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Insect Pests of Pulse Crops and their Management in Neolithic Europe

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ABSTRACT
Insect pests affecting standing and stored crops can cause severe damage and reduce yields considerably. Was this also the case in Neolithic Europe? Did early farming populations take a certain amount of harvest loss into account? Did they decide to change crops or rotate them when they became too infested? Did they obtain new crops from neighbouring communities as part of this process? Or did they actively fight against pests? This paper focuses on pulse crop pests, presenting the earliest evidence of fava beans displaying boreholes and of the presence of pea weevil in two different archaeological sites: Can Sadurní (in a phase dated to ca. 4800-4500 cal BC), located in the NE Iberian Peninsula and Zürich-Parkhaus Opéra (in a phase dated to ca. 3160 BC), located in Central Switzerland. Evidence suggests that early farmers were aware of the damages produced by pests and we propose different strategies for their management, including potential evidence for the use of repellent or trap plants in the plots.

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Introduction

Animal and insect pests, diseases and weeds are notable constraints on crop production (Dark and Gent 2001). Currently, without crop protection one could lose up to 50% of a barley or wheat harvest due to these multiple agents. Infestations during storage can be one of the most catastrophic of all depending on the crop, the type of storage and the climatic conditions. The FAO estimated yearly losses during storage due to insect attack of ca. 10% of the world's production in 1947, but some authors consider that this value is an underestimation when considering past societies (Buckland 1978; Smith and Kenward 2011). Ethnographic research shows how different farming populations, even those without access to chemicals or modern technology, actively fight against insect pests and other animals causing damages to their crops. They are aware of their existence and they aim to have pest-free crops (Narayanasamy 2006). One of the reasons of replacing a crop might be that it was too susceptible to insect pest infestation or other diseases (e.g. Dark and Gent 2001). Nowadays intensive industrial agriculture is widespread, and the production and storage of food has reached gigantic proportions. Pests in current monocultures, usually with plants that no longer resist local or incoming pests, can cause devastating damage, for which (often toxic) pesticides have been used at a large scale. Current knowledge about Neolithic farming practices establishes small-scale intensive mixed farming as the most widespread farming model in central and southern Europe, often based on considerable crop diversity (Antolín 2016; Bogaard 2004). To what extent should we then contemplate consideration of pests as a factor in crop choice and farming practices during the Neolithic period?

Some authors such as Dark and Gent (2001) have theorised that at the beginning of agriculture insect pests would not have survived long after arriving in new climatic areas, and that crop exchange was not frequent enough to sustain for any time populations that could arrive at sparse intervals. On the other hand, authors like Panagiotakopulu and Buckland (1991) consider that it would be impossible for early farmers to completely remove infested crops until the development of modern cleaning techniques, so we should assume that infested seeds were eaten, as also current ethnographic observations confirm (R. Pelling, pers. com.). One option to remove infested seeds would be to pan them or to float them. Whatever the case may be, in recent syntheses it has been observed that cereal grain pests did not survive long once crops spread towards central Europe and it is not until much more recent periods (mostly during the Roman period) when they seem to reappear and stay (Panagiotakopulu and Buckland 2017, 2018). The main difference between the effects of pests nowadays and in the Neolithic period is probably to be found in the scale: regional (at a large-scale) in the former, and local in

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the latter. All farmers in a settlement would have been threatened by the presence of a pest (Halstead and O'Shea 1989), but the likelihood that this pest was transmitted to a much larger scale (through exchange, for instance) is more limited than in more recent chronologies. We should therefore assume that measures were taken against pests, since the danger of having infested crops existed and it could have affected a whole community, but at a relatively local scale.

The existence of pests in the Neolithic has long been known, associated with cereal crops. Obata et al. found impressions of *Sitophilus zeamais/oryzae* on potsherds dating to ca. 9000 BP (King et al. 2014). Most of the first identifications in SW Asia such as in Hacilar layer VI or in Atlit-Yam are of wheat weevil (*Sitophilus granarius*) (King et al. 2014). The wheat weevil cannot fly and completes its life cycle in the storage area. It has also been documented in Neolithic Europe but largely disappeared around 4500 BC and only returned during the Iron Age (Panagiotakopulu and Buckland 2017, 2018). This cannot be an artefact of research tradition or preservation issues, since intensive insect-research has been conducted for some well-preserved lake-shore/bog sites dated to the 4th millennium cal. BC in central Europe (Büchner and Wolf 1997; Schäfer 2017; Schmidt 2006, 2011) and also in the UK. The eradication of this pest could relate to changing storage methods, since silo pits develop anoxic conditions during the storage of grain, thus preventing the survival of pests such as the wheat weevil, as demonstrated through experiments (Reynolds 1974). Previous research has already observed that economic changes starting in the Iron Age related to more extensive farming practices and the regular trade of crops, had favoured the arrival and propagation of insect pests that eventually caused significant damage to medieval and modern crop yields (Panagiotakopulu and Buckland 1991; Smith and Kenward 2011).

For this paper we would like to concentrate on pests affecting pulses, a topic which has not received as much attention in the literature. Among these, we have to highlight the significance of the Bruchidae group, which affect standing crops and can only be detected in the store (Kislev 1991).

The study of insect pests in Archaeology has several difficulties. First of all, identifying the crop to which these pests belong is not always straightforward. This is particularly the case for pulses (Medovic et al. 2011), which are usually underrepresented in most sites. In theory, archaeobotanists should be able to document attacked seeds, but pulses are scanty in prehistoric archaeobotanical assemblages of many areas of Europe, and insect boreholes, when present, are not always reported. The extraordinary preservation conditions of wetland sites are not helpful, since pulses are underrepresented in those sites as well. Likewise, for cereals, grains with boreholes have seldomly been noted by archaeobotanists (e.g. Kislev 2015). Boreholes are likely to go unnoticed, since attacked grains may survive charring in a less recognisable form and the original hole may disappear due to the effects of charring (with the swelling of the endosperm), and they may be more fragile in terms of post-depositional taphonomic agents. In this case, only desiccated contexts seem to be ideal for their recognition (Borojevic et al. 2010; Morales et al. 2014). In fact, infested seeds cannot always be identified, because if larvae died within the seed they can barely be detected (Panagiotakopulu and Buckland 1991).

Secondly, identifying the insect species is also difficult, even when a reference collection is available. Insect remains appear fragmented in archaeological sites and entomologists that are not trained with archaeological material are not necessarily skilled to identify them. There is another issue related to recovery biases. Insect remains are often preserved only under anoxic conditions. There are times when they are recovered in a charred state, but the remains become too fragile, and large-scale flotation techniques probably do not allow a proper recovery (Panagiotakopulu and Buckland 1991). In addition, not all archaeological contexts are equally suitable for the recovery of well-preserved insect remains. Ideally, primary contexts of accumulation of dumped material (pits or floors) should be sampled (Smith and Kenward 2011). One further problem involves contamination from recent layers or from recent material during sample processing and storage (King et al. 2014). Finally, not all taxa are equally resistant, so the most delicate taxa might always be underrepresented in the analyses (King et al. 2014).

If pests were present during the Neolithic period in Europe we should expect that farmers acted against them. Recent research, partly in the framework of the SNF-Funded AgriChange Project (2018–2021) (Antolín et al. 2018) has brought to light evidence of pests of pulse crops dated to the 5th and 4th millennia cal. BC. Beyond the mere attestation of these finds, our research questions ask if the available data suggests awareness of the existence of these pests by Neolithic farmers and if traditional methods could have been used to eradicate them.

Results: new evidence of pulse pests in Neolithic Europe

Can Sadurní Cave

The archaeological site of Cova de Can Sadurní is located at c. 425 m asl, in the Garraf Massif, next to the small village of Begues and ca. 30 km from the city of Barcelona (Spain). The site includes both the deposits inside the cave and an external terrace of c. 200 m^2. Inside of the cave, a surface of around

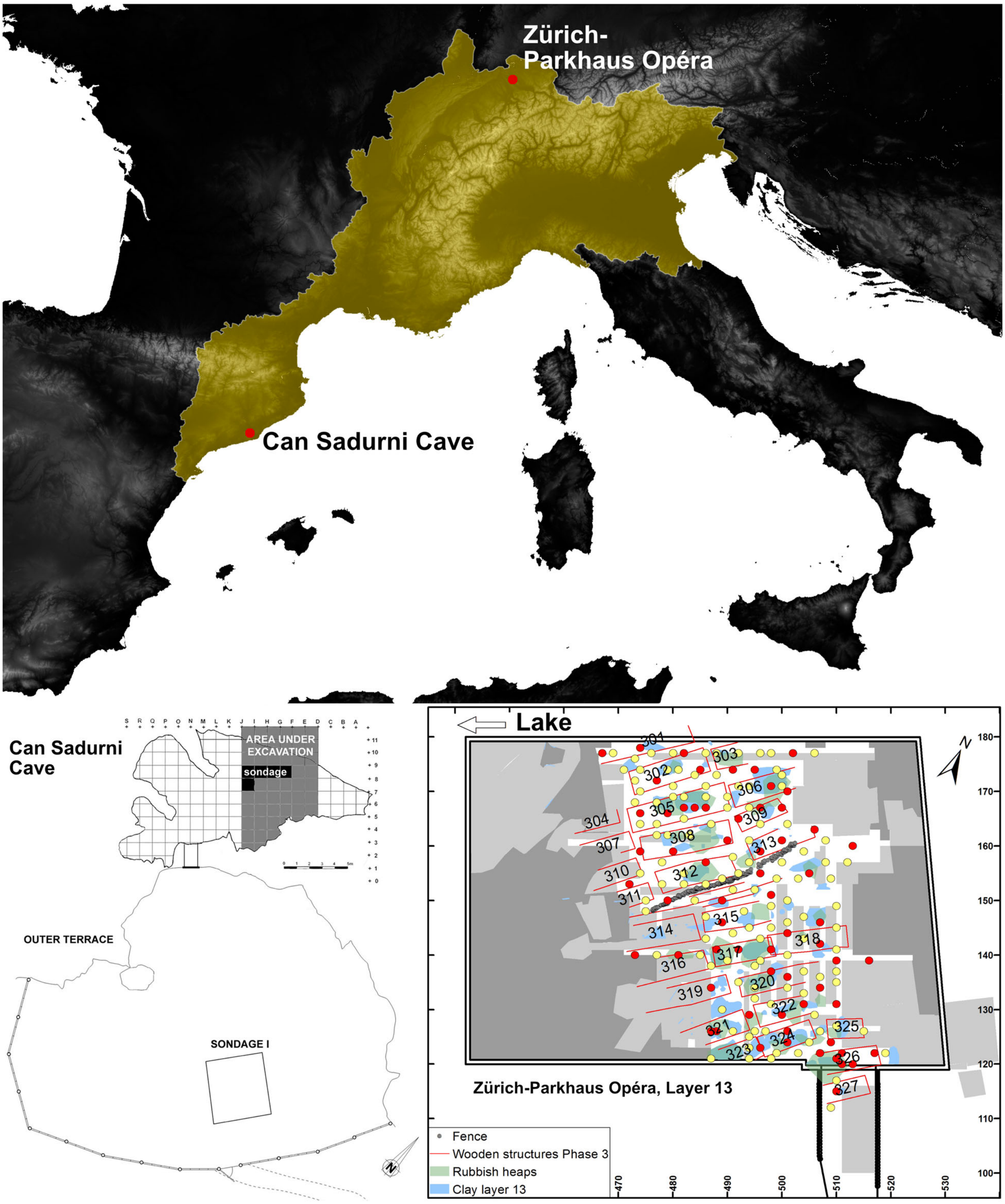

Figure 1. Map showing the area currently being studied by the AgriChange Project with the location of both sites presented in this paper and the site plans.

50 m^2 is being excavated (Figure 1). The stratigraphy recovered at the site to date is very impressive; over 4 m of deposits date from 10,500 cal. BC until Roman times (Edo et al. 2019; Edo and Antolín 2016; Edo, Blasco, and Villalba 2011). Recently, excavations have focused on the layers dated to the 5th millennium cal. BC (from layer 12 to layer 10, with several layers and sub-layers in between). There are a number of episodes that are clearly connected to the penning of domestic animals inside the cave. These are dated between 4800 and 4300 cal. BC (Table 1, Fig. 2). Sedimentologically, a high anthropogenic component is detected, basically consisting in very organic deposits, with *in situ* preservation of burnt herbivore dung, sometimes visible as stratigraphic units of deposits of white and black colour. These are known as *fumier*, frequently found in Neolithic cave deposits, mostly in the Mediterranean area (Bergadà et al. 2018) and the SW

Table 1. Radiocarbon dates from layers of burnt dung done on seed and fruit remains from Can Sadurní.

Lab reference	Sample reference	Dated material	Year	Date BP	Date cal BC	Layer	Publication reference
CNA-4618.1.1.	14CS-EST13-IIg-Capa4	Fruit *Arbutus unedo*	2018	5560 ± 35	4456-4346	11A4	Edo et al. (2019)
CNA-4621.1.1.	15CS-EST14-Capa2	Grain *Triticum 'nudum'*	2018	5740 ± 30	4686-4504	11A5	Edo et al. (2019)
CNA-4622.1.1.	15CS-EST17-G7-IIg-53	Fruit *Quercus* sp.	2018	5690 ± 35	4652-4452	11a5	Edo et al. (2019)
ETH-88892	17CS_G9_IIh_Estr_XVIII_c2	Grain *Triticum dicoccum*	2018	5788 ± 25	4709-4555	11a5	Unpublished
ETH-88895	98CS_G8_IIg_12_1al67	Grain *Triticum dicoccum*	2018	5827 ± 25	4779-4607	12	Edo et al. (2019)

Alps (Martin 2014). Ovicaprines were dominant in the animal assemblage (Saña et al. 2015).

The archaeobotanical study of the site is currently ongoing. Previous publications have dealt with the Early Neolithic funerary deposits uncovered by a smaller sondage (Antolín and Buxó 2011) and material from older excavations (between 1993 and 2008) from the Middle Neolithic deposits (Antolín 2016; Antolín, Buxo, and Edo i Benaiges 2015a). The sampling strategy has varied over time (Antolín 2008, 2016) but since 2010, 100% of the sediment has been processed using a flotation machine, and sieves of 2 and 0.5 mm have been used to recover the flot and a 2 mm mesh has been used to recover the heavy fraction. All fractions have been dried because most of the material is charred (only a small number of mineralised remains have been recovered so far). The heavy fraction has been sorted by naked eye, while the other fractions have always been sorted under the binocular microscope. Currently the whole Middle Neolithic sequence has been studied for 3 pilot squares, while the contents of the *fumier* deposits have also been analysed. The results will only be partially presented here (presence/absence per layer/stratigraphic unit) because it is not the goal of this paper to discuss them. We thus focus on layers 11a4 and 11a5 and the structures or *fumier* layers found within them: XIII, XIV, XVII, XVIII and 12. We consider the remains found outside of the burnt dung deposits for comparative purposes. The volume of sediment investigated from the structures is around 92 litres, while more than 1150 litres of sediment have been investigated from the surrounding deposits. All in all, almost 3000 plant macroremains have been retrieved (ca. 475 from inside the *fumier* deposits) and recorded in ArboDat (Kreuz and Schäfer 2014). The total results (presence/absence) can be found in the ESM 1.

At least five different cereals could have been cultivated at the site (Table 2): naked barley (*Hordeum vulgare* var. *nudum*), naked wheat (*Triticum aestivum/durum/turdigum* or *T. 'nudum'*), emmer (*T. dicoccon*), einkorn (*T. monococcum*) and the so-called 'new' glume wheat (*Triticum* sp., 'new type'). The most remarkable diversity is found among pulses: chickpea (*Cicer arietinum*), pea (*Pisum sativum*), bitter vetch (*Vicia ervilia*), fava bean (*Vicia faba*) and common vetch (*Vicia sativa*). Finally, two oil plants have been identified: flax (*Linum usitatissimum*) and opium poppy (*Papaver somniferum*). Regarding the evidence for pulse crop pests we want to highlight that the two seeds of fava bean recovered at the site have boreholes (Fig. 3). The holes are of less than 1 mm in width. We tried to date one of the seeds but it disintegrated during the cleaning process. Fava beans have been frequently recovered in Neolithic sites of the Iberian Peninsula (Peña-Chocarro, Pérez-Jordà, and Morales 2018), but less often in Catalonia (Antolín, Jacomet, and Buxó 2015b). It is very likely, though, that they are underrepresented and that their role in the economy is not yet well known. Chickpea has never been identified in the Neolithic of the central and western Mediterranean areas.

Among the wild plants, there is a considerable diversity (at least 32 taxa have been identified to date) and some of them are particularly abundant, such as *Trifolium* sp., *Hyoscyamus niger, Capsella bursa-pastoris* type, *Solanum nigrum, Quercus* sp., *Arbutus unedo, Pistacia lentiscus, Vitis vinifera* subsp. *sylvestris* or *Rubus* sp.

The contents of the different *fumiers* are quite diverse in terms of species found. Among the most common plants we have *Trifolium* sp., *Quercus* sp., *Arbutus unedo, Pistacia lentiscus, Vitis vinifera* subsp. *sylvestris* or *Rubus* sp.

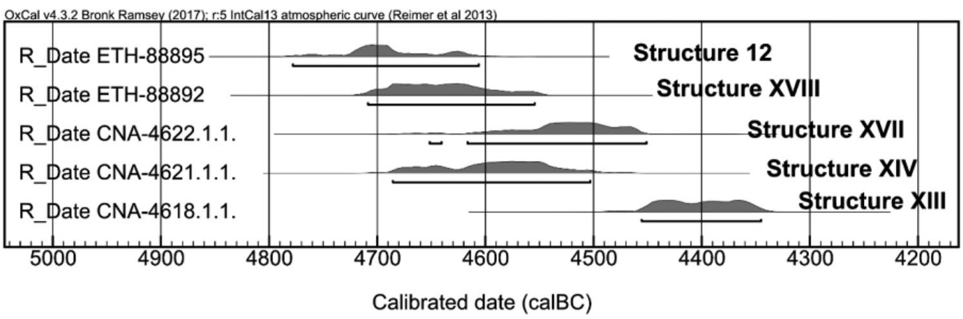

Figure 2. Calibrated radiocarbon dates from Table 1 done with OxCal (Bronk Ramsey 2009) with the IntCal13 atmospheric curve (Reimer et al. 2013).

Table 2. Presence/absence of cultivated taxa in the different *fumier* deposits of Can Sadurní and in the layers where they were embedded. Mostly unpublished, except for layer 12 (Antolín 2008).

		Contexts	C_12	Estr_XIII	Estr_XIV	Estr_XVII	Estr_XVIII	C_11a4	C_11a5
Cultivars	**Type of rest**								
Hordeum vulgare undiff.	seed/fruit	charred						+	
Hordeum vulgare undiff.	chaff	charred							+
Hordeum vulgare var. *nudum*	seed/fruit	charred	+	+		+	+	+	+
Triticum aestivum s.l./*durum*/*turgidum*	seed/fruit	charred	+		+		+	+	+
Triticum aestivum s.l./*durum*/*turgidum*	chaff	charred							+
Triticum dicoccon	seed/fruit	charred	+			+	+	+	+
Triticum dicoccon	chaff	charred							+
Triticum monococcum	seed/fruit	charred				+	+		+
Triticum monococcum	chaff	charred							+
Triticum monococcum, 2-grained	seed/fruit	charred							+
Triticum spec., 'new-type'	seed/fruit	charred						+	+
Triticum monococcum/*dicoccum*	seed/fruit	charred					+	+	+
Triticum monococcum/*dicoccum*	chaff	charred							+
Triticum spec.	seed/fruit	charred	+		+		+	+	+
Triticum spec.	chaff	charred							+
Cerealia indet.	seed/fruit	charred		+	+	+	+	+	+
Cicer arietinum	seed/fruit	charred					+		+
Pisum sativum	seed/fruit	charred						+	+
Vicia ervilia	seed/fruit	charred			+				
Vicia faba	seed/fruit	charred							+
Vicia sativa	seed/fruit	charred							+
Linum usitatissimum	seed/fruit	charred					+		
Papaver somniferum	seed/fruit	charred						+	+

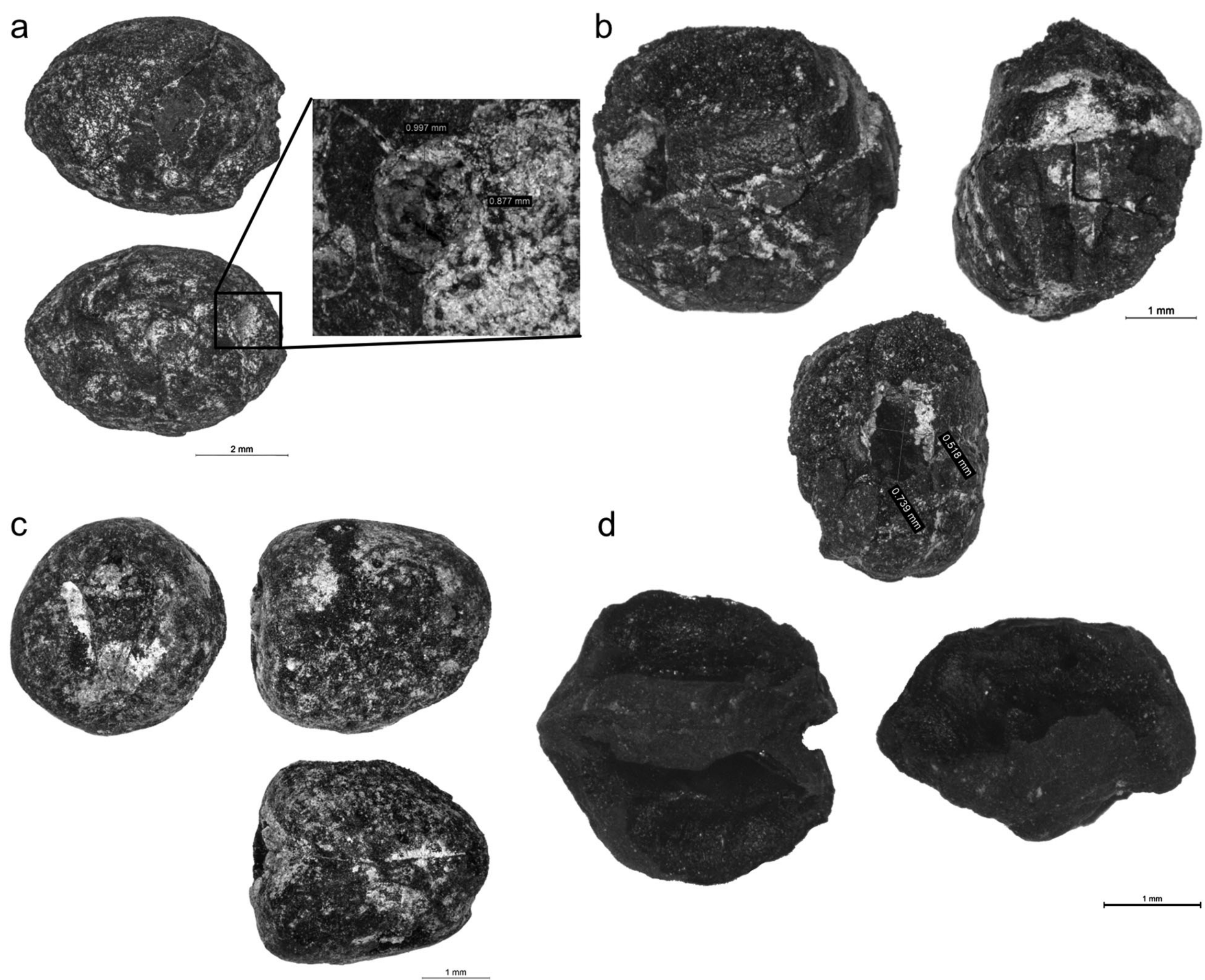

Figure 3. Remains of pulses found in Can Sadurní Cave: a and b. Fava beans with boreholes, c: bitter vetch, d: chickpea (Fotos: R. Soteras).

Zürich-Parkhaus Opéra

Zürich-Parkhaus Opéra is located in the northern shore of lake Zürich (Switzerland) (Fig. 1). It was excavated during 2010 and 2011, over an area of 3000 m^2. The main archaeological results of the site have already been published (Bleicher and Harb

2017; Bleicher, Harb, and Anselmetti 2015). In contrast to Can Sadurní, Parkhaus Opéra is a wetland site with waterlogged preservation. Up to 8 settlement phases were detected in this area. The results discussed in this paper focus on the two Horgen layers (Horgen Culture, 3450-2850 cal BC, see a full chronology table in Jacomet (2007)), particularly layer 13 (dendrodated to 3176–3153 BC, representing one settlement phase of no more than 25 years), but also layer 14 (dated to ca. 3090 BC). A total number of 27 constructed features and a fence were identified for layer 13 (Bleicher and Burger 2015) (Fig. 1). The sampling and sieving strategy was described in previous publications (Antolin et al. 2017; Antolín, Steiner, and Jacomet 2017; Antolín et al. 2015c; Steiner, Antolín, and Jacomet 2015; Steiner et al. 2017). In total, 296 samples (177 of which were sieved down to 0.35 mm) from layer 13, with a total volume of more than 1000 litres, were investigated by 2017. For layer 15, 53 samples (33 of which sieved down to 0.35 mm) were investigated, since the layer was preserved over a much smaller area.

Archaeobotanical analyses at the site allowed for the identification of around 225,000 plant macroremains (mostly seeds and fruits) from layer 13 and 40,000 for layer 14. Among the cereals, emmer (*Triticum dicoccon*), and naked wheat (*Triticum aestivum/durum/turgidum*, mostly belonging to the *durum/turgidum* type) are better represented in the uncharred record, while barley (*Hordeum vulgare*, multi-rowed and mainly of the naked type) is one of the most important cereals when considering the remains preserved by charring. Oil plants, including flax (*Linum usitatissimum*) and opium poppy (*Papaver somniferum*), were found in very large amounts. Additionally, dill (*Anethum graveolens*) has also been found. Dill is considered a potential crop coming from the Mediterranean regions (Jacomet 1988). During the identification process, the archaeobotany team was informed of the presence of the pea weevil (*Bruchus pisorum*) in the entomological record. We decided to look for reference material of pea pods and sub-fossilise them (namely, soak them in water for a long time). As a result, we realised that we had been missing their characteristic remains when the preservation quality was not optimal (Fig. 4). Pea pods have three functional cell layers: an exocarp, a mesocarp and an endocarp. Exocarp and mesocarp together make the most characteristic part of the pod, with the vascular network traversing them. Conversely, pea endocarps happen to be the most commonly found remains in archaeological sites with waterlogged deposits in Central and Southern Europe. They present two cell layers: an external one, showing parallel stripes (fibres); and an internal one, with packed small round cells that appear as a pitted surface (Craig et al. 1977 and references therein).

Remains of pea (*Pisum sativum*) were identified at Zürich-Parkhaus Opéra and it seems to have been an important crop considering the average concentration (ca. 40 remains/litre), the maximum concentration (ca. 500 r/L) and ubiquity (ca. 80%) of uncharred pea pod fragments in layer 14. In comparison, charred seeds were found in less than 10% of the samples (25) and normally only 1 per sample (in total, 27 seeds). In layer 13, pod fragments were identified in only 28 samples (due to the difficulties mentioned above), with a similar an average concentration of ca. 40 r/L and a maximum concentration of ca. 375 r/L, which suggests that this crop would have been equally well-represented in layer 13.

Large-seeded wild fruits (such as hazelnuts, acorns, and wild apple/pears) have also been observed to have played a very significant role in the economy of the settlement (Antolín et al. 2016, in press). A large number of other wild plant taxa has been documented (ESM 2): around 200 taxa. It is worth highlighting for the purposes of this paper the presence of *Mentha* sp., *Origanum vulgare*, *Solanum* sp., *Thymus serpyllum* and *Rubus* sp.

Insect remains were also studied from Parkhaus Opéra. From layer 13, 8263 insect fragments were analysed, with 1448 fragments from layer 14. They were sorted together with plant remains and, since the fractions were always subsampled, it was necessary to estimate the total amount of finds in each sample. It is estimated that 49980 insect elements were recovered from layer 13 and 7000 from layer 14 (Schäfer 2017). The assemblages of both layers are dominated by larvae of aquatic insects, which related to the local environment of the settlement. Invertebrate remains from terrestrial environments have also been found in significant amounts, particularly those of puparia of several types of flies. Decomposing organic material must have been lying around both inside and outside of the houses providing an optimal environment for flies to lay their eggs. Strongly sclerotised wing covers of different species of beetle were also found. Among these, the dominant ones are dung beetles, such as earth-boring dung beetle (*Hister funestus*), and scarab beetle (*Onthophagus taurus* and *Oxyomus silvestris*). In addition to these, woodland beetles have also been found. These live preferentially under the bark of trees or in tree fungi such as hair fungus beetle (*Litargus connexus*) or the cylindrical bark beetle (*Bitoma crenata*). Among all these insect remains only one pest was identified: the pea weevil (*Bruchus pisorum*). In total, 8 elytra were identified in layer 13 and none in layer 14 (Fig. 5). Despite intensive and active research for the identification of other pests affecting cereal crops, none was found among the weevils (Curculionidae) or the darkling beetles (Tenebrionidae).

The pea weevil is a thermophilic species that attacks mostly pea plants during their flowering period on the field. Females deposit the eggs on the young immature

Figure 4. Remains of pea pods (from top to bottom, from excellent -with exocarp- to bad preservation -only endocarp- conditions) found in Zürich Parkhaus-Opéra (Fotos: G. Haldimann).

pods. After hatching, the ca. 1.5 mm white larvae bore their way into the pod and nest themselves in a seed. The larvae feed on the seed and in warm conditions they emerge while the crop is still in the field, but under cooler conditions they may be harvested with the crop and overwinter within a puparium and eclose inside the storage structure. Pea beetles cause large crop failures, as each female is able to lay up to 400–500 eggs. The remaining pea seeds are not suitable for human consumption, and they are also barely viable, thus reducing the seed available for sowing in the coming year (Koch 1992; Reichmuth 1997; Weidner and Sellenschlo 2010).

The wing covers (elytra) of pea weevil found in Parkhaus Opéra are spread across the settlement in layer 13 and no concentration has been observed, so we can interpret that they were present in the stores of pea seeds in several houses of the settlement.

Figure 5. Elytron of pea weevil found at Zürich-Parkhaus Opéra layer 13 (Foto: R. Soteras).

Discussion

Were pulse pests recognised by prehistoric farmers?

There are records of seeds with boreholes (Table 3) and identifications of insect remains of the Bruchidae group (Table 4) from previous investigations of prehistoric sites in Europe and SW Asia.

The earliest legume seeds with boreholes are pea seeds from the sites of Beida (Jordan) and Hacilar (Turkey), dated to the 7th and 6th millennia cal BC. The seeds of fava bean found in Can Sadurní Cave are actually the oldest record for this species that we could find in the literature, being the chronologically closest ones already in Chalcolithic contexts (Table 3). These finds increase in the Bronze age, being reported in sites such as Kastanas (Greece) or Zug (Switzerland), which indicates that pests might have affected pulses more significantly during this period, both in central and southern Europe, probably continuing into the Iron Age, as shown by finds in Horbat Rosch Zayit (Israel) or Le Câtel de Rozel (United Kingdom). Unfortunately, it is not possible to judge how representative the available dataset is. The scarcity of records of seeds of pulses with boreholes might be due to the fact that specialists do not always mention it in publications. There are dozens of sites with more or less isolated finds of cultivated legumes (sometimes over 50 remains), and also sites with concentrations (>500 seeds): pea seeds in Les Valladas (L. Martin, unpublished), in France; fava beans in several sites of the Iberian Peninsula, such as Buraco da Pala (Rego and Rodriguez 1993), in Cueva del Toro (Buxó 2004) and Castillejos (Rovira 2007); and in northern Africa (Morales et al. 2016). No mention of the presence of boreholes was found in the publications. Some authors confirmed the absence of infested seeds at these sites (Martin, Buxó and Pérez-Jordà, pers. com.) but it is not possible to know if finds from other sites showed any boreholes or not, since their absence is not systematically recorded. Is it possible to suggest whether Neolithic farmers were aware of pests affecting pulses?

If pests were known, and infested seeds were deliberately avoided by farmers, seeds with boreholes would not necessarily appear in large concentrations of pulses, but as part of the discarded everyday waste, and thus, if present in archaeobotanical assemblages, the only evidence remaining would be in the form of some scattered finds as waste. In the case of Can Sadurní, the seeds were recovered in layers of burnt dung. This could indicate that they were detected by farmers, removed from the stored crop and given to animals as fodder.

Table 3. Compilation of records of legume seeds with boreholes from Prehistoric sites in Europe and SW Asia.

Site	Date	Land	Species	Citation
Beida	7th mil. BC	Jordan	*Pisum arvensis*	cited by Kislev and Melamed (2000)
Hacilar	5400-5050 BC	Turkey	*Pisum sativum* subsp. *elatius*	Helbaek (1970)
Can Sadurní	**4800-4300 BC**	**Spain**	***Vicia faba***	**unpublished**
Maydanits-koye	3500 BC	Ukraine	*Pisum sativum*	cited by Kislev (1991)
S. Pedro	Chalcolithic	Portugal	*Vicia faba*	cited by Kislev and Melamed (2000)
Belverde	Chalcolithic	Italy	*Vicia faba*	cited by Kislev and Melamed (2000)
Imamoglu	2300-2000 BC	Turkey	*Pisum sativum*	Oybak and Demirci (1997)
Grotta Misa	Bronze Age	Italy	*Vicia faba*	cited by Kislev (1991)
Kastanas	Bronze Age	Greece	*Vicia faba/Vicia erivilia*	cited by Kislev (1991)
Zitz	Late Bronze Age	Germany	*Vicia faba*	cited by Kislev (1991)
Zug	Late Bronze Age	Switzerland	*Vicia faba*	cited by Kislev (1991)
Salwood Tunnel	1120-910 BC	UK	*Vicia faba*	Stevens (2006)
Akrotiri	1500 BC	Greece	*Lathyrus clymenum*	cited by Kislev (1991)
Hissar	1350-1000 BC	South Serbia	*Vicia ervilia*	Medovic et al. (2011)
Aggtelek	Early Iron Age	Hungary	*Vicia faba/Pisum sativum*	cited by Kislev (1991)
Le Câtel de Rozel	Iron Age	UK	*Vicia faba*	Cambell in Cunliffe (1992)
Horbat Rosch Zayit	Iron age	Israel	*Vicia faba*	Kislev and Melamed (2000)

Table 4. Compilation of entomological finds of Bruchideae in archaeological sites of the circum-Mediterranean areas and Europe.

Site	Date	Land	Species	Citation
Runnymede	Neolithic	UK	*B. atomarius, B. loti*	cited by Huchet (2016)
Zürich-Parkhaus Opéra	**Late Neolithic**	**Switzerland**	***B.pisorum***	Schäfer (2017)
	Bronze age	Turkey	*B. signaticornis, B. pisorum*	cited by Huchet (2016)
La Motte	Late Bronze Age	France	*Bruchus* sp.	Bouby et al. (2016)
Akrotiri	1500BC	Greece	*Bruchus rufipes*	Panagiotakopulu and Buckland (1991)
Meare Village East	Iron Age	UK	*Bruchus rufipes*	Caseldine (1987)
Amarna	New Kingdom	Egypt	*Bruchus* sp.	Panagiotakopulu (2001)
Ashkelon	604 BCE	Israel	*Bruchus* sp.	Mahler-Slasky and Kislev (2010)

Regarding archaeoentomological remains, the number of finds of Bruchideae is quite low and, other than an indirect reference to the presence of other *Bruchus* species in Runnymede (UK), the oldest identification of pea weevil seems to be from Zürich-Parkhaus Opéra (Table 4). This might be due to the scarcity of archaeoentomological studies in the Mediterranean area, where sites with waterlogged deposits have rarely been investigated, hence it becomes even more important that infested seeds found in archaeobotanical analyses are systematically reported in order to have a comprehensive overview of the importance of these pests in prehistory. As observed regarding the presence of infested seeds, the finds of Bruchidae become slightly more common in the Bronze and Iron Ages, showing a similar trend to the one observed in the seed and fruit record.

In the case of Zürich-Parkhaus Opéra, we could not find any evidence of pea weevil in layer 14 (ca. 3090 BC), which was formed after a short settlement hiatus of ca. 50 years, while layer 13 (ca. 3160 BC) provided substantial evidence of the presence of this pest. It is unclear if the inhabitants of the site relocated anywhere far (they could have moved some hundred metres away along the lakeshore), or if they abandoned their fields during this time. It would anyway be hard to prove if they did this specifically to get rid of this pest. It is possible that they had adopted measures against it during the first occupation (layer 13) or that the weather was no longer favourable for the warmth-loving pea weevil once they settled again.

Traditional methods for fighting against pests

If we consider the possibility that pests were recognised by early farmers, it should be expected that some decisions were taken in order to eliminate them from the fields or grain stores. This sort of discussion has rarely entered the archaeological discourse and archaeological evidence for such practices is not straightforward. There are several sources for the investigation of traditional methods to fight against crop pests: textual sources from the classical and medieval authors, and current ethnological and ethnobotanical records. Both have advantages and disadvantages. Most classical authors refer to extensive farming methods applied in the Mediterranean area from Roman times until the Middle Ages, so they are only partly relevant to our case studies. On the other hand, ethnographic data may also come from completely different environments, crops and scales of farming.

There are a variety of methods that have been reported as useful for the protection of standing or stored crops from pests (Table 5). The Ebers Papyrus XCVIII (an Egyptian medical document dated to ca. 3552 BP) contains instructions for deterring insects using burnt gazelle dung diluted in water (King et al. 2014). Zadoks (2013) compiled data from classical and medieval agronomists, including several Iberian ones such as Columella (4–70 AD), Gabriel Alonso de Herrera (1474–1540) and Miquel Agustí (1560–1630). He provides a long list of plants that are useful to fight different types of pests: dill (*Anethum graveolens*), henbane (*Hyoscyamus niger*), bay leaves (*Laurus nobilis*), oregano (*Origanum vulgare*), mastic oil (*Pistacia lentiscus*), acorns (*Quercus* sp.), *Rubus* sp. (often the shrub is used as fencing), *Solanum nigrum* (recommended as a strong vinegar against insects (aphids) on fruits and vegetables), thyme (*Thymus serpyllum*) (toxic to storage insects when its essential oil is fumigated), fenugreek (*Trigonella foenum-graecum*) (grown mixed with other pulses because its strong scent prevents the rest from being eaten), bitter vetch (*Vicia ervilia*) (the seeds contain tannins, useful repellent in storage; sown among vegetables to protect against fleas, lice and birds). The author also mentions ashes.

The use of ashes as pesticides is also commonly recorded in the ethnographic record (kitchen ash, wood ash, dung ash). They can be used both with the stored crop or on the standing crop (Chandola, Rathore, and Kumar 2011) and basically prevent insect from biting the vegetative tissues. Additionally, leaves of certain trees (e.g. walnut tree, or *Vitex*), water-diluted cow dung or urine, and salt (Chandola, Rathore, and Kumar 2011; Mehta et al. 2012; Narayanasamy 2006) are also mentioned. Another important processing step to avoid pests and diseases is drying the crop under the sun (Chandola, Rathore, and Kumar 2011). Usually it is women who are in charge of keeping the crop pest-free (Mehta et al. 2012).

Used specifically against pulse beetles, turmeric powder or powdered *Vitex* leaves has been recorded with the purpose of protecting stored seeds (Narayanasamy 2006), as have essential oils of *Artemisia* (Titouhi

Table 5. Methods reported in classical and medieval texts for protecting crops (from Zadoks 2013) and recorded in current indigenous populations.

		Textual evidence – Agronomists	Indigenous knowledge	Citation
On the standing crop	Dusting with ash (kitchen ash, wood ash, dung ash)	+	+	Chandola, Rathore, and Kumar (2011)
	Spattering with water-diluted cow dung or urine	+	+	Chandola, Rathore, and Kumar (2011); Tesfaye and Gautam (2003)
	Fumigating	+		
	Trap crops (bitter vetch, chickpea)	+	+	Tesfaye and Gautam (2003)
	Protective/repellent plants around the plots (chickpea, bramble, oregano) or spreading chimney soot/olive oil	+		
During/after threshing	Sun-drying of the harvested crop	+	+	Chandola, Rathore, and Kumar (2011); Tesfaye and Gautam (2003)
	Cooling overnight before storage	+		
	Pouring salt-water and drying	+		
Before storage	Dusting	+		
	Mixing with ashes		+	Chandola, Rathore, and Kumar (2011); Abate, Huis, and Ampofo (2000); Tesfaye and Gautam (2003)
	Leaves of walnut, Vitex		+	Chandola, Rathore, and Kumar (2011)
	Turcmeric powder, Vitex leaves powder		+	Chandola, Rathore, and Kumar (2011); Narayanasamy (2006)
	Rubbing with oil (mustard)		+	Chandola, Rathore, and Kumar (2011); Abate, Huis, and Ampofo (2000); Tesfaye and Gautam (2003)
	Sinking the seeds in water to remove attacked seeds	+		
	Spattering with water-diluted cow dung or urine		+	Abate, Huis, and Ampofo (2000); Tesfaye and Gautam (2003); Mehta et al. (2012)

et al. 2017). There are mentions of the use of a small amount of mustard oil (sometimes mixed with other products such as dried leaves of walnut), rubbed over the seed coat (with different species of *Vigna* but also lentils, chickpea and pea seeds) with the hands (Chandola, Rathore, and Kumar 2011; Mehta et al. 2012; Tesfaye and Gautam 2003). A long list of plants is recorded as being useful against seed beetles (Boeke et al. 2001; Dietsch-Sellami and Pradat 2016).

Did Neolithic farmers implement pest management strategies?

In order to know if any measures could have been applied by Neolithic farmers to fight against pests, we compared our datasets for Can Sadurní and Parkhaus Opéra with the lists of plants recorded in the literature as being used as repellents or trap crops (Table 6), or used for their volatile oils (ESM 3) or non-volatile oils (ESM 4). Despite the different preservation types in both sites, several useful plants have been recorded, such as mastic tree, mint, oregano and thyme. There are two remarkable taxa: dill and chickpea. Dill is found in several lakeshore sites north of the Alps, despite being a Mediterranean plant (Jacomet 1988), but never in high amounts, which renders its status as a crop as uncertain. In addition to its edible value, one reason for the arrival of *Anethum* in central Europe is as a repellent sown within or around plots to keep away certain insects. It could have thus arrived with other crops that entered central Europe during the late 5th and early 4th millennium BC, such as naked

Table 6. List of plants recorded as used as trap crops or repellents in or around plots.

Family	Taxon	Common name	Can Sadurní	Zürich Parkhaus-Opéra
Anacardiaceae	*Pistacia lentiscus*	mastic tree	+	
Apiaceae	*Anethum graveolens*	dill		+
Fabaceae	*Cicer arietinum*	chickpea	+	
Fagaceae	*Quercus* sp.	oak	+	+
Fabaceae	*Trigonella foenum-graecum*	fenugreek	+	
Jugandaceae	*Juglans spp.*	nut		
Lamiaceae	*Lavandula angustifolia*	lavender		
Lamiaceae	*Mentha* sp.	mint		+
Lamiaceae	*Ocimum basilicum*	basil		
Lamiaceae	*Origanum vulgare*	oregano		+
Lamiaceae	*Rosmarinus officinalis*	rosemary	?	
Lamiaceae	*Thymus serpyllum*	thyme		+
Lamiaceae	*Thymus vulgaris*	thyme	?	
Lauraceae	*Laurus nobilis*	laurel		
Polygonacease	*Polygonum hydropiper*	water-pepper	+	+
Rosaceae	*Rubus* sp.	bramble	+	+
Solanacease	*Hyoscyamus niger*	henbane	+	
Tiliaceae	*Tilia cordata*	lime		+

wheat and opium poppy. Although speculative, chickpea might have arrived to the Iberian Peninsula in the same way. This is a rare crop in the Neolithic period, only well documented in Turkey and in Bulgaria, and authors do not interpret it necessarily as a crop in the latter case (Marinova and Popova 2008). Chickpea needs warm temperatures for germinating and it is considered to be a summer crop (Halstead 2014). It is reported ethnographically for being used as a trap crop planted around cereal fields (Tesfaye and Gautam 2003) and in classical texts as a plant that would attract pests (snails and slugs, for instance) thus minimising the effect of pests on other plants around them (Zadoks 2013, 142). It is usually grown as a mixed crop nowadays in places like India, either with oil-seeds (rape-seed, mustard, linseed) or with lentil and barley (Saxena 1987) and it has been recorded as a typical plant sown in cultivated fallows (Halstead 2014). If we rule out the unlikely possibility that chickpea arrived to the site through long-distance trade, it seems plausible that it was a tolerated 'weed' in the fields that was perceived to be favourable for the main crop and possibly also consumed by humans, even though it is only rarely found in the archaeological record. Animals could have also consumed repellent or trap crops that were present in the fields after the harvest, and the seeds potentially incorporated in the archaeobotanical record in layers of charred dung. In fact, the only other unsure identification of chickpea in Neolithic contexts from the Iberian peninsula is from Mirador Cave, in Atapuerca, in similar chronologies and context (Rodríguez, Allué, and Buxó 2016), which would suggest a similar taphonomic origin for the finds from both sites. Unfortunately, under the current state of research we cannot offer a conclusive interpretation for these finds, and only raise awareness of the importance of certain plants for pest management in traditional societies and highlight that these plants may be archaeobotanically detected.

Conclusions

The discovery of the earliest finds of pea weevil (in Switzerland) and of infested fava beans (in Catalonia, Spain) led us to review the current record for pulse crop pests in Prehistoric Europe and to query the significance of these pests, whether they were perceived as such by Neolithic farmers and if measures may have been taken to eradicate them.

Although losses might have only been significant at a local scale, ethnography seems to indicate that farmers would have strived for pest-free crops. It had already been observed by other authors (Panagiotakopulu and Buckland 2018) that pests associated with cereals disappeared from Europe short after the arrival of farming. This might be due to the changing climatic conditions in central Europe, or due to the isolation of villages (insects such as *Sitophilus granarius* cannot fly), or indeed as a result of the existence of pest management strategies and adequate storage practices.

Nevertheless, the data presented here shows that pulse crop pests appear in the 5th and 4th millennia BC. The presence of infested seeds in a layer of burnt dung in Can Sadurní is discussed as potential evidence that these seeds had been discarded and given to animals as fodder, which would suggest awareness of pests by Neolithic farmers. In Parkhaus Opéra, two settlement phases dated to the 32nd and 31st centuries BC, with a hiatus of several decades between them, were investigated. The pea weevil was found in the oldest phase but not in the youngest one, which could suggest the existence of a successful strategy to remove this pest or that the abandonment of the site facilitated its eradication. We found several plants present in both of our case studies that could have potentially been used either as trap crops or as insect repellents. Based on ethnographic and textual resources, we discussed the possible uses of dill and chickpea (besides for edible purposes) as pest repellents or trap crops.

We highlight the need for more systematic archaeoentomological analyses (particularly in continental Europe) and a standardised recording of infested seeds in archaeobotanical reports. Likewise, the management of pests seems to be a poorly explored subject in prehistoric farming and further research might contribute to interesting insights into traditional methods of protecting standing or stored crops against them.

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