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Archaeoentomological indicators of long-term food plant storage at the Prehispanic granary of La Fortaleza (Gran Canaria, Spain)

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ABSTRACT

Storage is crucial to the sequence of food management. It is nonetheless at times difficult to recognize in the archaeological record due to problems of preservation of ancient food remains. Archaeoentomology in this sense can be of great value as it sheds light on past storage techniques. This study presents the findings of the archaeoentomological analyses carried out at the ancient granary of La Fortaleza (Gran Canaria, Spain, ca. 600-1450 AD), a site where the favorable conditions of preservation allow recording the food plants and insect pests associated with storage. Moreover, the recovery of several taxa of primary and secondary pests connected to different stages of store infestation (i.e. *Sitophilus granarius* (L.), *Oryzaephilus surinamensis* (L.), *Tenebrioides mauritanicus* (L.), *Mezium americanum* (Laporte de Castelnau), *Stegobium paniceum* (L.) and *Cryptolestes* sp.) offers data as to the storage conditions and time intervals of the Prehispanic Canarian indigenous population. Finally, new radiocarbon-datings of the pests yield data casting light on the origin and spread of several cosmopolitan taxa such as *M. americanum* and on past relations between Africa, Europe and the New World.

1. Introduction

There are numerous cultural contexts marked by specific nutritional and ecological conditions in which the study of insects merges with that of archaeology. Within the bioarchaeological disciplines, the study of insect remains from Quaternary deposits is a science that emerged in Britain in the second half of the 20th century (Coope, 1977, 1986; 1990; Osborne, 1969; Buckland, 1976). Designated as "Quaternary entomology", this discipline includes two distinct entities respectively referred as "Palaeoentomology" and "Archaeoentomology". Although based on the same principles and methods, the first focuses on examining insect assemblages for palaeoclimatic and palaeoenvironmental reconstructions, while the second, exclusively related to archaeological contexts, serves to reconstruct the way of life and health of past populations, the evolution of dietary patterns, agro-pastoral practices, and the impact of human activities on the past environments.

The advent of the Neolithic period, with the emergence of sedentarization, animal husbandry, agriculture and population growth, had an impact on local natural ecosystems that inevitably had a significant influence on biodiversity and, consequently, on invertebrate fauna. The study of the insect and parasites recovered from archaeological contexts reveals that many managed to adapt perfectly to these new, anthropogenic niches and, consequently, had a considerable impact on the subsistence economy, as they provoked major losses of food reserves.

Archaeoentomology yields data leading to the reconstruction of human-made environments or indoor spaces and the activities that took place in these areas, as the presence of certain pests in archaeological contexts can be linked to specific plants and animal species (Buckland, 1979; Forbes and Milek, 2014; Giordani et al., 2020). The discipline also serves to identify features such as pens and latrines (Panagiotakopulu and Van Der Veen, 1997; Panagiotakopulu et al., 2010). Furthermore, insects can be a factor in the degradation of organic matter and hence

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their study can serve as a taphonomic marker of the conditions of preservation of certain sites (Adams, 1984). Another interesting application relates to past storage since many species of insects are closely linked to types of food and their different stages of processing (Buckland, 1990; Panagiotakopulu, 2001; Huchet, 2017).

Despite the great potential of entomological analyses to identify storage spaces, there is still little archaeoentomological research focusing on granaries and other specific structures due to problems of preservation and identification of these foods and features. This study offers evidence of archaeobotanical and archaeoentomological remains from the granary of La Fortaleza (Gran Canaria), a collective place of storage serving between the 6th-15th centuries AD. The organic materials recovered at this site include both plant remains and insect pests in an exceptional state of preservation. Their study identifies which pests are associated with the different types of stored food, determines the conditions in which the granary was maintained, estimates the time of silage, and finally offers unpublished data as to the function of Gran Canaria's collective granaries and subsistence strategies.

2. Storage and collective granaries in Gran Canaria

The Canary Islands is an archipelago in the eastern Atlantic comprising eight volcanic islands that are at least 100 km from the North African coast (Fig. 1). They were initially settled since at least the outset of the 1st millennium AD by Berber populations from the Northwest of Africa (Springer, 2001; Maca Meyer et al., 2004; Hagenblad et al., 2017; Rodríguez-Varela et al., 2017; Fregel et al., 2019, Velasco-Vázquez et al., 2020). Although they initially settled all the islands, the different populations remained isolated from each other leading each island to individual historical developments until the arrival of European explorers in the 14th century AD. To cover their nutritional needs, the first settlers brought from the continent cereals, pulses and a single fruit (fig), as well as livestock (sheep/goats and pigs). The development of livestock and agriculture on the different islands progressed unevenly, with that of Gran Canaria predominating over that of the other islands as evidenced both by the archaeological record (Morales, 2010) and by diet analyses of human remains of Prehispanic populations (Velasco Vázquez, 1998; Delgado-Darias, 2009; Arnay de la Rosa et al., 2009, 2010) (see Fig. 2).

The many large indigenous settlements on the Island of Gran Canaria suggests a substantial population characterized by a complex society (Onrubia Pintado, 2003). Both archaeological evidence and information gleaned from old texts penned by early European explorers signal that agriculture played a fundamental role in the diet of the indigenous population (Morales, 2010). Among the most compelling archaeological features linked to agriculture are the collective fortified granaries distributed throughout the island. These sites share links with the *igudar* troglodytic features and the *magasins de falaise* of the Maghreb (Marcy, 1940; Onrubia Pintado, 1986, 2003; Rodríguez et al., 2011–2012). These structures in Gran Canaria were dug into volcanic rock cliffs of difficult access near fertile agricultural soils (Morales et al., 2018). Their inner spaces consist of silos directly cut into the rock organized in rows or along the walls of circular chambers. Although the silos no longer retain their original covers, they were once sealed by large stones or wood doors (Morales et al., 2014; Naranjo-Mayor and Rodríguez-Rodríguez, 2015). Two factors explain the conditions of desiccation inside the silos that led to the preservation of foodstuffs for centuries. The first is the constant temperature and humidity throughout the year averting the spread of pests (Culver and Pipan, 2009; Bescherer and Beaudry, 2015). The second is their inaccessibility, despite that they remained open, which reduced postdepositional disruption by humans, large mammals and other external factors.

Radiocarbon datings of the plants and insects from several granaries indicate that they served mainly between the 10th and 15th centuries AD (Morales et al., 2018). This time frame coincides with a period of great demographic growth among the indigenous population as evidenced by the expansion of settlements and cemeteries (Morales et al.,

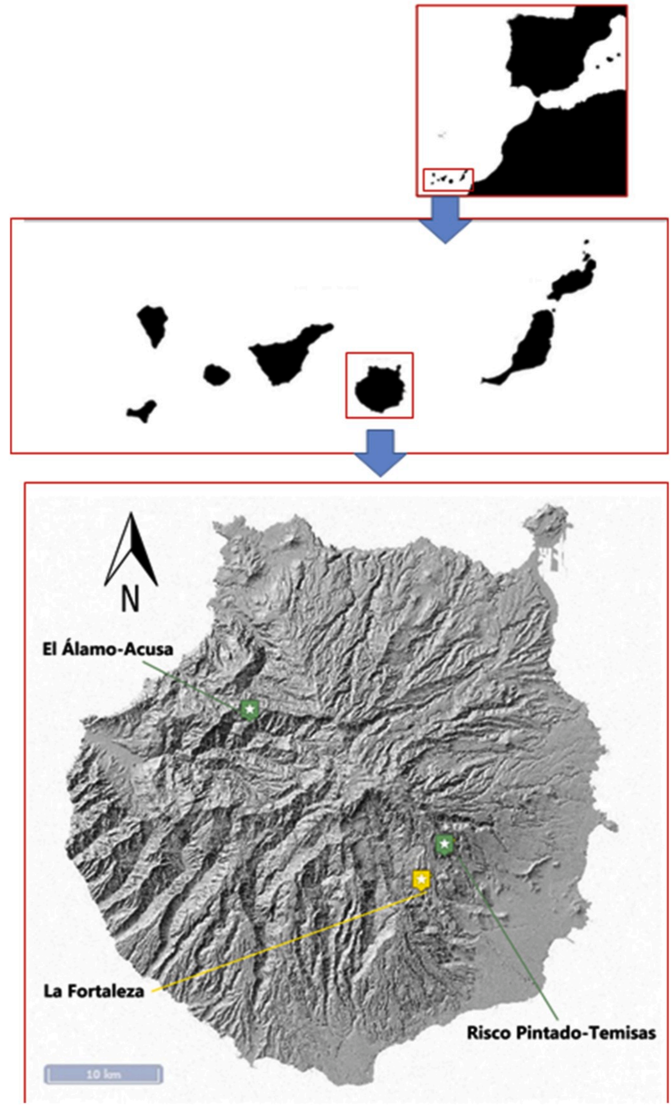

Fig. 1. Top: map of the Canary Islands. Center: Position of Gran Canaria in the archipelago. Bottom: Digital shadow model of Gran Canaria with the sites mentioned in the text (source: IDECanarias.es).

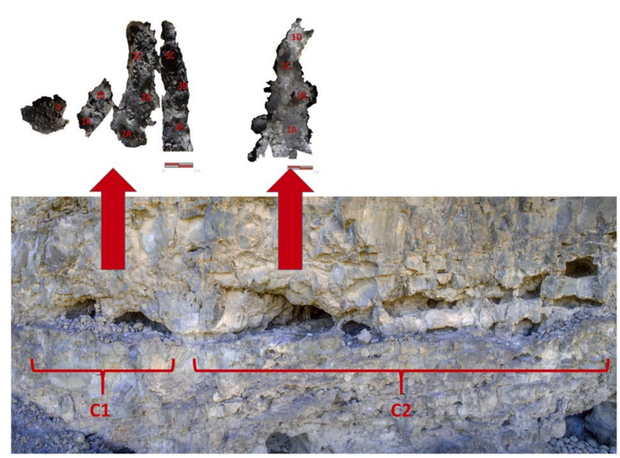

Fig. 2. La Fortaleza (Cave 31). Top: Floor of the silos of Unit 1 and of Silo 1 of Unit 2. Unit 1 is marked as C1 and Unit 2 as C2. Bottom: view of the mouths of the caves along the cliff.

2014; Alberto Barroso et al., 2019).

The study of the storage features evidences that the products intended for storage most likely comprised both cultivated and wild plants (Morales et al., 2014, 2018; Henríquez-Valido et al., 2019). The domestic species were barley *(Hordeum vulgare* subsp. *vulgare*), durum wheat (*Triticum durum*), lentil (*Lens culinaris*), broad bean (*Vicia faba*) and fig (*Ficus carica*). Barley and figs are among the main crops of the early Canarian diet (Morales, 2010). Seeds of wild species such as Canarian palm (*Phoenix canariensis*) and Canary Island pine (*Pinus canariensis*) suggest that they could have also been stored. Finally, certain silos contained laurel leaves (*Laurus novocanariensis*), a plant known for its insecticide properties (Morales et al., 2018) and active principles that inhibit the spread of insects and fungi (Rodilla et al., 2008).

The data available to date suggest that the storage techniques were complex and designed to preserve the crops for long periods of time (Morales et al., 2018). Besides introducing plants serving as insecticides, the indigenous Canarians developed other strategies such as storage of grains attached to their ear or in their pod. This technique offers protection from temperature fluctuations and pests, but also requires larger silos.

The volume of the harvest increases when the grains are stored with their glumes and other floral covers forming part of their spike. Although storage in these spaces supposes a greater seed aeration, improving their conservation, it also implies a greater investment in labor to fashion the storage unit (Sigaut, 1988). Several of the silos reveal traces of mortar or plaster covers, as well as channels cut through the rock to increase air circulation. Despite the efforts to condition and maintain the silos, the samples reveal the presence of pests through damaged grains and insects themselves, in particular granary weevils (*Sitophilus granarius* L.) (Morales et al., 2014, 2018; Henríquez-Valido et al., 2019).

Unprocessed plants were likewise stored in these granaries. Finds of hand driven querns at the granary of Cenobio de Valeron, a site dated by radiocarbon between 1040 and 1440 cal AD, suggests food processing took place at the granary itself (Naranjo-Mayor and Rodríguez-Rodríguez, 2015). Moreover, the absence of unprocessed plants in settlements also bolsters the notion that the querns in these granaries served to process the cereal after storage, before its transport to where it was consumed (Morales et al., 2018).

3. La Fortaleza granary

La Fortaleza (510 m a.s.l.) is in the Municipality of Santa Lucía de Tirajana in the southeast of Gran Canaria. It is in the bed of the Caldera de Tirajana, a large erosive depression that includes three knife-shaped elevations named respectively La Fortaleza Grande, La Fortaleza Chica and Titana (Moreno, 2017). These natural towers rise above a basaltic base and are covered by ignimbritic flows of rhyolitic to trachyphonolitic and peralkaline (Balcells et al., 1990).

The vegetation surrounding the site is typical of the thermocanarian bioclimatic level of the semiarid ombroclimate with forests of Canary Island pine (*Pinus canariensis*) in the higher altitudes and Canary Island palm (*Phoenix canariensis*) in the mid-low areas accompanied by other thermophilic shrubs. It is noteworthy that some of these shrubs such as *balo* (*Plocama pendula*) are also recorded among the anthracological finds of the granary (Vidal-Matutano et al., 2020).

The indigenous populations dug out and raised dwellings, places of worship, cemeteries, as well as granaries, in these volcanic towers between the 5th and 15th centuries AD. The dating of an ovicaprine bone from a structure at the top of La Fortaleza Grande offers a range between the 5th-7th centuries AD (Moreno et al., 2017), although historical records suggest that the settlement was occupied until the end of the 15th century (Moreno et al., 2017).

The granary is actually located at a great height with access requiring climbing equipment. Although the site is made up of a series of caves cut into the eastern slope of La Fortaleza Grande, its main features correspond to two groups of caves (Cave 31) interconnected by a horizontal passage 6.1 m long.

4. Material and methods

Samples were collected from all of the silos of Cave 31 of the granary of La Fortaleza. These hollows contain fillings only a few centimeters thick and thus do not offer conventional archaeological stratigraphic sequences. The fills in the silos consist of a combination of aeolian deposits, elements detached from their walls and an organic matrix of plant and insect remains (Fig. 3). These factors, together with the difficulty of access, led to the decision to only collect several random samples from each silo. In the case of the smaller silos, samples were limited to a single 1-L probe collected from the middle. The probes from the larger silos of Unit 1, and Silo 1 of Unit 2, by contrast, were collected from several equidistant points (a, b, c and d). A total of 18 L of sediment was collected. Despite this relatively modest volume, the samples are rich in organic materials and yield enough data to undertake the comparative study.

The samples were then dry-screened with meshes of 10, 5, 2, 1 and 0.5 mm. The finds surpassing 2 mm, analyzed in their entirety, were separated according to their nature (wood, seeds and insects). Those recovered in the 1 and 0.5 mm meshes, due their abundance, were subsampled through a riffle box. Their study focused respectively on 1/4 and 1/8 of their volume. Several samples verified with meshes inferior to 0.5 mm (250 and 125 μm) revealed no insect or botanical remains.

The intention of sub-sampling was to reduce the work time (each probe can contain more than 1000 plant and insect remains) and to estimate the number of invertebrates in each silo. This was carried out by multiplying the number of specimens identified in each probe by four in the case of the 1 mm sieve and by eight in the case of the 0.5 mm sieve. This method, applied in earlier studies of Gran Canaria granaries (Morales et al., 2014; Henríquez-Valido et al., 2019) and other sites elsewhere containing desiccated organic remains (Alonso Martínez et al., 2000; Panagiotakopulu et al., 2010, 2013), has proven the most suitable. The number of pronota, the exoskeleton's most durable part, served to calculate the minimum number of insects (MNI) of each taxon. If other parts of the insects were more numerous, then that number was applied for the calculation.

Separating the plant and entomological remains was carried out with a Nikon SMZ-2T (8-80 X) stereo microscope. Identification of insect remains was undertaken by consulting specialized publications (Haines, 1991; Delobel and Tran, 1993) and by directly comparing the specimens from the modern reference collection in the Archaeology Laboratory of the Department of Historical Sciences of the University of Las Palmas de Gran Canaria and the PACEA Laboratory of the University of Bordeaux.

Digital images of the insect remains were carried out at the PACEA

Fig. 3. View of Silo 3a (Unit 1) serving as an example of how the storage features are preserved at the granary of La Fortaleza.

Laboratory with a Canon E0S 6D digital camera (zoom MP-E 65 mm) mounted on a Kaiser RTx column. The zstepper was controlled through the focus stacking software Helicon Remote 3.8.6w and images were processed using Helicon focus 6. The digital images were ultimately imported into Adobe Photoshop CS4 for post-processing, labelling and plate composition.

4.1. Radiocarbon datings

Ten AMS datings were obtained on the materials from the silos (Table 1). Four were carried out on insects [*S. granarius, Oryzaephilus surinamensis* (L.), *Stegobium paniceum* (L.), and *Mezium americanum* (Laporte de Castelnau)] providing radiocarbon dates that range between 776 and 981 cal AD and 1184–1275 cal AD. The other six datings were carried out on plant remains from the silos containing insects so as to confirm their antiquity. They range from 545 to 645 cal AD and 1274–1393 cal AD.

These datings as a whole indicate that the granary of La Fortaleza served for at least 800 years, between the 6th and 14th centuries AD. However, most of the radiocarbon dates point to the 1169–1393 cal AD range, suggesting this time period witnessed the most intensive use of the silos.

5. Results and discussion

5.1. Archaeobotanical remains

The dating of the content of the silos suggest the storage of plants by the Prehispanic populations analogous to that observed at other granaries in Gran Canaria (Table 2). Although the analyses of the current study are still in progress, its preliminary findings indicate the predominance of barley (*H. vulgare*) and fig (*F. carica*) (ca. 90%) and lesser proportions of durum wheat (*T. durum*) and pulses, i.e., lentils (*L. culinaris*) and broad beans (*V. faba*).

There is likewise evidence that certain wild species were collected and stored, notably Canary Island palm dates (*Phoenix canariensis*), pine nuts (*Pinus canariensis*) and bay leaves (*L. novocanariensis*). *Mocán* (*V. mocanera*), a small fruit tree endemic to the Canary Islands and Madeira, is also present.

Wood remains are also recorded at La Fortaleza (Table 3). Among them are a few anthracological (wood charcoal) remains probably associated with the disintegration of the mortar covering the walls since mortar usually contained ashes and charcoals. Most, in turn, are xylological (desiccated) fragments corresponding to different uses (e.g. tools, containers, elements serving for the spatial organization inside the silos, silo covers, etc) (Vidal-Matutano et al., 2020). Other fragments, especially those of Canary Island pine (*Pinus canariensis*), could have served as constructive features. To a lesser extent, and spread out heterogeneously in the silos, are the remains of fig tree (*F. carica*), dragon tree (*Dracaena* sp.), palm tree (*Phoenix canariensis*), *balo* (*P. pendula*), Asteraceae and woody legumes (Fabaceae). There is also evidence of different monocotyledons probably evidencing plant fibers serving to make ropes, mats or containers. A few fragments of Lauraceae in certain silos can also be linked either to the introduction of green laurel branches with their leaves as insecticide (Morales et al., 2018; Vidal-Matutano et al., 2020) or for woodworking.

5.2. Archaeoentomological remains

The statistical estimation of the insects of the granary of La Fortaleza indicates 9143 subfossil insect remains belonging to 2 classes, 4 orders, 14 families and 22 genera (Table 4; Fig. 4 and Supplementary data S1). Coleoptera at 98.83% is the most represented order. The other classes are Isopoda (0.62%), Hymenoptera (0.50%) and Heteroptera (0.05%). Arachnida are represented by the remains of spiders and mites.

Archaeoentomological analyses of the granary of La Fortaleza identified at least six species of pests that inflict damage to stored plants. The most common is the granary weevil (*S. granarius*) represented by 4291 remains (47% of the entomological assemblage). This worldwide species is one of the main dangers to stores of barley and wheat (Delobel and Tran, 1993) and thrives in temperate climatic zones in environments of approximately 30 °C and 70% relative humidity (Haines, 1991).

This species is highly synanthropic as it depends on humans for mobility. This is due, unlike the two other *Sitophilus* species (*Sitophilus oryzae* (L.) and *Sitophilus zeamais* Mots.), to the loss of its ability to fly (Huchet, 2017). It is the main pest at La Fortaleza as it bored holes into the whole grains to lay its eggs (Buckland, 1990; Trematerra et al., 2000; Panagiotakopulu and Buckland, 2018). Its origin is probably in the Middle East (Zohary, 1969) from where it spread throughout Europe during the Neolithic (Plarre, 2010). Archeologically it has been detected in different Neolithic contexts of Greece and Turkey (Panagiotakopulu and Buckland, 2018), as well as in the Bronze Age stores of Akrotiri (Santorini, Greece) (Panagiotakopulu and Buckland, 1991). In Egypt it was found among the remains of barley deposited as offerings in the tomb of the pyramid of Saqqara (Solomon, 1965; Panagiotakopulu, 2001). This pest in France is also known in Romanized contexts at Amiens in a granary that burned down at the end of the 2nd century BC (Matterne et al., 1998) as well as at the Gallo-Roman *villa* of Touffréville (Calvados, France) where it led to the identification of storage spaces (Ponel et al., 2000). This pest in Great Britain is among the charred cereal deposit at Malton, Yorkshire (Buckland, 1981) and in the cereal deposits of Tanner Row, York (Kenward and Carrott, 2006). In America it is identified in colonial Boston at the 17th century site of Cross Street Back Lot (USA) associated with products stored in a household (Bain, 1998). It is nonetheless very likely that this pest attained the Americas earlier, with the first European settlers. In Gran Canaria, the granary weevil is identified at the granary of El Álamo-Acusa between 1020 and 1150 cal AD (Morales et al., 2014) and at Risco Pintado-Temisas between 1020 and 1155 cal AD (Henríquez-Valido et al., 2019).

La Fortaleza offers nonetheless the oldest range of dates (776–981 cal AD) of *S. granarius* in Gran Canaria. This timeframe, together with that obtained of the Gran Canaria granaries of El Álamo-Acusa (Morales et al., 2014) and Risco Pintado-Temisas (Henríquez-Valido et al., 2019), confirms its contemporaneity with the indigenous Prehispanic

Table 1
Radiocarbon dates of the insect and seed remains from the granary of La Fortaleza.

Material	Common designation	Type material	Lab. Code	Sample ref.	Location	14C age BP	cal. AD (95,4%)
Visnea mocanera	mocán	seed	Beta-477343	FOR17S5C2VIS	Silo 5-Unit 2	1470 ± 30	545–645
Sitophilus granarius	granary weevil	insect	Beta-477349	FOR17S2AC1SIT	Silo 2a-Unit 1	1140 ± 30	776–981
Lens culinaris	lentil	seed	Beta-477347	FOR17S2C2LENS	Silo 2- Unit 2	950 ± 30	1024–1155
Mezium americanum	black spider beetle	insect	Beta-477351	FOR17S1DC2MEZ	Silo 1d- Unit 2	810 ± 30	1169–1270
Stegobium paniceum	biscuit beetle	insect	Beta-554542	FOR17C2S1DSTE	Silo 1-Unit 2	800 ± 30	1184–1275
Oryzaephilus surinamensis	sawtoothed grain beetle	insect	Beta-477350	FOR17S1AC2ORY	Silo 1a- Unit 2	760 ± 30	1219–1284
Pistacia lentiscus	mastic tree	seed	Beta-477348	FOR17S1AC1PIS	Silo 1a- Unit 1	680 ± 30	1270–1390
Hordeum vulgare	barley	seed	Beta-477344	FOR17S2AC1HOR	Silo 2a-Unit 1	670 ± 30	1274–1391
Hordeum vulgare	barley	seed	Beta-477346	FOR17S2BC1HOR	Silo 2b- Unit 1	670 ± 30	1274–1391
Hordeum vulgare	barley	seed	Beta-477345	FOR17S2CC1HOR	Silo 2c -Unit 1	660 ± 30	1276–1393

Table 2
Presence of carpological remains at the granary of La Fortaleza. X: 0–500 remains; XX: 501–1000 remains; XXX: 1001–1500 remains; XXXX: more than 1501 remains.

		Unit 1									Unit 2								
		1a	1b	2a	2b	2c	3a	3b	3c	4	1a	1b	1c	1d	2	3	4	5	6
Cultivated plant	**Common name**																		
Hordeum vulgare, grain	Barley	x	x	x	x	x	x			x			x	x	x		x	x	x
Hordeum vulgare, articulated set of hulls	Barley	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hordeum vulgare, rachis	Barley	x	xxx	xx	xx	x	x	x	x	x	x	x	x	x	x	xx	xxx	x	x
Hordeum vulgare, basal rachis	Barley	x	x	x	x	x	x			x	x	x	x	x	x	x	x		
Triticum durum, grain	Wheat				x		x				x			x				x	
Triticum durum, rachis	Wheat	x	x	x	x	x	x	x	x	x	x				x	x	x	x	
Triticum durum, basal rachis	Wheat		x	x	x	x		x		x					x				
Vicia faba, hilum	Broad bean	x	x		x	x	x	x	x	x	x			x	x	x		x	
Vicia faba, pod	Broad bean								x										
Vicia sativa, seed	Broad bean															x			
Lens culinaris, seed	Lentil	x						x		x			x		x	x	x	x	x
Lens culinaris, hilum	Lentil			x	x	xx	x	x		x	x	x	x		x		x	x	
Lens culinaris, pod	Lentil									x	x	x	xx		x		x	x	
Ficus carica, endocarp	Fig tree	xxx	x	xxx	xxx	x	xxxx	x	xx	xxxx	xx	x	x	x	xxx	xxxx	xxx	xx	xxxx
Ficus carica, peduncle	Fig tree	x	x	x	x		x	x		x	x		x		x		x		x
Ficus carica, fruit	Fig tree						x		x	x		x					x		
Harvested wild plants																			
Laurus novocanariensis, leaf fragment	Laurel	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x
Phoenix canariensis, perianth	Canarian palm tree						x												
Phoenix canariensis, rachis	Canarian palm tree	x					x								x				
Pinus canariensis, needle	Canary Island pine			x			x			x			x						
Pinus canariensis, seed	Canary Island pine			x			x			x								x	
Pinus canariensis, cortex	Canary Island pine			x															
Pinus canariensis, peduncle	Canary Island pine					x													
Pistacia lentiscus, seed	Mastic tree	x								x	x				x			x	
Visnea mocanera, seed	*Mocán*																	x	

population. As noted above, the granary weevil is synanthropic and requires humans to disperse. It is therefore reasonable to speculate that it was introduced in Gran Canaria together with the grains transported to the island by the first settlers from the northwest of Africa.

It must be noted, however, that the datings obtained from barley from the same silo containing the granary weevil suggest a later date (1270–1393 cal AD). This insect certainly appears in the granary with the stored seeds. There is also no doubt as to the consistency of the AMS dating of the remains of the insect preserved by desiccation in another archaeological context (Panagiotakopulu et al., 2015). Hence the dates linked to this pest preceding those of the grains can be explained by the lack of systematic cleaning of the silos allowing certain pests to remain.

The granary weevil, as previously stated, likewise spread to other granaries in Gran Canaria such as El Álamo-Acusa and Risco Pintado-Temisas (Morales et al., 2014; Henríquez-Valido et al., 2019). This dispersion throughout different parts of the island, coupled with a mobility depending on humans, suggests an exchange of contaminated seeds.

Another insect infesting the granaries of La Fortaleza is the saw-toothed grain beetle (*O. surinamensis*), a cosmopolitan pest that thrives in granaries in tropical climates. It is a secondary synanthropic pest since it is not identified among the grains collected before the harvest and is unable to attack whole grains. Hence it requires grains to be damaged by a primary pest or processed by humans. It rarely flies, and most often develops in spaces at 20-35 °C and 70% r.h. (Haines, 1991; Halstead, 1993). Its adults usually consume the larvae of other pests such as *S. granarius* (Lepesme, 1944; Huchet, 2017).

The sawtoothed grain beetle very likely has an origin in Africa (Panagiotakopulu and Buckland, 2018), although the oldest evidence of this pest so far is from a Neolithic context in Macedonia where a head was recovered in sediments from the earliest layers of the site of Mandalo (Valamoti and Buckland, 1995). It is identified in the Bronze Age together with *S. granarius* in the stores of Akrotiri (Santorini, Greece) (Panagiotakopulu and Buckland, 1991). In Egypt, it was contained in one of the jars of Tutankhamun's tomb (Zacher, 1937). In Roman times, *O. surinamensis* appears in storage contexts in England (Coope and Osborne, 1968; Buckland, 1981; Kenward and Carrott, 2006), Germany (Buckland, 1981) and Italy (Dal Monte, 1956; Buckland, 1981).

Radiocarbon analyses at La Fortaleza place it in the Prehispanic period between 1219 and 1284 cal AD and at Risco Pintado-Temisas, also in Gran Canaria, between 886 and 1013 cal AD (Henríquez-Valido et al., 2019). It is therefore safe to assume that the indigenous population had to contend with this pest. Like *S. granarius*, it is synanthropic and was probably introduced with seeds from the continent. This suggests that it was already widespread in the Maghreb, the origin of the archipelago's first inhabitants.

Another pest of interest at La Fortaleza granary is the American spider beetle (*M. americanum*). Although there is little data regarding its biology, it is a cosmopolitan Ptinidae that consumes the residues of food and other insects. It is classified for this reason as a secondary pest (Haines, 1991). It consumes dried animal and plant remains such as skins, fruits and seeds, and develops in temperate zones (Hagstrum and Subramanyam, 2009).

There is no archaeological evidence of this pest in Europe prior to 1492. The find at the site of Chimù-Chancay (Peru) is the only case in the Americas in Pre-Inca funerary context (McCauley et al., 2014; Huchet, 2017). Certain authors, nonetheless, claim that the origin of *M. americanum* is in the African continent (Borowski, 2009), or possibly, although not corroborated, in the Canary Islands (Borowski, 2017). The problems in tracking its origin may in fact stem in part from its poor

Table 3
Quantification of the xylological and anthracological remains at La Fortaleza. X: 0–5 remains; XX: 6–10 remains; XXX: 11–15 remains; XXXX: more than 16 remains. D: desiccated; C: carbonized (wood charcoal).

		Unit 1											Unit 2												
		1a		1b		2a	2b	2c	3a	3b	3c	4	1a		1b		1c	1d	2		3	4		5	6
Taxa	Common name	D	C	D	C	D	D	D	D	C	D		D	C	D	C	C	C	D	C	D	D	C	D	D
Angiosperm			x											x											
Asteraceae			xx		x																				
Dracaena sp.	dragon tree																		x						x
cf *Dracaena* sp.	dragon tree																								x
Fabaceae	woody legume	x	xxx	x	x											x	x						xx		
cf Fabaceae	woody legume		x																						
Ficus carica	fig tree	x	x		x	x			x	x			x			x			xx	x			x		
Lauraceae	laurel				x																				x
Monocotyledoneae		x																							
Monocotyledoneae tp. Poales				x											x				x			x			
Phoenix canariensis	Canarian palm tree									x															
Pinus canariensis	Canary Island pine	xx	xxxxx	x	xx	x	x	xx	xx	x	x		x	x	xx	xx	x	x	xx	x	x	x	x	x	xx
Plocama pendula	*balo*	x			x	x				x			x		x				x						x
cf *Plocama pendula*	*balo*																		x						

conservation in archaeological contexts due to its weak sclerotized exosqueleton. *M. americanum* was, nonetheless, identified elsewhere in the Canary Islands at the granary of Risco Pintado-Temisas (Henríquez-Valido et al., 2019). Radiocarbon datings of it at La Fortaleza indicate a 1169–1270 cal AD range confirming a precocious presence (preceding the 15th century) in the Canary Islands. In any case, the question of this taxon's origin requires further research.

The biscuit beetle (*S. paniceum*) is a secondary pest that affects processed products. Its presence at La Fortaleza is the first to be dated in Gran Canaria, and confirms that it was likewise introduced by the early indigenous Canarians (1184–1275 cal AD). It is recorded beyond the archipelago since the Bronze Age in Greece (Panagiotakopulu and Buckland, 1991) and the Iron Age in the United Kingdom (Chowne et al., 1986). It was identified in ancient Egypt in the tomb of Tutankhamun (Alfieri, 1931) and in a variety of other storage features (Levinson and Levinson, 1985, 1994; Panagiotakopulu, 2001). It is also known in England in Roman times (Buckland, 1981). This beetle develops in environments between 15 and 34 °C and from 60 to 90% r.h. Under optimal conditions it can live up to 40 days (Haines, 1991).

Other less numerous pests at La Fortaleza are not directly dated and therefore cannot be assumed to have been contemporary to the Prehispanic Canarians. The most common is the cadelle beetle *Tenebroides mauritanicus* (L.). Among the members of the family Trogossitidae, this is the only taxon that affects stored products. It is cosmopolitan and not only inflicted damage on stored products but preyed on the other pests cited above (Haines, 1991). Although it probably comes from Africa (Denux and Zagatti, 2010; Huchet, 2017), certain authors claim an origin in the forests of southern Europe (Crowson, 1958). Remains of *T. mauritanicus* are found in Neolithic contexts in Germany (Schmidt, 1998, 2013; Panagiotakopulu and Buckland, 2018). In Egypt it was identified in a cave by the Red Sea storing plant products arriving at the Port of Mersa/Wadi Gawasis (Borojevic et al., 2010). It is also in England among the remains of a Bronze Age shipwreck (Buckland, 1981). It is recorded in Roman Israel among the storage facilities of Masada (Kislev and Simchoni, 2007). It presumably spread across the European continent in Roman times (Huchet, 2017). Although lacking direct AMS dating, the cases at La Fortaleza make up the earliest archaeological evidence of this species in the Canary Islands suggesting that it also arrived with the early settlers from northwestern Africa.

The insect family Tenebrionidae is represented at La Fortaleza by five cases of depressed flour beetle (*Palorus cf. subdepressus*), a minor pest that consumes both processed plant products (Haines, 1991) and those consumed previously by primary pests such as *S. granarius* which is also its prey. It is identified in Egypt in the storage rooms of Amarna together with *S. granarius* (Panagiotakopulu, 2001) and in Roman contexts in England (Buckland, 1981). Its presence at La Fortaleza is, once again, the earliest evidence of this species in a Canarian archaeological context. Although it does not benefit from any direct radiocarbon dating confirming its Prehispanic context, its association with stored food and other synanthropic insects suggests it was introduced, like other cases, by the first settlers from North Africa.

Cryptolestes sp. (Laemophloeidae), also present at La Fortaleza, is a secondary granary pest that consumes flour and materials attacked previously by primary pests such as *S. granarius*. Several species of this family are known to damage plant products (Hagstrum and Subramanyam, 2009). However, only *Cryptolestes minutus* (or *C. pusillus*) (Olivier), *Cryptolestes ater* (Olivier) and *Cryptolestes granulatus* (Wollaston) are recorded in Gran Canaria (Machado and Oromí, 2000). Members of this genus are cited in Roman contexts in England (*C. ferrugineus*: Buckland, 1981; Kenward and Carrott, 2006).

The diet of the insects identified at La Fortaleza indicates that the silos served to store plant products, for the most part cereals. However, a single *Dermestes frischii* Kugenlann, an insect known to consume bones, cheese and dried fish and other insects (Hagstrum and Subramanyam, 2009), was recorded in Silo 6 - Unit 2. This pest could also have arrived accidently at the granary as it consumed other non-stored foods

Table 4
Statistical estimation of insect remains from Units 1 and 2 of the granary of La Fortaleza.

	Common name	Unit 1									Unit 2									TOTAL
		1a	1b	2a	2b	2c	3a	3b	3c	4	1a	1b	1c	1d	2	3	4	5	6	
Pests																				
Coleoptera																				
Sitophilus granarius, entire	Granary weevil	4	4	28	4		69	24	24	8	16		20	32	40	55	18	12		358
Sitophilus granarius, head	Granary weevil		8	428	40	24	476	20	32			36	4		144	24	8	16	16	1.276
Sitophilus granarius, pronotum	Granary weevil		8	560	36	24	452	24	40		32	40	8	24	216	80	24	61	8	1.637
Sitophilus granarius, abdomen	Granary weevil	12		152	24		224		36	8	28	4	8	24	48	44	24	20		656
Sitophilus granarius, elytra	Granary weevil			104	24		160				16				40	16				360
Oryzaephilus surinamensis, entire	Sawtoothed grain beetle			72				8			25			8	12	40	8			173
Oryzaephilus surinamensis, head	Sawtoothed grain beetle						8	16	4		72	8				2	8		32	150
Oryzaephilus surinamensis, pronotum	Sawtoothed grain beetle	8			48	32	40	64	60		336	40			133	8	24		96	889
Oryzaephilus surinamensis, abdomen	Sawtoothed grain beetle						64	40	12		180	96	24		64	13	28		8	529
cf. *Casapus*, head																1				1
cf. *Casapus*, pronotum																2		4		6
cf. *Casapus*, elytra		4		2											10	8	2	2	2	30
Mezium americanum, entire	Black spider beetle	17	1		12	1			4	24	16	148	82	113	209	116	91	33	80	947
Mezium americanum, pronotum	Black spider beetle				32			40					8		40	16		12	16	164
Mezium americanum, abdomen	Black spider beetle				4															4
Stegobium paniceum, entire	Biscuit beetle	8					3		4		8		228	348	68			5		672
Stegobium paniceum, tórax	Biscuit beetle						1						64							65
Stegobium paniceum, abdomen	Biscuit beetle						8						40		8			12		68
Tenebroides mauritanicus, entire	Cadelle												1	1						2
Tenebroides mauritanicus, head	Cadelle			12	4		16	9	4						36		8			89
Tenebroides mauritanicus, pronotum	Cadelle			8		1	12	1	4		8		4		51	4				93
Tenebroides mauritanicus, abdomen	Cadelle																			
Tenebroides mauritanicus, mandible	Cadelle	8																		8
Tenebroides mauritanicus, elytra	Cadelle				4		22	4	12	1					9	1				53
Tenebroides mauritanicus, pupae	Cadelle			4																4
Cryptolestes sp. entire														4						4
Cryptolestes sp., head											8									8
Cryptolestes sp., pronotum											8									8
No pests																				
Coleoptera																				
Hegeter sp., head						2				2			1		1	1			1	8
Hegeter sp., pronotum		1						1		2			1		2	1	6	1	2	17
Hegeter sp., elytra						2	1								8	2	12			25
Hegeter sp., sternum									4						9		2			15
Hegeter sp., metasternum																	1			1
Melansis cf. *kazsabi*, head																				
Melansis cf. *kazsabi*, pronotum																	1		1	2
																			1	1

(*continued on next page*)

Table 4 (*continued*)

	Common name	Unit 1									Unit 2									TOTAL
		1a	1b	2a	2b	2c	3a	3b	3c	4	1a	1b	1c	1d	2	3	4	5	6	
Melansis cf. *kazsabi*, abdomen																				
Palorus cf. *subdepressus*, head							8													8
Palorus cf. *subdepressus*, pronotum				8			8								8					24
Scleron cf. *asperulum*, pronotum														1						1
Aphodius hydrochaeris, pronotum																	2			2
Aphodius hydrochaeris, head																	1			1
Tropinota squalida canariensis, head																	1		1	2
Tropinota squalida canariensis, pronotum																	2			2
Tropinota squalida canariensis, elytra					1													4		5
Dermestes frischii, entire																			1	1
Dermestidae											8		16	56						80
Dermestidae, pronotum								1											1	2
Dermestidae, pupae														4						4
Latriidae													1							1
Latriidae, pronotum				8				12	4										8	32
Curculionidae, head																				
Curculionidae, pronotum				8			8			4	16					8				44
Curculionidae, elytra																				
Hymenoptera																				
Formicidae, head				8			8			4		16				8				44
Isopoda																				
Isopoda, segments												4	16		9	10			14	53
Heteroptera																				
Heteroptera, pronotum											4									4
Arachnida																				
Arachnida, chelicerae										5							1			6
Acari						1											1			2
Other undetermined remains		35	27	20	28	39	17	52	4	10	46	44	2	50	1	6	76	38	7	502
TOTAL																				9.143

(Kingsolver, 1991). It is therefore possible that it only colonized the silo after its abandonment, perhaps attracted by the modest decaying remains of Soricidae or Muridae, Lacertidae and Columbidae.

Aphodius remains were likewise identified in Silo 4 (Unit 2). Their presence in the granary of this coprophagous family (Beynon et al., 2012) is interpreted either as accidental or due to the use of excrement to prepare the mortar covering the silo's walls.

Finally, the existence of certain insect remains in the silos, not necessarily pests, may be fortuitous. Although members of the genus *Scleron,* for example, can be present in storerooms (Hagstrum and Subramanyam, 2009), this is not the case of *S. asperolum*, the taxa identified in La Fortaleza.

The origin of the other non-pest insects of the granary of La Fortaleza must be accidental. Their low number also points to an anecdotal nature, probably arriving after the abandonment of the site. There are also insects at the site endemic to the Canary Islands with no relationship to humans such as *Hegeter* sp., *Melansis* cf. *kazsabi*, and *Tropinota squalida canariensis* Lindberg.

Although primary pests induce the greatest amount of damage due to their consumption of whole grains, secondary pests must be taken into account when assessing the state of stored products (Huchet, 2017) as a granary infested by these pests also suffers total damage that offers compelling information as to the storage timeframe. For this reason, although the percentage of primary pests (47%) at La Fortaleza is significantly higher than that of secondary pests (37%), the latter yields broader information as to the conditions and length of storage.

An example is that the life cycle of *S. granarius* can endure up to one year (Haines, 1991), while that of secondary insects (e.g. *O. surinamensis*) can extend up to three years and three months in optimal conditions of temperature and humidity (Back and Cotton, 1926; Sahito et al., 2017). Furthermore, the life cycle of *T. mauritanicus* exceeds a year during which it can lay several eggs (Cotton, 1924).

The life cycles exceeding one year indicate either inadequate conditions of hygiene leading to the infestation or that of grain storage over long stretches of time. As mentioned above, plant processing by the indigenous Prehispanic population could also serve as evidence of long-term storage in these silos. The different techniques linked to preserving grains observed at the sites of Gran Canaria such as storing in their spikes or resorting to insecticide plants bolsters the idea of their desire for long-term crop preservation. Pulse pods and palm rachis also form

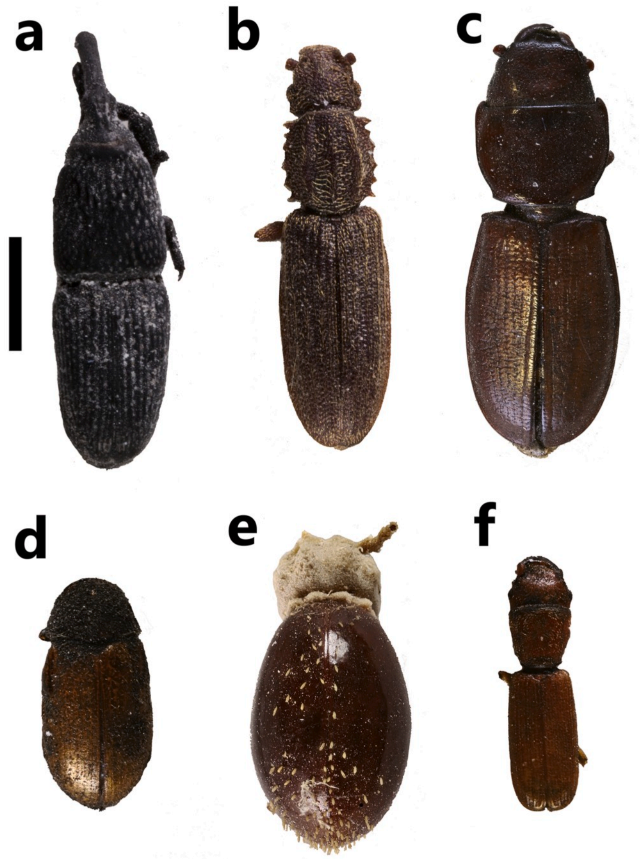

Fig. 4. Views of insect pests from the granary of La Fortaleza: a. granary weevil (*Sitophilus granarius*); b. saw-toothed grain beetle (*Oryzaephilus surinamensis*); c. cadelle (*Tenebroides mauritanicus*); d. biscuit beetle (*Stegobium paniceum*); e. black spider beetle (*Mezium americanum*); f. *Cryptolestes* sp. (scale bar = 1 mm).

part of the plants found in the granaries. Hence, cereals, as well as pulses and fruits, were stored in their natural envelopes (Morales et al., 2018). Resorting to these techniques, although not totally effective against certain insects, suggests that the ancient Canarians were aware of the pests.

Complete pest elimination (with the exception of those that can survive in extreme temperatures, e.g. below 10 °C or above 50 °C) requires very long periods of time in subtropical climates such as that of Gran Canaria (Bell, 2014) because the warm weather allows survival of eggs and insects not detected by the naked eye. It is probable that a lack of silo care and short intervals between each use, essential for total insect eradication, led to a propagation of secondary pests over a long period of time. Radiocarbon dates from *S. granarius* of Silo 2a-Unit 1 are ca. 300 years earlier than barley from the same silo (Table 1), confirming an incomplete cleaning of the silos. Although cooling below 10 °C for a prolonged period of time is difficult to achieve in subtropical climates such as that of the Canary Islands, heating above 50 °C was probably effective. Yet there is currently no evidence implying the use of fire for pest eradication.

Long-term food storage also requires frequent ventilation, especially when the seeds are stored in their ears (Sigaut, 1988). This leads to a drop in temperature inside the silo preventing the arrival of secondary pests. The proliferation of pests, on the other hand, increases silo temperature and humidity provoking more damage (Trematerra et al., 2000). The presence of both primary and secondary pests in the granary of La Fortaleza therefore indicates either a lack of silo aeration or that the grains were not sufficiently stirred and storage in these conditions over a period of at least 1–3 years.

The narratives penned by European explorers in the 15th century AD, although vague as to the exact lengths of storage time, reinforce the notion that the indigenous Canarian populations stockpiled their harvests in granaries “for many years” (Gómez Escudero, in Morales Padrón, 2008: 436). Ethnographic records on the use of historical collective granaries in the Maghreb, traditionally serving for comparison with the granaries of Gran Canaria (Marcy, 1940; Onrubia Pintado, 1986), advance an imprecise timeframe of ‘several years’ (Lefébure, 1985; Delaigue et al., 2006, 2011; 2013).

The lack of accuracy of the ethno-historical texts confirms the importance of archaeoentomological analyses for the understanding of former storage techniques. Evidence obtained at La Fortaleza suggests that pests offer accurate information as to long-term storage and serve as indicators of this activity in other archaeological contexts of the Canary Islands and beyond.

6. Conclusions

Ensuring human survival in isolated contexts such as the Canary Islands requires a correct managing of a series of different resources. The first settlers of Gran Canaria built granaries high in the cliffs with the aim of storing mostly cereals, pulses and figs all domesticated plants whose origins can be traced to the African continent. The arrival of these plants for future cultivation involuntarily introduced pests that spread throughout a landscape molded by humans. Archaeoentomology is therefore a new and relevant discipline in the Canary Islands as it allows pinpointing the propagation of different pests coexisting with the Prehispanic Canarians and identifying how their presence affected human activities. Nevertheless, the data available are still limited to a few communal granaries, and future studies should extend their analyses settlements and other sites such as burials, where entomological evidence is still missing.

The study of the insects of the granary of La Fortaleza reveals that certain insect pest species, especially those of secondary type, developed during storage periods extending for more than one year. Ethnohistorical written records corroborate long-term storage in collective granaries, a notion bolstered by the fact that the grains were stored with the protection of the ear. Therefore, data obtained at La Fortaleza confirm that insect remains in certain archaeological contexts can be used to estimate the length of food storage. This scenario could be extrapolated to other geographical areas and chronological periods where taphonomical conditions allow the preservation of insect remains.

Finally, an unexpected find of this study is the presence of the spider beetle *M. americanum* in the Old World in a timeframe prior to the European conquest of America (1492). This suggests an African or Eurasian origin rather than one of the New World.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2020.105179.

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