 until *c*. 1605 by the brewery and home of a family of wealthy brewers who paid high taxes. While the business was located on the Stille Rijn side of the block, as map 2 of the *Grachtenboek* (Book of Canals) (Erfgoed Leiden en Omstreken, 0501A, inventory number 5113) shows, the home of the brewer was located on the Haarlemmerstraat. When the 1591 map was made (Figure 2), brewer Cornelis Adriaensz van Barrevelt owned the plot. He had been the owner since 1558. A few years earlier, in 1543, his father Adriaen Jans van Barrevelt (also a brewer) was the owner and it is very likely that as early as 1498 this site was already a brewery (van Steensel 2016).

Leiden had at least 22 brewers in 1498 (van Steensel 2016) and 15 brewers in 1607 (Walle & Hooymans 2021). Brewers in the mid-sixteenth century belonged to the financial elite (Noordam 2001: 31). That their wealth was visibly greater than that of other residents

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

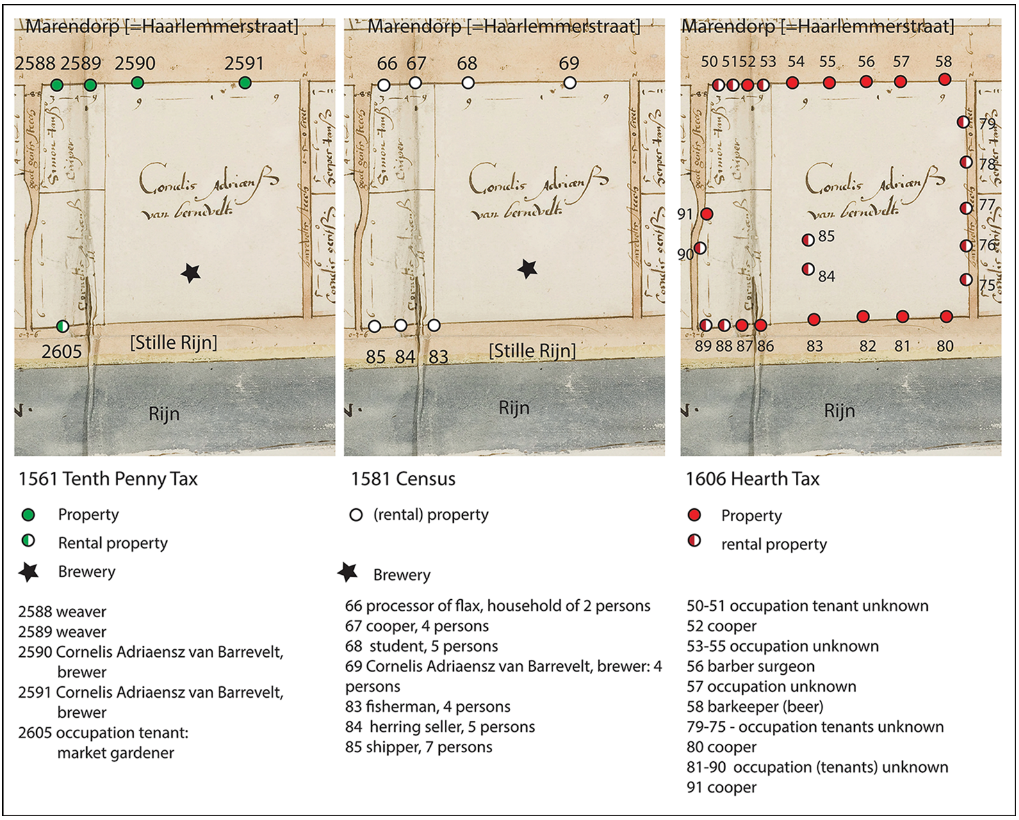


Figure 2. Detail from Stratenboek *(Book of streets) 28 'Kaart van Marendorp van de Vrouwenkerk tot de Marebrug' dd. 1591 (Erfgoed Leiden en Omstreken, 501A, inv. nr. 5153 Stratenboek 28, available at: https://www.erfgoedleiden.nl/collecties/archieven/archievenoverzicht/details/NL-LdnRAL-0501A/path/1.2.2.8.1.6.5.1/deep:view/scans/deep:highlight/8/deep:start/50/deep:limit/10). The occupations of the main occupants (not the owners) of the houses are indicated with dots in the years 1561, 1581 and 1606. The numbers correspond with Mapping Historical Leiden (www.historischleideninkaart.nl) and can be looked up via Looproutes, 1561 Tiende Penning (Tenth Penny), 1581 Volkstelling (Census) and 1606 Schoorsteengeld (Hearth tax) and then by selecting the ward Overmare Rijnzijde (RvO) (figure by authors).*

can be illustrated by the size of the area occupied by breweries. The plot of Cornelis Adriaensz is five to six times wider than the average plot within the city. A further illustration of their prominent role in society is that quite a few brewers had seats on the city council. Cornelis Adriaensz served on the town council for 30 years, following in the footsteps of his father who served for 23 years.

A total of 14 features within the excavated area were interpreted as potential cesspits (Figure 3, Table 1). One or more sediment samples of at least 1 litre were taken from each pit, and where more than one sample was available from the same cesspit, these were taken from different sediment layers. The samples were assessed using the quickscan approach for the presence of botanical macro remains (van Haaster 2020). Based on this assessment, six of the pits were regarded as cesspits used for human faecal waste and submitted for further analysis for organic macro remains (van Amerongen 2022) and intestinal

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Figure 3. a) cesspit S859 during excavation, showing round brick lining; b) its cross-section (cesspit use dates from 1475–1525) (figure by authors).

parasites. Analysing samples for parasite eggs also allowed us to double check whether the quick-scan approach was a reliable method for identifying cesspits. Two of the features disregarded based on the quick-scan results were tested for parasite eggs and both were found to be negative (marked in green on Figure 1b), supporting the original interpretation. Feature

Table 1. Details of the cesspits analysed in this study.

Feature	Date range (AD)	Plot	Shape	Dimensions
S736	1250–1350	Haarlemmerstraat 105–107	Quadrangular (small) cess cellar	1.40 × 1.20m/inside 0.7 × 0.5m, only 0.5m deep
S467	1350–1600	Haarlemmerstraat 111	Round	diameter 2.5m at top level, 2.20m at deeper level
S728	1375–1500	Haarlemmerstraat 105	Round	diameter 2.0m
S703	1375–1550	Haarlemmerstraat 105/ Stille Rijn 5–6	Round	diameter 2.20m
S598	1450–1500	Haarlemmerstraat 101–103	Round	diameter 2.10m
S859	1475–1525	Stille Rijn 9	Round	diameter 2.20m at top level 1.90m at lower level

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

S724 did contain three parasite eggs (two whipworm and one trematode) but the paucity of parasite eggs compared with other samples (which contained in excess of a thousand times more eggs) suggests that these may represent contamination, perhaps having been washed in by flooding in the past. It cannot, however, be excluded that the feature was originally a cesspit that was subsequently emptied and filled with other material.

Methods

Microscopy for intestinal parasite eggs

Fourteen sediment samples from the six cesspits dating from AD 1250–1600 underwent analysis for intestinal parasites. They were dated from pottery fragments recovered from the cesspit fill, and the type and size of the bricks used to construct the cesspits. Analysis was performed at the Ancient Parasites Laboratory at the University of Cambridge, following the modified RHM (rehydration, homogenization, micro-sieving) protocol described by Anastasiou and Mitchell (2013). A 0.2g subsample was measured and disaggregated (placed into suspension) using 0.5% trisodium phosphate. The suspension was washed through three microsieves (mesh sizes 300, 160 and 20μm). The material trapped on the 20μm micro-sieve was rinsed free with distilled water, collected in a 15mL tube, centrifuged for five minutes at 4000rpm, and the supernatant removed. The concentrated material at the base of the tube was mixed with glycerol, mounted on microscope slides and analysed with digital light microscopy at 400× magnification (Olympus BX40F microscope with GXCAM-9 digital camera). The eggs of intestinal parasitic worms were identified by their shape, colour, dimensions and special characteristics using reference manuals such as Garcia (2016). Egg dimensions were measured using the GX Capture-T software. Egg counts per gram were calculated by multiplying the number of eggs noted in each 0.2g sample by five.

ELISA for intestinal protozoa

Enzyme-linked immunosorbent assay (ELISA) kits, *Entamoeba histolytica* II™, *Giardia* II™ and *Cryptosporidium* II™, produced by TECHLAB® (Blacksburg, Virginia, USA), were used to analyse five of the samples for three species of protozoan parasites which can cause diarrhoea and dysentery. We did not test all 14 samples for reasons of cost, but the samples chosen covered the full time depth while focusing on those samples with good parasite egg survival. A 1g subsample was measured and disaggregated (placed into suspension) using 0.5% trisodium phosphate and passed through the sieves. The material from the catchment container measuring less than 20μm was collected, as the cysts and oocysts of protozoa that cause diarrhoea and dysentery in humans typically measure 5–19μm in diameter. The fluid was centrifuged to concentrate it to the volume required for the ELISA analysis. Eight wells were tested for each sample. Each ELISA analysis was repeated one month after the first run using a new sample prepared using the same method, and results were only considered positive if both tests were positive. Following manufacturer instructions, a positive and negative control were included in each plate. The absorbance values for each well were generated using an ELISA plate reader (BioTek Synergy HT). Past research has indicated these test kits have 97–100% sensitivity and specificity in modern samples (Boone *et al.* 1999; Silva *et al.* 2016).

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Results

All 14 samples from the six cesspits analysed contained intestinal parasite eggs (Table 2). We identified six species of helminth parasite in total: whipworm (*Trichuris* sp.), roundworm (*Ascaris* sp.), fish tapeworm (Diphyllobothriidae), *Dicrocoelium* sp., cf. *Echinostoma* sp. fluke and cf. *Fasciola hepatica* fluke (Figure 4).

The dominant parasites were whipworm and roundworm, which were found in all samples (Table 2). Whipworm was identified by its lemon shape, polar plugs, smooth wall, and dimensions, while roundworm was identified by its mamillated coat, oval shape, brown colour and dimensions. The eggs of trematodes from the genera *Echinostoma* and *Fasciola* are morphologically similar and overlap in size: the size range for *Echinostoma* eggs (80–135μm long by 55–80μm wide (Centers for Disease Control and Prevention 2019a) is only slightly lower than for *Fasciola* (130–150μm long by 60–90μm wide (Centers for Disease Control and Prevention 2019b), although Valero and colleagues (2002) report *Fasciola* eggs as short as 125μm in modern cattle). Significantly however, the literature reports different size ranges for trematode eggs (for example, compare the ranges described in Ash and Orihel (2015: 177) with those in Garcia (2016)); egg sizes were also noted to vary regionally and by host (Valero *et al.* 2009). Here we rely on the egg size ranges provided by the Centers for Disease Control and Prevention (CDC) because these references are easily accessible (https://www.cdc.gov/) for no charge and are commonly employed in the palaeoparasitological literature. The eggs of the fish tapeworm (Diphyllobothriidae) cestodes are oval and range between 55–75μm long and 40–50μm wide, although Leštinová and colleagues (2016) report eggs of *Dibothriocephalus latus* as long as 59–81μm in modern human populations in Italy. *Dicrocoelium* was identified by its dimensions (typically 35–45μm long and 20–30μm wide), operculum, wall thickness and shape, often with one side flatter and the other more curved.

ELISA analysis was positive in two cesspits (S728, dated 1375–1500, and S703, dated 1375–1550) for the protozoan *Giardia duodenalis*, which causes severe watery diarrhoea (Table 3). All ELISA tests were negative for *Entamoeba histolytica* and *Cryptosporidium parvum*.

Discussion

The taxonomic diversity of parasites and the dominance of roundworm and whipworm are consistent with previous findings from the Low Countries (Rocha *et al.* 2006; Appelt *et al.* 2014; Deforce *et al.* 2015; Rácz *et al.* 2015; Graff *et al.* 2020; De Cupere *et al.* 2021; Rabinow *et al.* 2023). Roundworm, whipworm and the protozoan *Giardia duodenalis* are all spread via the faecal-oral route of parasite transmission. Their presence within cesspits indicates that the level of sanitation in medieval Leiden was insufficient to prevent the contamination of food and drink with faeces and the reinfection of the population with these parasites.

Parasites spread by the consumption of raw freshwater fish or other freshwater foods (cf. *Echinostoma* and Diphyllobothriidae) were also present in some cesspits. Both these helminths can infect humans through the consumption of raw, undercooked, smoked or pickled freshwater fish; *Echinostoma* can also infect freshwater shellfish and waterfowl and may be

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Table 2. Digital-light microscopy and ELISA results. 'Trematode' indicates eggs whose measurements fit both with *Echinostoma* sp. and *Fasciola* sp. Egg counts represent an estimate of number of eggs per gram (raw counts for 0.2g multiplied by 5). ELISA results are not quantified, positive samples are shown with '+ve', negative samples are shown with '-ve'.

Start date (AD)	End date (AD)	Cesspit feature	Sample	*Ascaris* sp.	*Dicrocoelium* sp.	Diphyllobothriidae	cf. *Echinostoma*	cf. *Fasciola*	Trematode	*Trichuris* sp.	*Giardia duodenalis*
1250	1350	S736	562.2	505	0	0	0	0	5	1005	Not tested
1250	1350	S736	567.2	2225	5	5	5	0	0	10705	Not tested
1350	1600	S467	312.2	2380	0	0	0	0	0	1250	-ve
1375	1500	S728	744.2	4220	0	0	0	0	0	6325	Not tested
1375	1500	S728	747.2	10925	0	0	5	0	0	7110	+ve
1375	1500	S728	587.2	5475	0	0	5	0	0	3440	Not tested
1375	1500	S728	588.2	2410	0	5	5	0	0	3555	Not tested
1375	1500	S728	589.2	2780	0	0	0	0	0	2240	Not tested
1375	1500	S728	590.2	2115	0	5	0	10	0	665	Not tested
1375	1550	S703	580.2	3950	0	0	0	0	0	1300	+ve
1375	1550	S703	648.2	5440	0	0	0	0	0	3875	Not tested
1375	1550	S703	699.2	2310	0	0	0	0	0	3690	Not tested
1450	1500	S598	462.2	6180	0	0	0	0	0	5530	-ve
1475	1525	S859	908.2	8925	0	0	0	0	5	3895	-ve

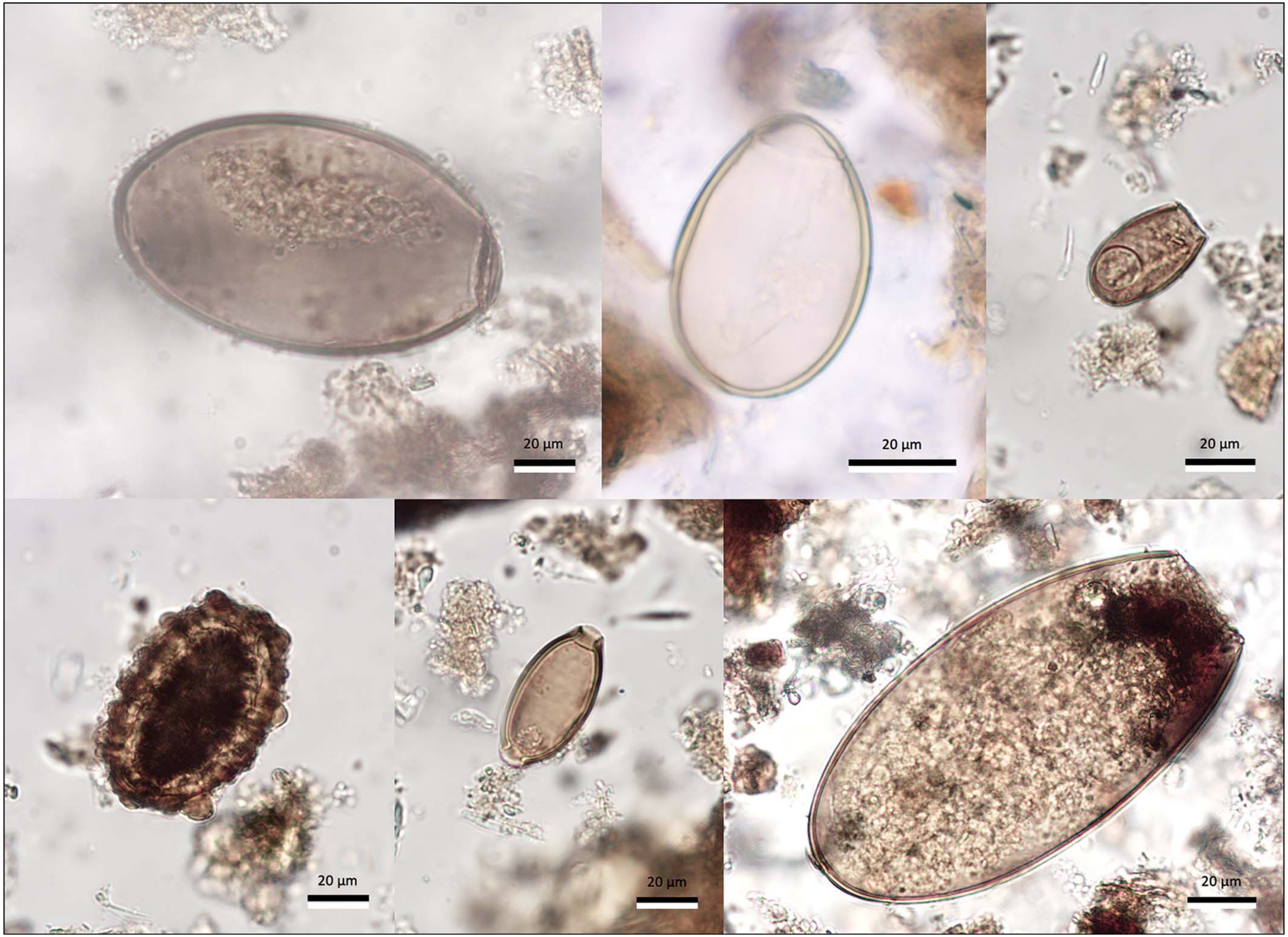


Figure 4. Parasite eggs from the Leiden cesspits. Top left: cf. Echinostoma *sp. (dimensions 119 × 72µm); top centre: Diphyllobothriidae (52 × 36µm); top right: cf.* Dicrocoelium *sp. (36 × 22µm); bottom left: roundworm (78 × 48µm); bottom centre: whipworm (53 × 26µm); bottom right: cf.* Fasciola hepatica *(141 × 73µm) (figure by authors).*

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Table 3. Raw data for the samples positive for *Giardia duodenalis* on ELISA analysis. Manufacturer guidance for the ELISA test kits state that a result with absorbance value greater than 0.150 is positive.

Start date (AD)	End date (AD)	Cesspit feature	Sample	First analysis positive results 8 wells tested	Second analysis positive results 8 wells tested
1375	1500	S728	747.2	0.422	0.258
				0.425	0.262
				0.434	0.269
				0.395	0.241
				0.376	0.256
				0.370	0.266
				0.378	0.236
				0.384	0.241
1375	1550	S703	580.2	0.653	0.176
				0.664	0.154
				0.701	0.157
				0.649	0.287
				0.665	0.152
				0.628	
				0.651	
				0.698	

passed to humans if consumed (Huffman & Fried 1990; Garcia 2016). We should bear in mind the possibility that *Echinostoma* eggs might theoretically be found in cesspit sediments in the absence of human infection, for example if infected rodents accessed the cesspits, or if the offal discarded from infected waterfowl was tossed into the cesspit. While mussel shells were found discarded in two of the cesspits, these were of marine species and not freshwater species, so could not have spread *Echinostoma*. Similarly, low numbers of *Dicrocoelium* and *Fasciola hepatica* eggs in human faeces are unlikely to indicate true human infection. These parasites generally infect the liver of ruminant animals such as sheep and cattle. If humans then eat raw or undercooked animal liver, the eggs can pass through the digestive system largely unaltered. Use of cesspits for the disposal of animal manure could also explain the presence of these parasite eggs.

Whipworm and roundworm eggs were consistently found in all six cesspits in high counts relative to the zoonotic parasites present, as is common in palaeoparasitological studies of medieval populations (Mitchell 2015b). Zoonotic parasites are often present in much lower counts (Graff *et al.* 2020; Rabinow *et al.* 2023). In our study area, zoonotic parasites were not found in every sample, or even in every latrine. This suggests parasites contracted by eating meat or seafood caused considerably fewer infections among the population of Leiden than did parasites caused by poor sanitation. We have chosen not to statistically interrogate differences in the egg counts for whipworm and roundworm in the different cesspits, as such differences could be caused by taphonomic and depositional factors irrelevant to infection burdens, for example the number of eggs produced (which varies by individual worm),

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

the number of people using the cesspits, and the degree to which the eggs may have been diluted with non-faecal refuse.

Modern clinical understanding of the health consequences of parasitic infections suggests that *Giardia duodenalis* would have had the greatest impact upon the population of medieval Leiden. This protozoan can cause outbreaks of severe diarrhoea, which can lead to dehydration and death, especially in children (Ryan *et al.* 2019). The cesspits positive for *Giardia duodenalis* date from 1375–1500/1550. From just two samples it is hard to tell if this was by chance or if it might indicate that diarrhoea was more of a public health problem around the 1400s compared with earlier or later centuries. Roundworm and whipworm infection may cause malnutrition, stunted growth and reduced intelligence in children when significant numbers of worms are present (Brooker 2010). In adults with a healthy diet, roundworm and whipworm in low numbers may be tolerated without significant symptoms.

Given the similarity in dating and location, it seems possible that cesspit S467 was used by the household of the brewer Cornelis Adriaensz van Barrevelt. The cesspit contained crab or lobster (Table 4), a typical high-status food (Brinkhuizen *et al.* 2018), similar to the abundance illustrated in many late sixteenth- and seventeenth-century still-life paintings (Kwak 2014). Cesspit S859 is located closer to the Stille Rijn, directly next to a fire pit and therefore probably belonged to the business premises. This cesspit fell into disuse in 1525–1550, long before Cornelis Adriaensz Barrevelt was in charge of the brewery, but at this time it was probably already a brewery and was potentially run by his grandfather. The archaeological assessment of the cess identified pomegranate seeds (Table 4), a typical food of the upper-class (Van Haaster 2008: 11).

Map 28 from the *Stratenboek* indicates that cesspit S598 was located within a much smaller plot in the second half of the sixteenth century so was probably used by craftsmen. This is likely to also have been the case around 1450–1500—the date for the layer analysed from this pit—because quite a few marine mussel shells were found in the cesspit. Marine mussels were a typical food of the less fortunate, as illustrated in the print 'The Lean Kitchen' from 1563: while the table in 'The Fat Kitchen' is lavish with fresh meat, mussels are the only food depicted in 'The Lean Kitchen' (Figure 5) (van der Heyden 1563). Cesspits S703 and S728 also belong to plots that were inhabited by craftsmen, at least in the second half of the sixteenth century (Figure 2). The cesspits may have been used by several households as they were located near the property boundary. The finds in cesspit S703 include marine mussels, as well as grains, the seeds of fig, apple, black mulberry, cherry, plum and grape, and bone from cattle and sheep/goat.

The archaeological organic data seem to be consistent with historical records: cesspits S467 (1350–1600) and S859 (1475–1525) contained rare and exotic taxa, while S598 (1450–1500), S703 (1375–1550) and S728 (1375–1500) did not and are therefore interpreted as households of low or moderate wealth. Despite this, parasite data did not identify variation between different households and professions. Roundworm and whipworm were the dominant species of parasite in all the cesspits and the eggs of zoonotic trematodes occurred in cesspits from both the poorer (S728) and possibly wealthier (S736, S859) families.

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Table 4. Summary of organic macro remains, parasitological and historical data by cesspit. 'Trematode' indicates eggs whose measurements fit both with *Echinostoma* sp. and *Fasciola* sp. Archaeological macro remains results from Van Haaster (2020) and Van Amerongen (2022).

Feature	Date range (AD)	Methods	Historical evidence
S736	1250–1350	Organic macro remains assessment: cess, but not well preserved. Parasite analysis: roundworm, whipworm, Diphyllobothriidae, cf. *Echinostoma*, trematode, *Dicrocoelium*. As it is an early cesspit, and presumably one-storey house, a well-to-do household? Other archaeological indications for status are lacking.	No information, too early for historical records in Leiden, pre-urbanisation.
S467	1350–1600	Seven layers, parasite sample comes from upper layer, *c*. AD 1550–1600. Organic macro remains assessment: elite. Crab or lobster. Parasite analysis: roundworm, whipworm.	Property used from *c*. 1550 to 1591 by Cornelis Adriaensz van Barrevelt, a brewer, and his household.
S728	1375–1500	Small pottery sherds, perhaps pit regularly emptied. Organic macro remains assessment: indicates cess. Parasite analysis: roundworm, whipworm, Diphyllobothriidae, cf. *Echinostoma* and cf. *Fasciola*, *Giardia* that causes diarrhoea.	Presumably a craftsman.
S703	1375–1550	Organic macro remains assessment: a range of finds including marine mussels. Parasite analysis: roundworm, whipworm, *Giardia* that causes diarrhoea.	Accessed by various households, as the cesspit is on the property boundary (shared). Poor or medium status users.
S598	1450–1500	Upper layer of cesspit not present, longer use possible. Organic macro remains assessment: human excrement, marine mussels shells. Parasite analysis: roundworm, whipworm.	Presumably a craftsman.
S859	1475–1525	Organic macro remains assessment: human excrement. Elite status (pomegranate). Parasite analysis: roundworm, whipworm, trematode.	Cesspit perhaps belonging to brewery, or at the home of brewer.

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

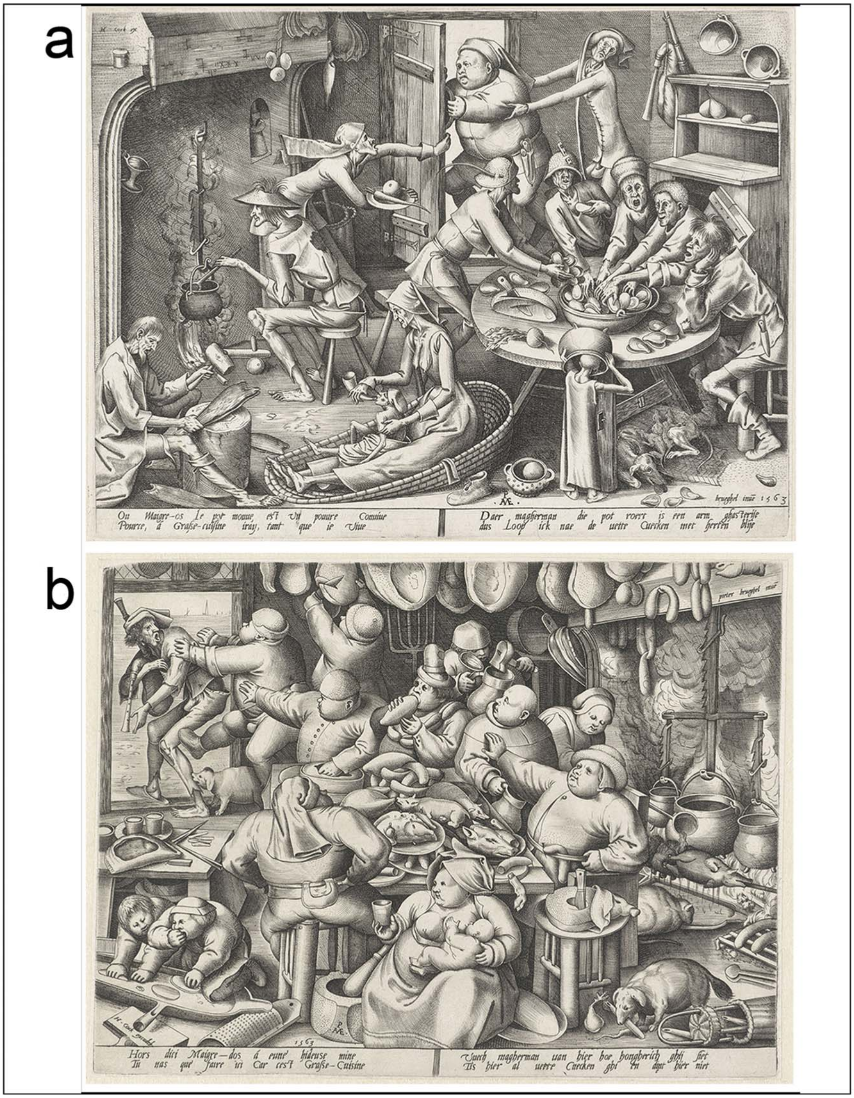


Figure 5. Engravings by P. Van der Heyden, after P. Bruegel. Printed in Antwerp in 1563: a) Magere Keuken (lean kitchen); b) Vette Keuken (fat kitchen) (© Rijksmuseum, Amsterdam; figure by authors).

Conclusion

Here we present the parasite analysis of samples from six cesspits in use from 1250 to 1600 in Leiden, and integrate our findings with archaeological organic and historical evidence for the same properties. Most of the eggs identified within the cess were from roundworm and whipworm, and ELISA tests indicated the presence of the protozoan *Giardia duodenalis* within two cesspits. These species can all infect humans, causing symptoms that include diarrhoea, and are spread by poor sanitation. The zoonotic parasites Diphyllobothriidae and *Echinostoma* fluke were also likely present in the population. Identification of *Dicrocoelium* and

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Fasciola hepatica eggs within the cess likely indicates the consumption of infected ruminant livers rather than infection of the human population by these parasites. Parasite analyses also verified archaeological organic findings by contributing to the characterisation of the function of the six archaeological features as cesspits (AD 1250–1600).

Combined macro and micro analysis of animal and plant remains and parasite eggs can provide a more comprehensive understanding of the lifestyle, diet and disease of past groups, while historical records can be valuable for contextualising archaeological data. However, the narrative they provide cannot be understood as a faithful or unbiased record for specific archaeological contexts. Earlier pre-urban contexts may also lack any historical records. For these reasons the potential for analysing the contents of cesspits as a proxy for intestinal health is more straightforward than when considering the wealth and social status of their users, which remains a complex and challenging area.

Here, the taxonomic diversity of the parasites identified showed similarity between the different professions of the Leiden households, which may suggest broad consistency in lifestyle between different households or the shared use of the cesspits. These findings contrast with the archaeobotanical and zooarchaeological data, which showed variation between households, consistent with the professions outlined in historical records. Parasites therefore appear to be a less effective proxy for identifying social variation, but remain significant as broad dietary markers and for characterising the function of archaeological features.

Acknowledgements

We are grateful to Techlab©, Blacksburg, USA for donating the ELISA test kits used in this study. Thanks also go to Martin Hooymans (Leiden, coordinator Mapping Historical Leiden), Nina Linde Jaspers (Amsterdam, Terra Cotta Incognita) and Otto Brinkkemper (Cultural Heritage Agency of the Netherlands). Use of material from the CDC does not constitute endorsement or recommendation by the United States Government or CDC. All material from the CDC is available on the agency website (https://www.cdc.gov/) for no charge.

Funding

SR would like to acknowledge the following funding bodies: the H.M. Chadwick Fund Studentship (University of Cambridge, UK), the Mary P. Dole Medical Fellowship (Mount Holyoke College, USA) and The Louise Fitz-Randolph Fellowship (Mount Holyoke College, USA).

References

ANASTASIOU, E. & P.D. MITCHELL. 2013. Simplifying the process of extracting intestinal parasite eggs from archaeological sediment samples: a comparative study of the efficacy of widely-used disaggregation techniques. *International Journal of Paleopathology* 3: 204–7. https://doi.org/10.1016/j.ijpp.2013.04.004

APPELT, S., F. ARMOUGOM, M. LE BAILLY, C. ROBERT & M. DRANCOURT. 2014. Polyphasic analysis of a Middle Ages coprolite microbiota, Belgium. *PLoS ONE* 9: e88376. https://doi.org/10.1371/journal.pone.0088376

ASH, L.R. & T.C. ORIHEL. 2015. *Atlas of human parasitology*. Fifth Edition. Chicago: American

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

Society for Clinical Pathology Press. https://doi.org/10.3201/eid1306.070321

Boone, J.H., T.D. Wilkins, T.E. Nash, J.E. Brandon, E.A. Macias, R.C. Jerris & D.M. Lyerly. 1999. TechLab and alexon *Giardia* enzyme-linked immunosorbent assay kits detect cyst wall protein 1. *Journal of Clinical Microbiology* 37: 611–614. https://doi.org/10.1128/jcm.37.3.611-614.1999

Brand, H. 2008. Een pre-industriële samenleving onder spanning. Leiden rond 1500. *Leids Jaarboekje. Eeuwig Leiden* 100: 95–120.

Brinkhuizen, D., B. Cooremans, A. Ervynck, S. Stoops & W. Van Neer. 2018. Schepenhuisstraat - Hoogpoort: aan tafel bij de Gentse bourgeoisie uit de eerste helft van de 18de eeuw. *Stadsarcheologie. Bodem en monument in Gent* 2: 113–42.

Brooker, S. 2010. Estimating the global distribution and disease burden of intestinal nematode infections: adding up the numbers – a review. *International Journal for Parasitology* 40: 1137–44. https://doi.org/10.1016/j.ijpara.2010.04.004

Centers for Disease Control and Prevention. 2019a. Echinostomiasis. Available at: https://www.cdc.gov/dpdx/echinostomiasis/index.html (accessed 1 July 2023).

– 2019b. Fascioliasis. Available at: https://www.cdc.gov/dpdx/fascioliasis/index.html (accessed 1 July 2023).

de Baar, P.J.M. 1985. Jan van Hout en zijn Straten- en Grachtenboek, in *Ups en Downer. Bundel artikelen bij het afscheid van mr. W. Downer als gemeentearchivaris van Leiden*: 5–18. Leiden. Available at: https://oudleiden.nl/images/janvanhout/publicaties/elo/Jan%20van%20Hout%20en%20zijn%20Straten-%20en%20Grachtenboek%20met%20voetnoten%20V4%2020160701.pdf (accessed 22 April 2023).

De Cupere, B. *et al.* 2021. A multidisciplinary analysis of cesspits from late medieval and post-medieval Brussels, Belgium: diet and health in the fourteenth to seventeenth centuries. *International Journal of Historical Archaeology* 26: 531–72. https://doi.org/10.1007/s10761-021-00613-8

Deforce, K., M.L. Van Hove & D. Willems. 2015. Analysis of pollen and intestinal parasite eggs from medieval graves from Nivelles, Belgium: taphonomy of the burial ritual. *Journal of Archaeological Sciences: Reports* 4: 596–604. https://doi.org/10.1016/j.jasrep.2015.10.027

De Vries, B., J. Lucassen, J. Lourens & H. Nijboer. 2003. Het economisch leven: spectaculair succes en diep verval, in S. Groenveld (ed.) *Leiden de geschiedenis van een Hollandse stad, 1574–1795*: 85–107. Leiden: Stichting Geschiedschrijving.

Garcia, L.S. 2016. *Diagnostic medical parasitology*. Washington, D.C.: ASM Books.

Graff, A., *et al.* 2020. A comparative study of parasites in three latrines from medieval and Renaissance Brussels, Belgium (14th–17th centuries). *Parasitology* 147: 1443–51. https://doi.org/10.1017/S0031182020001298

Huffman, J.E. & B. Fried. 1990. *Echinostoma* and Echinostomiasis. *Advances in Parasitology* 29: 215–269.

Hupperetz, W. 2010. Micro history, archaeology and the study of housing culture. Some thoughts on archaeological and historical data from a cesspit in 17th-century Breda, in K. De Groote, D. Tys & M. Pieters (ed.) *Exchanging medieval material culture*: 279–84. Brussels: Vlaams Institut voor het Onroerend Erfgoed.

Kwak, Z.S.M. 2014. 'Proeft de kost en kauwtse met uw' oogen'. Beeldtraditie, betekenis en functie van het Noord-Nederlandse keukentafereel (ca. 1590–1650). Unpublished PhD dissertation, University of Amsterdam.

Ledger, M.L. & P.D. Mitchell. 2022. Tracing zoonotic parasite infections throughout human evolution. *International Journal of Osteoarchaeology* 32: 553–64. https://doi.org/10.1002/oa.2786

Leštinová, K., M. Soldánova, T. Scholz & R. Kuchta. 2016. Eggs as a suitable tool for species diagnosis of causative agents of human Diphyllobothriosis (Cestoda). *PLoS Neglected Tropical Diseases* 10: e0004721. https://doi.org/10.1371/journal.pntd.0004721

Mitchell, P.D. (ed.) 2015a. *Sanitation, latrines and intestinal parasites in past populations*. Farnham: Ashgate.

– 2015b. Human parasites in medieval Europe: lifestyle, sanitation and medical treatment. *Advances in Parasitology* 90: 389–420. https://doi.org/10.1016/bs.apar.2015.05.001

MITCHELL, P.D. 2023. *Parasites in past civilizations and their impact upon health*. Cambridge: Cambridge University Press.

NOORDAM, D.J. 2001. Leiden in Last. De financiële positie van de Leidenaren aan het einde van de Middeleeuwen. *Jaarboek der sociale en economische geschiedenis van Leiden en omstreken* 2001: 16–40.

POSTHUMUS, N.W. 1908. *De geschiedenis van de Leidsche lakenindustrie*, vol. 1. Gravenhage: M. Nijhoff.

RABINOW, S., K. DEFORCE & P.D. MITCHELL. 2023. Continuity in intestinal parasite infection in Aalst (Belgium) from the medieval to early modern period (12th-17th centuries). *International Journal of Paleopathology* 41: 43–49. https://doi.org/10.1016/j.ijpp.2023.03.001

RÁCZ, S.E. *et al.* 2015. Parasitology in an archaeological context: analysis of medieval burials in Nivelles, Belgium. *Journal of Archaeological Sciences* 53: 304–15. https://doi.org/10.1016/j.jas.2014.10.023

ROCHA, G.C.D., S. HARTER-LAILHEUGUE, M. LE BAILLY, A. ARAÚJO, L.F. FERREIRA, N.M. SERRA-FREIRE & F. BOUCHET. 2006. Paleoparasitological remains revealed by seven historic contexts from 'Place d'Armes', Namur, Belgium. *Memorias do Instituto Oswaldo Cruz* 101 (S2): 43–52. https://doi.org/10.1590/s0074-02762006001000008

RYAN, UNA, NAWAL HIJJAWI, YAOYU FENG & LIHUA XIAO. 2019. *Giardia*: an under-reported foodborne parasite. *International Journal for Parasitology* 49: 1–11. https://doi.org/10.1016/j.ijpara.2018.07.003

SILVA, R.K.N.R. *et al.* 2016. Performance of microscopy and ELISA for diagnosing *Giardia duodenalis* infection in different pediatric groups. *Parasitology International* 65: 635–40. https://doi.org/10.1016/j.parint.2016.08.012

STEPHENSON, L.S., M.C. LATHAM & E.A. OTTENSEN. 2000. Malnutrition and parasitic helminth infections. *Parasitology* 121(S1): S23–S38. https://doi.org/10.1017/S0031182000006491

VALERO, M.A., M. PANOVA, A.M. COMES, R. FONS & A. MAS-COMA. 2002. Patterns in size and shedding of *Fasciola hepatica* eggs by naturally and experimentally infected murid rodents. *Journal of Parasitology* 88: 308–13. https://doi.org/10.1645/0022-3395(2002)088[0308:PISASO]2.0.CO;2

VALERO, M.A., I. PEREZ-CRESPO, M.V. PERIAGO, M. KHOUBBANE & S. MAS-COMA. 2009. Fluke egg characteristics for the diagnosis of human and animal fascioliasis by *Fasciola hepatica* and *F. gigantica*. *Acta Tropica* 111(2): 150–59. https://doi.org/10.1016/j.actatropica.2009.04.005

VAN AMERONGEN, Y.F. 2022. Macrobotanie, in Y. Meijer (ed.) *Archeologische opgraving Haarlemmerstraat 101–111 tot Stille Rijn 8–9 in Leiden, gemeente Leiden*: 597–606. Noordwijk: IDDS Rapport 2335. https://doi.org/10.17026/AR/P6RH8X

VAN DER HEYDEN, P. 1563. Engravings entitled *Magere Keuken* (lean kitchen) and *Vette Keuken* (fat kitchen) after P. Bruegel. Printed in Antwerp. Curated in Rijksmuseum Amsterdam. Available at: http://hdl.handle.net/10934/RM0001.COLLECT.344470 and http://hdl.handle.net/10934/RM0001.COLLECT.344471 (accessed 22 April 2023).

VAN HAASTER, H. 2008. *Archeobotanica uit 's-Hertogenbosch. Milieuomstandigheden, bewoningsgeschiedenis en economische ontwikkelingen in en rond een (post)Middeleeuwse groeistad* (Groningen Archaeological Studies 6). Groningen: Barkhuis.

– 2020. *Leiden, Haarlemmerstraat/Stille Rijn: Waarderend onderzoek van botanische macroresten en voorstel voor selectieadvies*, in Y. Meijer (ed.) *Archeologische opgraving Haarlemmerstraat 101–111 tot Stille Rijn 8–9 in Leiden, gemeente Leiden*: 565–96. Noordwijk: IDDS Rapport 2335. https://doi.org/10.17026/AR/P6RH8X

VAN OOSTEN, R.M.R. 2015. *De stad, het vuil en de beerput: de opkomst, verbreiding en neergang van de beerput in stedelijke context*. Leiden: Sidestone.

– 2016a. Nightman's muck, gong farmer's treasure: local differences in the clearing-out of cesspits in the Low Countries, 1600–1900, in D. Sosna & L. Brunclíková (ed.) *Archaeologies of waste: encounters with the unwanted*: 41–56. Oxford: Oxbow.

– 2016b. The Dutch Great Stink: the end of the cesspit era in the pre-industrial towns of Leiden and Haarlem. *European Journal of Archaeology* 19: 704–27.

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press

https://doi.org/10.1080/14619571.2016.1147677

VAN STEENSEL, A. 2016. *Historisch Leiden in Kaart: Vermogensbelasting, 1498*. DANS Dataset. https://doi.org/10.17026/dans-zfa-srjh

– 2020. Measuring urban inequalities. Spatial patterns of service access in sixteenth-century Leiden, in G. Nigro (ed.) *Economic inequality in pre-industrial societies: causes and effect*: 369–88. Florence: Firenze University Press.

WALLE, K. & M. HOOYMANS. 2021. Brouwerijen 1607, een transcriptie van het rapport van Jan van Hout over de bierfraude (SAII, inv. nr. 1969). Historischleideninkaart (Mapping Historical Leiden). Available at: https://www.historischleideninkaart.nl/brouwerijen1607/ (accessed 22 April 2023).

https://doi.org/10.15184/aqy.2024.72 Published online by Cambridge University Press