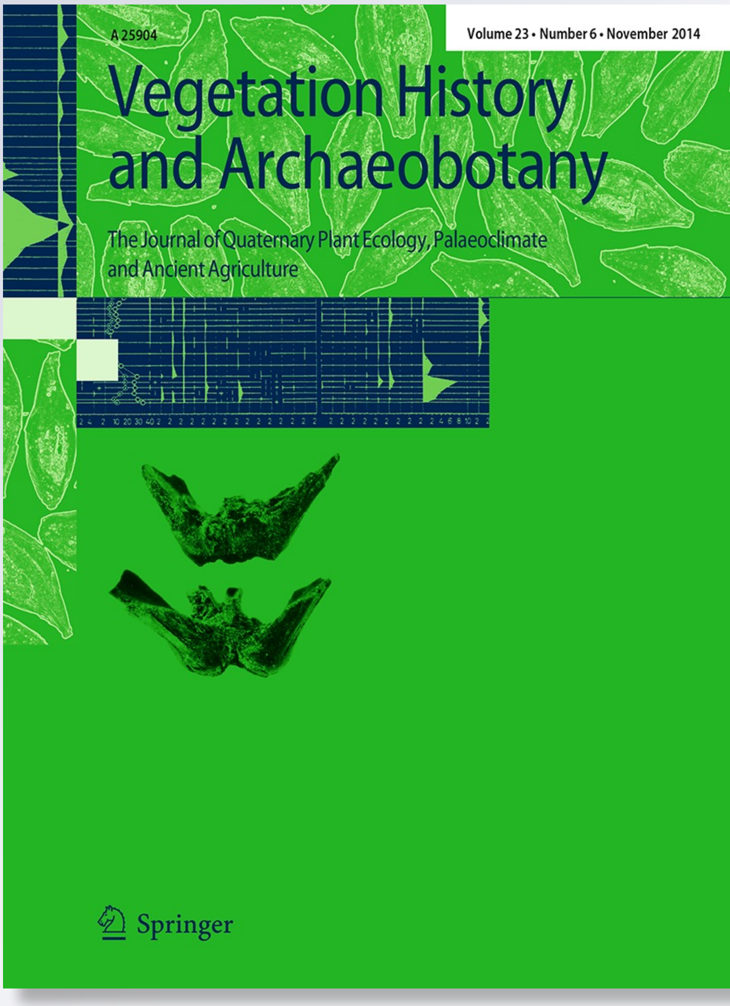
The archaeobotany of long-term crop storage in northwest African communal granaries: a case study from pre-Hispanic Gran Canaria (cal. ad 1000–1500)

Jacob Morales, Amelia Rodríguez-Rodríguez, María del Cristo González-Marrero, Ernesto Martín-Rodríguez, Pedro Henríquez-Valido, et al.

Vegetation History and Archaeobotany
The Journal of Quaternary Plant Ecology, Palaeoclimate and Ancient Agriculture - Official Organ of the International Work Group for Palaeoethnobotany

ISSN 0939-6314
Volume 23
Number 6

Veget Hist Archaeobot (2014)
23:789-804
DOI 10.1007/s00334-014-0444-4



Springer

Veget Hist Archaeobot (2014) 23:789–804
DOI 10.1007/s00334-014-0444-4

ORIGINAL ARTICLE

The archaeobotany of long-term crop storage in northwest African communal granaries: a case study from pre-Hispanic Gran Canaria (cal. AD 1000–1500)

Jacob Morales · Amelia Rodríguez-Rodríguez · María del Cristo González-Marrero · Ernesto Martín-Rodríguez · Pedro Henríquez-Valido · Miguel del-Pino-Curbelo

Received: 9 May 2013 / Accepted: 10 February 2014 / Published online: 16 March 2014

Abstract Communal granaries are a widespread and very significant feature of northwest Africa. Here the first systematic archaeobotanical study of such a granary is presented, with desiccated plant macro-remains retrieved from the pre-Hispanic site of El Álamo-Acusa, Gran Canaria, Spain (cal. AD 1000–1500). While modern contamination caused by animals was evident, most plant remains found there were ancient, including cereals, pulses, cultivated fruits and wild gathered plants. *Hordeum vulgare* ssp. *vulgare* and *Ficus carica* were the most common taxa, which appear to have been the two main staple foods for the pre-Hispanic population. The high frequencies of chaff and other plant residues indicate that crops were stored unprocessed. Most food plants had been eaten by insects and other animals, and only unpalatable parts were present. Remains of *Sitophilus granarius* (grain weevil) were common in the samples, suggesting problems of insect pests during long-term storage. In addition, we have identified leaves of cf. *Laurus novocanariensis*, which may have been used as an insect repellent.

Keywords Plant storage · Crop processing · Insect pest · Insect repellent plants · Canary islands · Pre-Hispanic

Communicated by M. van der Veen.

Electronic supplementary material The online version of this article (doi:10.1007/s00334-014-0444-4) contains supplementary material, which is available to authorized users.

J. Morales (✉) · A. Rodríguez-Rodríguez ·
M. d. C. González-Marrero · E. Martín-Rodríguez ·
P. Henríquez-Valido · M. del-Pino-Curbelo
G.I. Tarha, Departamento Ciencias Históricas, Universidad de Las Palmas de Gran Canaria, Pérez del Toro 1,
35003 Las Palmas de Gran Canaria, Canary Islands, Spain
e-mail: jacobmoralesmateos@gmail.com

Introduction

Communal granaries are a widespread and very significant feature of northwest Africa during the medieval and post medieval periods. They usually consist of a set of silos that are located in inaccessible places, such as in cliff faces, at the top of mountains, or in fortified buildings, where they can be easily protected and defended. According to historical and ethnographic studies, these structures have been used as long-term food stores in rural areas of Libya, Tunisia, Algeria and Morocco until very recently (Adam 1978; Despois 1953). Nowadays they have different names in each region: in Morocco they are designated with Amazigh/Berber words such as *agadir* and *tighremt*; but Arabic words such as *guelâa* in Algeria and *gasr* in Tunisia and Libya are also used (Onrubia-Pintado 1995). In the Iberian Peninsula there are also communal granaries that were built and used during the Islamic period in the 8–15th centuries AD when a large group of Berber people from North Africa settled there (Bazzana 1996; De Meulemeester 2005).

In addition, ethnohistorical sources record that communal granaries were used by the ancient Canarian people (Morales-Padrón [1500/1525] 1993, p. 373). According to archaeological and genetic data, the Canary Isles were first populated around the 3rd–2nd centuries BC by Berber people from north western Africa, although there are very few data about the exact chronology and the geographical origin of the first human colonization of the archipelago (Maca-Meyer et al. 2004). The colonizers apparently then remained isolated from the mainland and made very few contacts with people on the other islands, until Europeans reached the archipelago in the 13–14th centuries AD. The Castilian Crown conquered all the islands at the end of the 15th century AD.

Ethnographic studies carried out in the Maghreb during the early part of the 20th century indicate that granaries were communally owned and protected, but that each silo within them belonged to a different owner (Ferchiou 1979; Meunié 1951; Rosenberger 1985). Crops were the most common items stored inside the silos (Louis 1979), but precious objects were kept there as well (Bokbot et al. 2002; Delaigue et al. 2006). Communal granaries were mostly intended for long-term storage and some ethnographic testimonies indicate that cereals were still well preserved after several years and even decades (Lefébure 1985).

There are to date very few archaeological studies of these communal granaries. Most research has focused on the architectural design, and little information is available about their chronology, the plants that were stored in them, the methods and problems of storage, or the role they played in the economy and society of the past Berber people (Bazzana 1996; De Meulemeester 2005; Onrubia-Pintado 1995).

The site El Álamo-Acusa

In Gran Canaria, communal granaries are very common, but no systematic surveys of them have been carried out so far (Onrubia-Pintado 1995; Velasco-Vázquez et al. 2001). Granaries, and silos inside them, are carved into the volcanic tuff rock, which keeps the temperature and humidity at a constant level and allows excellent preservation of organic materials. There are no records of granaries in other islands of the archipelago (Onrubia-Pintado 1995). Although agriculture was practised in most of them, palaeodietary studies on human bones suggest that cultivated plants were more important for the population of Gran Canaria than for the rest of the islands (Arnay-de-la-Rosa et al. 2009; Delgado-Darias et al. 2005; González-Reimers and Arnay-de-la-Rosa 1992; Velasco-Vázquez et al. 1999). According to archaeological and ethnohistorical data, Gran Canaria was densely populated at the time of the Spanish contact in the late 15th century and there is evidence of the existence of large villages (Onrubia-Pintado 2003).

El Álamo-Acusa is located near the centre of the island, in a mountainous region, at 945 m a.s.l. (Fig. 1). It is part of a large complex of caves carved into a cliff on the Acusa plateau, which also includes dwellings and a cemetery, although these have not been systematically surveyed or excavated so far (Velasco-Vázquez et al. 2001). The granary is divided into two floors. The first one contains six silos at ground level and it is easily accessible, having been used as a corral until recently. In contrast, the second floor can only be reached after a very risky climb of several metres up the face of a 40 m cliff (Fig. 2). This second floor consists of an oval chamber of 10 by 8 m carved into the rock and it contains 12 silos that are arranged around the walls of the enclosed area (Figs. 3, 4). A "stone structure" (SS) was built in the middle of the chamber to facilitate access to the silos. There is another cave carved into the cliff (designated here as the "adjacent cave"; AC), 5 m away from the main chamber, which seems to have been used as a resting place. The silos are currently uncovered, but they were almost certainly sealed when they

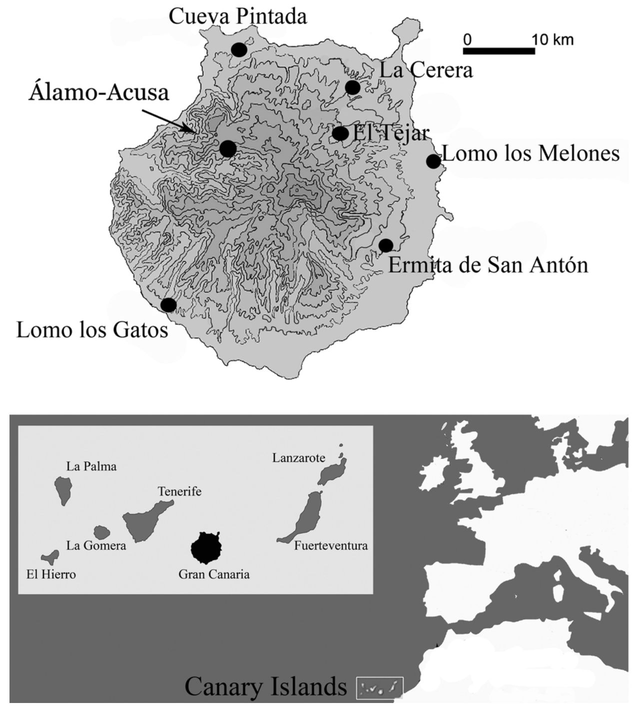


Fig. 1 Location of the granary site of El Álamo-Acusa and other sites mentioned in the text

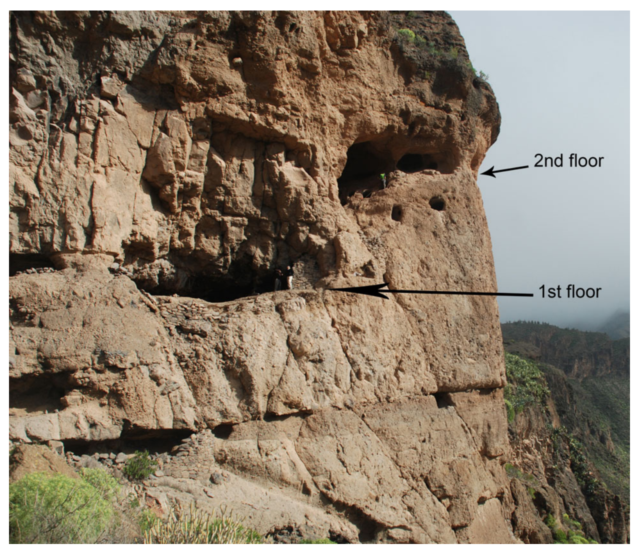


Fig. 2 General view of El Álamo-Acusa granary

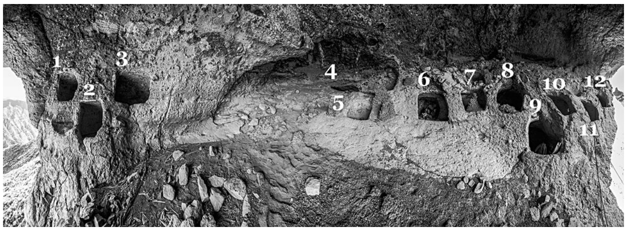


Fig. 3 360° view of the second floor of the granary; numbers indicate location of each silo

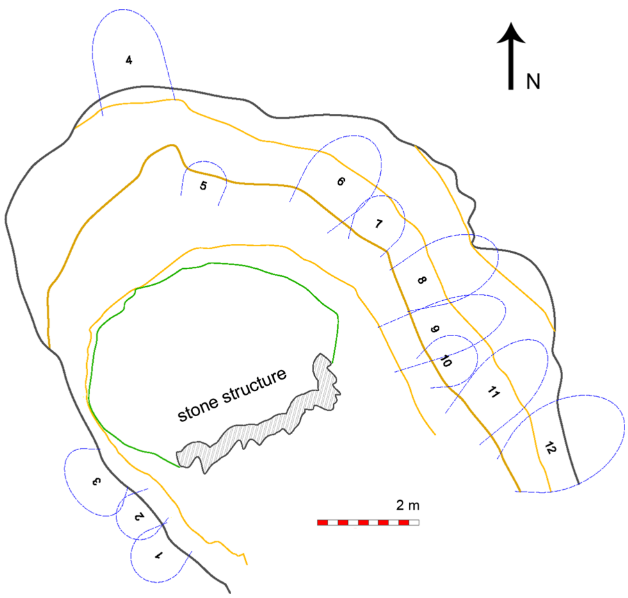


Fig. 4 Plan of the second floor of El Álamo-Acusa granary; numbers indicate locations of the silos

were used in the past, as frames carved in the rock are still visible at their entrance, and wood and stone gates have been recovered from past surveys of other granaries in Gran Canaria (Onrubia-Pintado 1995). The silos have volumes that range from 0.37 to 5.37 m^3 (ESM 1).

Due to the difficulty of access, the second floor of the granary is very well preserved and some of the original content of the silos is still visible to the naked eye. As a result of this extraordinary preservation, the remains of El Álamo-Acusa constitute a perfect opportunity to study the botanical content of the silos and to throw some light on the long-term storage of food plants in the past.

In this paper the first archaeobotanical study of such a communal granary is presented (Fig. 1). First the general structure of such granaries is briefly discussed, followed by details of this particular site, sampling strategy and identification criteria. Then the results of the analysis are presented, followed by a discussion of modern contamination, crops found in settlement sites of pre-Hispanic Gran Canaria, processing of plants, storage methods, insect infestation and insect repellent plants.

Materials and methods

Sampling

All the analyzed samples come from the second floor of the granary. We did not sample the first floor because the silos there were badly preserved and did not contain any visible remains. Due to the exceptional preservation and density of remains in the sediment, it was decided to collect only 1 l samples from the central surface of each silo. Silo 7 was completely covered by animal droppings and was not sampled (Fig. 3). In addition, 1 l samples were collected from the stone structure SS and the adjacent cave AC in the cliff. The silos mostly contained 1–2 cm thick layers of sediment, composed of cereal chaff and animal droppings (ESM 2). Samples from each of these sediments were dry-sieved using a stack of sieves of 2, 1 and 0.5 mm. Flotation of the samples was not necessary as most of the sediment matrix was made up of plant remains. Due to the high density of remains, especially cereal chaff, we decided to completely sort the 2 mm fraction but only a quarter of the 1 mm fraction and an eighth of the 0.5 mm fraction. Figures in Table 1 show the estimated number of seeds after multiplying the results in each fraction, and calculation of the total number of remains in each sample. In the case of *Hordeum* (barley) in addition to seeds, articulated sets of barley hulls (lemma and palea) with no grain inside were preserved. These articulated sets of hulls look like grains but in fact they are the result of kernels having been eaten by beetles, as holes made by weevils were evident in most of the hulls (Fig. 5). Sets of hulls were counted as one item each and they are listed separately from the complete grains in Table 1. For cereal rachis, we have counted each node segment of the axis as one item, and for pulses we have also quantified each detached hilum as one item. In the case of figs, we have identified fruit fragments, seeds (endocarp) and fruit peduncles, which have been counted as one item each, but we must consider that a whole fig can contain up to 1,000 seeds and we must be cautious when comparing the numerical importance of this fruit with other taxa. For other uncommon macro-botanical remains such as leaves or rachillae we have counted each fragment as one item.

All the samples contained abundant plant remains preserved by desiccation. No charred plant remains were found. The preservation is excellent and this has allowed an accurate identification of most of the taxa. The identification was done with a binocular microscope of 8× and 80× and by comparing the archaeological remains with the

Table 1 Plants and insects identified in the silos, the stone structure (SS) and the "adjacent cave" (AC), ff = fragments, ffff = many fragments; given are numbers of seeds unless otherwise noted

Silo	1	2	3	4	5	6	8	9	10	11	12	AC	SS	Total
Ancient plants														
Hordeum vulgare ssp. *vulgare*, grain	.	.	.	1	.	.	.	.	.	.	.	.	1	2
H. v. ssp. *vulgare,* articulated set of hulls	2	34	136	372	6	6	36	1	56	67	9	4	221	950
H. v. ssp. *vulgare*, rachis	1	144	1,487	1,131	74	47	339	21	353	713	896	87	502	5,795
H. v. ssp. *vulgare*, basal rachis	.	.	14	21	.	.	4	.	2	10	12	.	6	69
Triticum aestivum/durum, grain	1	.	.	.	.	.	.	.	.	.	.	.	1	2
T. durum, rachis/basal rachis	3/1	2/	179/2	.	8/	.	16/	4/	25/	89/2	28/1	16/1	42/1	412/8
Cereal culm node	.	.	.	.	.	.	.	.	2	3	.	2	.	7
Glume/hull/awn fragments	ff	ff	ffff	ffff	ff	ff	ffff	ffff	ffff	ffff	ffff	ff	ff	
Fabaceae, seed/hilum/peduncle	//49	.	1//1	.	.	.	5/4/	/8/	.	.	2//	1//14	.	9/12/64
Ficus carica, fruit/fragment/peduncle	/1/	.	.	.	.	.	.	.	.	//2	//1	.	1//2	7
F. carica, endocarp	.	132	613	88	152	56	264	53	291	1,353	564	340	552	4,458
Lens culinaris, seed/hilum/pod	.	.	/4/	/8/	.	.	.	.	3/17/1	.	/12/	.	/17/	62
Pisum sativum, hilum	.	.	.	.	.	.	.	1	.	.	.	1	.	2
Vicia faba, hilum/funicle	1/	.	.	.	.	.	2/	.	.	4/	5/	.	2/1	15
Phoenix canariensis, seed/rachilla	.	.	.	/1	.	.	.	.	1/	/1	/1	.	.	4
Pinus canariensis, seed/seed scale	.	.	.	2/	.	/1	1/	1/	1/1	1/	1/	.	1/	10
cf. *Laurus novocanariensis*, leaf fragment	.	.	.	.	.	.	1	.	.	2	.	.	.	3
Modern plants														
Aizoon canariense	.	.	.	.	.	.	.	.	8	.	.	.		8
Anagallis arvensis		.	.	.	.	.	.	.	8	.	.	.	8	16
Apiaceae	.	.	.	.	.	.	.	.	16	8	.	.	.	24
Asteraceae, seed/flower head	9/	12/	10/	4/	3/	2/	5/	6/	6/	12/	14/	2/2	8/	95
Avena sp., spikelet	.	.	.	.	.	.	.	.	.	1	.	1	.	2
Bituminaria bituminosa	10	.	.	.	.	.	7	1	.	1	3	7	.	29
Boraginaceae	26	.	.	.	.	.	3	.	.	2	.	.	.	31
Brassicaceae	32	.	11	.	.	.	.	.	.	.	4	8	.	55
Bromus sp.	.	.	.	.	.	.	.	.	.	.	4	1	.	5
Calendula arvensis	5	.	8	.	4	.	.	.	.	4	.	2	.	23
Chenopodium murale	.	.	8	.	.	.	12	.	.	.	.	8		28
Citrus sp.	.	.	.	.	.	.	.	.	.	.	.	1		1
Emex spinosa	.	.	.	.	.	.	.	.	.	.	.	.	1	1
Euphorbia regis-jubae	24	.	4	7	.	.	21	5	1	2	8	.	1	73
Euphorbia sp., capsule fragment	.	5	.	1	.	.	.	.	.	.	.	2	.	8
Fumaria sp.	.	.	.	.	4	.	.	.	.	.	.	12	4	20
Galium sp.	1	.	.	.	.	.	.	.	.	.	.	.	1	2
Hippocrepis sp.	.	.	.	1	.	.	.	.	.	.	.	.	.	1
Lathyrus clymenum	1	.	.	.	.	.	.	.	.	.	.	.	.	1
Malva parviflora		.	1	.	.	.	.	.	.	5	4	.	.	10
Medicago sp., fruit	.	.	.	.	.	.	.	.	.	2	.	.	.	2
Opuntia sp.	3	1	1	.	2	2	4	2	.	4	.	6	48	73
Oxalis pes-caprae, tuber	.	1	.	1	1	1	1	1	1	1	1	1	.	10
Phalaris sp.	4	.	5	.	1	.	.	.	8	.	8	.	.	26
Plantago sp.	.	.	2	.	.	.	.	.	5	4	.	4	.	15
Poaceae	16	.	.	.	.	.	.	.	.	.	.	4	.	20
Raphanus raphanistrum, pod	4	.	4	4	3	.	3	.	1	2	13	4	5	43
Rumex sp.	.	.	1	.	.	.	.	.	.	.	.	4	.	5
Sherardia arvensis	.	.	.	.	.	.	.	.	.	.	.	.	12	12
Silene gallica	.	.		.	.	.	8	.	32	.	12	.	8	60
S. vulgaris	.	.	.	4	.	.	.	.	.	.	4	.	.	8
Silybum marianum	1	.	1	2	.	.	5	.	.	1	6	4	.	20
Sisymbrium sp.	48	.	.	.	.	.	.	.	.	.	.	.	.	48
Small seeded legume	16	5	4	.	4	8	.	.	.	.	24	4	8	73
Solanum alatum/nigrum	.	.	1	.	.	.	.	.	.	.	.	4	.	5
Solanaceae	.	4	.	.	.	.	.	.	.	.	4	1	.	9
Spergularia fallax	.	.	172	.	.	.	.	.	.	.	.	.	.	172
Vicia ervilia	.	.	.	.	1		.	.	.	.	.	.	.	1
V. sativa, seed/hilum	3/9	.	1/2	/1	.	.	1/	1/1	.	.	6/4	2/25	.	56
Vitis vinifera	.	.	.	.	.	.	.	.	.	.	.	10	.	10
Indeterminate	.	.	8	4	4	.	.	.	3	.	17	.	9	45
Total number of ancient plants	59	312	2,437	1,624	240	110	672	89	753	2,247	1,532	467	1,350	11,892
Total number of modern plants	212	28	244	29	27	13	70	17	89	49	136	119	113	1,146
Total number seeds	271	340	2,681	1,653	267	123	742	106	842	2,296	1,668	586	1,463	13,038
Sediment volume (l)	1	1	1	1	1	1	1	1	1	1	1	1	1	13
Dropping volume (l)	0.6	0.16	0.07	0.06	0.02	0.06	0.02	0.05	0.06	0.04	0.25	0.3	0.02	1.71
Insects														
Sitophilus granarius, Curculionidae	1	65	19	47	10	9	21	18	37	24	66	34	142	493
Stegobium paniceum, Anobiidae	4	.	.	.	.	.	1	.	1	2	1	.	1	10

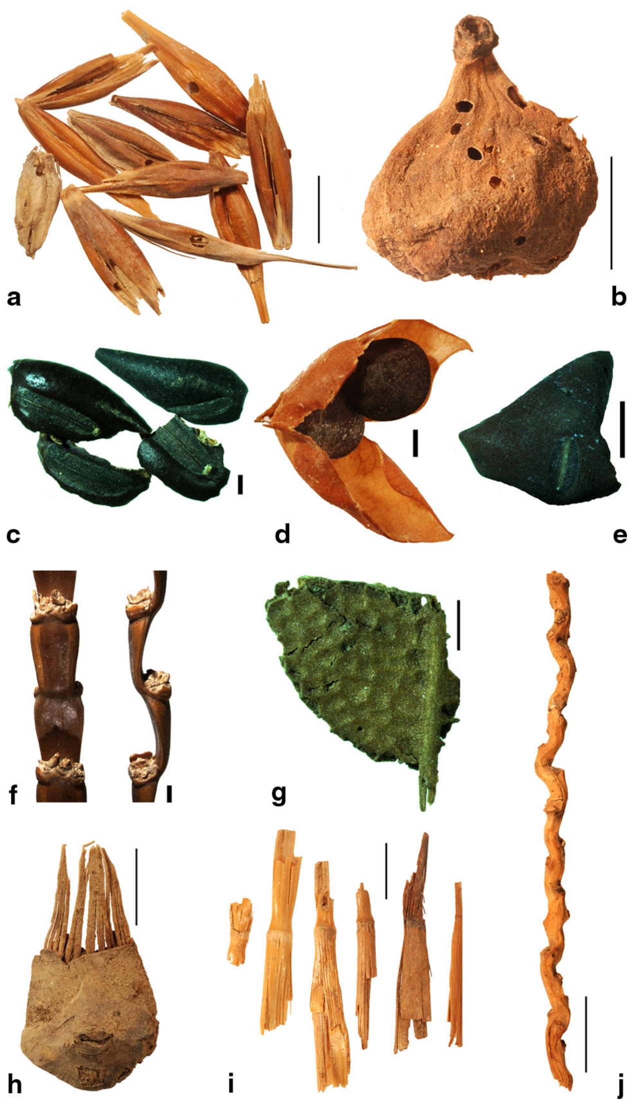


Fig. 5 Plant remains discussed in the text: **a** *Hordeum vulgare* ssp. *vulgare*, articulated set of hulls, **b** *Ficus carica*, complete fruit, **c** *Vicia faba*, detached hila, **d** *Lens culinaris*, pod and seeds, **e** *Pisum sativum*, detached hilum, **f** *Triticum durum*, rachis, **g** cf. *Laurus novocanariensis*, leaf, **h** *Pinus canariensis*, seed scale, **i** cereal culm node, **j** *Phoenix canariensis*, rachilla; scale 10 mm (*thin bar*) and 1 mm (*thick bar*)

reference collections at the Department of Historical Sciences, in the University of Las Palmas de Gran Canaria, Spain, and at the McDonald Institute for Archaeological Research, University of Cambridge. Botanical nomenclature for crops follows the traditional binomial classification (Zohary et al. 2012), for their modern grouping on the basis of cytogenetic and molecular affinities, while for the wild plants we used Acebes-Ginovés et al. (2010).

Modern plants were also present in the samples because the silos were not (no longer) sealed. These items cannot be distinguished from the ancient plants merely by examining the external morphology, and we have tried to identify the potential routes of entry of seeds into the silos and have classified the taxa according to these criteria (Table 1). In sites in Egypt and other arid parts of North Africa where preservation through desiccation is common, the same problem arises, as ancient and modern plant remains look similar (Cappers 2006; Newton 2004; Van der Veen 2007, 2011).

Results

A total of 13,038 macro-botanical items were retrieved from the samples. Plant assemblages from Silo 3 (2,681 items) and Silo 11 (2,296 items) were the richest, while the poorest results were obtained from Silo 9 (106 items) and Silo 6 (123 items). Samples collected in the SS and the AC were also rich, especially in the SS. Density of remains is extremely high (931 items/l) and we were able to identify 55 taxa including both domesticated and wild plants. All the silos contained a similar set of plants that included cereals, pulses, cultivated fruits and wild plants. Table 1 shows the list of taxa recovered from each silo and Fig. 5 illustrate the most important plants discussed in the text.

Crops

Hordeum vulgare ssp. *vulgare* (six-row hulled barley) was the most common species and has been retrieved from all samples. Grains, articulated sets of hulls, and rachis segments were present and in some cases the rachis segments were still fully articulated and with the sets of hulls attached in complete ears. Only two complete grains were recovered, rachis segments and sets of hulls being the most frequent items. In addition we have identified articulated basal rachis segments attached to the top section of the culm (straw). These fragments show clear cut marks on the straw, suggesting that the ears were cut from the rest of the plant before being deposited in the silos (Fig. 6). A fragment of these ears from Silo 4 was radiocarbon dated to 540 ± 30 BP (Beta 317651) (cal. AD 1320–1430) (Table 2).

Triticum durum (durum wheat) was also present in the samples, but it was not as abundant as *Hordeum*. Here most remains consisted of rachis segments; only two *Triticum* grains have been found. Fragments of *Triticum* glumes were also collected (see category glume/hull/awn in Table 1). As in the case of *Hordeum*, some articulated segments of rachis were present, including the basal parts of the ear attached to segments of the straw, the latter showing clear cut marks (Fig. 6). One fragment of a *Triticum* ear from Silo 3 was radiocarbon dated to 630 ± 30 BP (Beta 317650) (cal. AD 1290–1410).

It is worth noting here that the 1 and 0.5 mm fractions of all the samples contained fragmented cereal hulls and

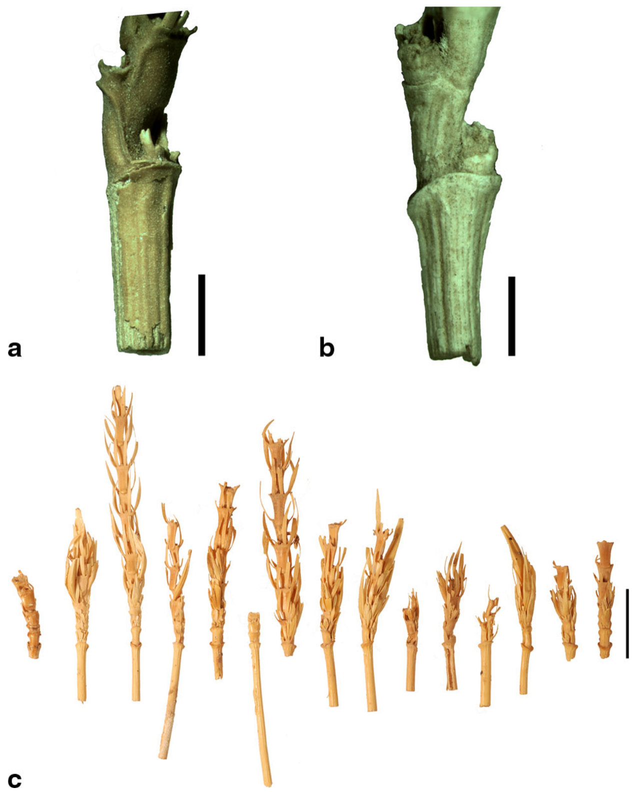


Fig. 6 Cereal ears from silo 3: **a** *Hordeum vulgare* ssp. *vulgare*, basal rachis, **b** *Triticum durum*, basal rachis, **c** *Hordeum vulgare* ssp. *vulgare*, basal rachises and near complete ears without the grain; scale 10 mm (*thin bar*) and 1 mm (*thick bar*)

awns. These were not removed or counted due to their large number but their presence was noted (Table 1). A few cereal culm or straw nodes were also present.

Pulses were present in most structures, except in silos 2 and 6, but in smaller numbers than the cereals. Both seeds and detached hila of *Vicia faba* (broad bean) *Lens culinaris* (lentil) and *Pisum sativum* (pea) were present, as was one whole pod of *Lens*, still including the seeds (Fig. 5). Pod peduncles were also retrieved from the samples, but accurate identification of them was not possible. In addition, we have identified seeds of *Vicia ervilia* and *V. sativa*. These two pulses are considered to be modern intrusions, for there is no archaeological or textual evidence of these crops in pre-Hispanic sites of Gran Canaria. In order to confirm this hypothesis we radiocarbon dated one seed of *V. sativa* from Silo 10, which indeed showed a historic date 180 ± 30 BP (Beta 317652) (Table 2).

Fruit was also identified in all the samples. *Ficus carica* (fig) remains were the most common and they included 4,458 seeds (endocarp), as well as some peduncles, fruit fragments and one complete fruit. Seeds of *Vitis vinifera* (grape) were also recovered from the AC. This fruit is considered an early introduction by the first Spanish colonizers during the late 15th century AD (Morales 2010), but we decided to date one seed. This resulted in a date of 130 ± 30 BP (Beta 317654), confirming the grape to be a modern intrusion. Seeds from *Opuntia* sp. (prickly pear) were also abundant, but this is a native plant from America that was introduced into Gran Canaria in historical times. In addition, one seed of *Citrus* sp. was identified. As with *Vitis* and *Opuntia*, fruit trees from the *Citrus* genus, which include orange, lemon and clementine, were introduced in the early 16th century AD to Gran Canaria by the Spanish (Gil 2011), so they should all be considered modern contamination (see "Discussion", below).

Wild plants

In addition, we have identified a large set of wild taxa, most of which are common weeds in cereal fields, the most frequent being *Spergularia fallax* and Asteraceae. We consider that most plants in this set could have reached the silos through the wind or in animal droppings (see "Discussion", below). But in this group of plants we have also included three taxa that belong to the native flora of Gran Canaria and they were probably gathered by the pre-Hispanic population. These include cf. *Laurus novocanariensis* (Canarian bay tree), *Pinus canariensis* (Canarian pine) and *Phoenix canariensis* (Canarian palm).

Table 2 Radiocarbon dates on plants and insects from El Álamo-Acusa

Material	Location	Lab. code	Sample reference	^{14}C age BP	cal. AD [2 σ]
Sitophilus granarius	Silo 12	Beta 317653	ACUSILO12SIT	980 ± 30	1020–1150
Laurus novocanariensis	Silo 8	Beta 358369	ACUSIL8LAU	920 ± 30	1030–1210
Triticum durum	Silo 3	Beta 317650	ACUSILO3TRI	600 ± 30	1290–1410
Hordeum vulgare	Silo 4	Beta 317651	ACUSILO4HOR	540 ± 30	1320–1430
Vicia sativa	Silo 10	Beta 317652	ACUSILO10VIC	180 ± 30	1650–post 1950
Vitis vinifera	AC	Beta 317654	ACUSILO13VIT	130 ± 30	1670–post 1950
Euphorbia regis-jubae	Silo 12	Beta 358367	ACUSIL12EUP	80 ± 30	1680–post 1950
Euphorbia regis-jubae	Silo 4	Beta 358366	ACUSIL4EUP	113.4 ± 0.3 pMC	post 1950

Fragments of leaves of *L. novocanariensis* have been identified in samples from silos 8 and 12. Preservation of the remains in El Álamo-Acusa is insufficient to accurately identify the taxa, as there are another three Lauraceae species growing in Gran Canaria, which have similar leaves (Acebes-Ginovés et al. 2010). However in ongoing sampling from other granaries in Gran Canaria we have recovered some more complete leaf fragments that have enabled us to confirm the identification of *L. novocanariensis*. One fragment of *L. novocanariensis* leaf from Silo 8 was radiocarbon dated to 930 ± 30 BP (Beta-358367) (cal. AD 1030–1210). *Pinus canariensis* remains were collected from nine samples and we could identify both seeds and seed scales. A seed and three rachilla fragments of *Phoenix canariensis* were also identified. *Ph. canariensis* is similar to *Ph. dactylifera* L. (date palm) but its fruits are smaller and have a more bitter taste than those of true dates.

Insects

Most samples also contained small beetles that were preserved through desiccation (Fig. 7). Two species were initially separated and identified as *Sitophilus granarius* (granary weevil) and *Stegobium paniceum* (bread weevil) although there was evidence of fly puparia and further insects which are still in the process of study. These identifications were confirmed by P. Oromí (Department of Biology, University of La Laguna, Spain). Granary weevils were abundant, with a minimum number of 493 individuals and they were present in all samples. A sample of *S. granarius* from Silo 12 was radiocarbon dated to 980 ± 30 BP (Beta 317653) (cal. AD 1080–1150). *S. paniceum* was less common, with only ten specimens found, and it has only been identified in five silos and in the SS (Table 1). During revision of the samples, some live *S. paniceum* were recorded inside the animal droppings, so we consider them as modern.

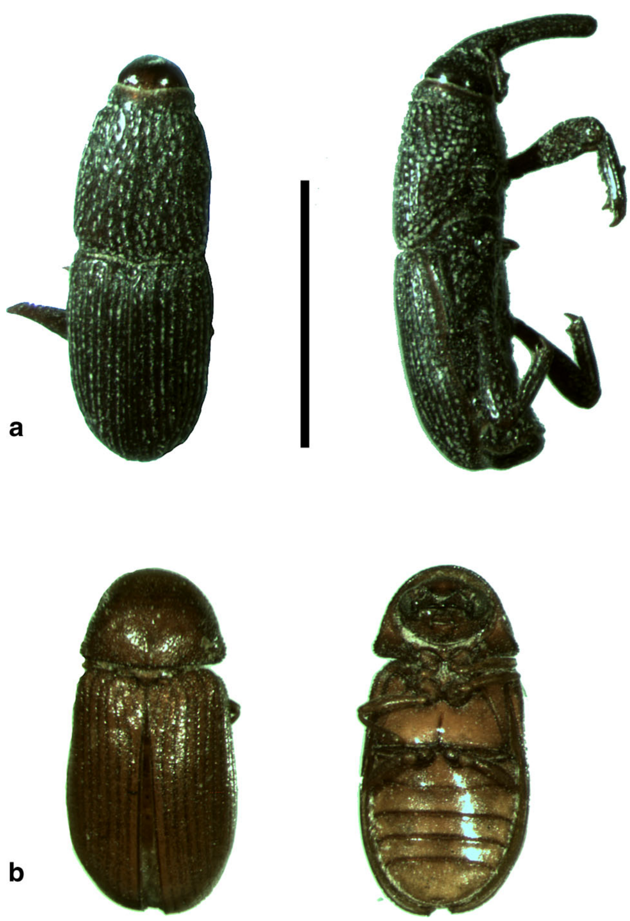


Fig. 7 Weevils from El Álamo-Acusa: **a** *Sitophilus granarius*, **b** *Stegobium paniceum*, *scale bar* 1 mm

Discussion

Plants in the silos: ancient stores and modern contamination

Modern contamination

The presence of both ancient and modern plant remains in the silos raises some problems when identifying the plants originally stored in them. While the silos were probably sealed when they were in use, since then they have been open to the elements, and contaminants could have entered by several different routes. Although the second floor of the granary was not re-used during the historical period and it can only be reached after a difficult climb, seeds and other plant parts may have been introduced there by animals and by the wind.

In order to identify these introduced taxa we have characterized all the wild plants from El Álamo-Acusa according to their dispersal methods (Table 3). Weed seeds were classified according to the presence of aerodynamic features (wings or hairs), density and size, as these are relevant to wind dispersal (van der Pijl 1982). Light and small seeds with wings or hairs are more prone to be transported over long distances, and this could be the case for seeds of *Spergularia fallax* and members of the Asteraceae family, which are the most frequent wild seeds in the samples. Other taxa such as *Rumex* sp. or *Avena* sp., which were preserved as complete dispersal units, could also have reached the silos in the wind.

Additionally, many of the plants identified in the silos also use animals as dispersal agents, among other strategies. In order to identify the possible animals visiting the site, droppings collected from the silos were shown to specialist A. González-Castro (Department of Biology, Pennsylvania State University), who was able to identify

Table 3 Classification of weed seeds at El Álamo-Acusa according to seed dispersal mechanisms, presence of aerodynamic features, density, and size. An additional column shows the plant habit of each taxon (after Baiges et al. 1991; Cohen and Plitmann 1997; Gutterman 1993, 1994)

	Mechanism of seed dispersal	Aerodynamic features	Density	Size	Plant habit
Aizoon canariense	Water	absent	heavy	small	prostrate
Anagallis arvensis	Gravity	absent	heavy	small	decumbent
Apiaceae	Gravity, wind, rain, animal	absent	heavy	small	erect
Asteraceae	Gravity, wind, rain, animal	present	heavy	big	erect
Avena sp. spikelet	Gravity, wind, animal	absent	light	big	erect
Bituminaria bituminosa	Gravity, animal	absent	heavy	big	erect
Boraginaceae	Gravity, wind, rain, animal	absent	heavy	small	erect
Brassicaceae	Gravity, wind, rain, animal	absent	heavy	small	erect
Bromus sp.	Gravity, animal	absent	heavy	big	erect
Calendula arvensis	Gravity, animal	absent	heavy	big	erect/prostrate
Chenopodium murale	Gravity, animal	absent	heavy	small	erect
Emex spinosa	Gravity, animal	absent	heavy	big	erect/prostrate
Fumaria sp.	Gravity, animal	absent	heavy	small	climbing
Galium sp.	Gravity, animal	absent	heavy	big	climbing
Hippocrepis sp.	Gravity, animal	absent	heavy	small	erect
Lathyrus clymenum	Gravity, animal	absent	heavy	big	climbing
Malva parviflora	Gravity, animal	absent	heavy	small	erect/prostrate
Medicago sp. fruit	Gravity, animal	absent	heavy	small	erect/prostrate
Phalaris sp.	Gravity, animal	absent	heavy	small	erect
Plantago sp.	Rain, animal	absent	light	small	erect
Raphanus raphanistrum, pod	Gravity, animal	absent	heavy	small	erect
Rumex sp.	Wind, animal	absent	heavy	small	erect
Sherardia arvensis	Gravity, animal	absent	heavy	small	climbing
Silene gallica	Gravity, animal	absent	heavy	small	erect
Silene vulgaris	Gravity, animal	absent	heavy	small	erect
Silybum marianum	Wind, rain, animal	present	heavy	big	erect
Sisymbrium sp.	Gravity, water, animal	absent	heavy	small	erect
Small seeded legume	Gravity, animal	absent	heavy	small	erect/prostrate
Solanum alatum/nigrum	Gravity, animal	absent	heavy	small	erect
Spergularia fallax	Wind	present	light	small	prostrate

the excrement of birds, *Rattus* sp. (rat) and *Gallotia stehlini* (lizard). *G. stehlini* is a large mostly vegetarian lizard that consumes considerable quantities of seeds, 30–40 % of its diet (Carretero et al. 2006). The presence of droppings in the samples suggests that birds, rats and lizards visited the granary frequently and it is possible that seeds from plants eaten in the fields by these animals could have been transported to the site and deposited in the droppings.

The volume of droppings in each silo was recorded (see Table 1) and the contents of the droppings were checked with a binocular microscope, showing the massive presence of crop fragments, mostly *Hordeum* hulls, but also *Triticum* grains and *Ficus* seeds, and wild plants (Fig. 8). The statistical significance of the correlation between the frequency of wild plants and the volume of droppings in each silo was tested at $\alpha = 0.05$ level using SPSS version 22. The result of this analysis shows a significant correlation between the number of seeds of wild plants and the animal droppings ($r = 0.576$). This evidence suggest that animals were introducing plants into the silos, and also that they were eating the stores, since crops were identified in the droppings. There is moderate negative correlation between the frequency of ancient crops and the volume of droppings ($r = -0.304$). Two samples of *Euphorbia regis-jubae*, a native shrub of the Canaries that produces a toxic sap, were radiocarbon dated to a recent age (Table 2), confirming that they are modern contaminations, probably introduced by lizards as they commonly eat this plant (Carretero et al. 2006).

Evidence of weeds in the silos is thus problematic and we consider most of them to be wind or animal contaminations. In addition, the group of wild plants identified in El Álamo-Acusa is different to the ones from settlement sites (Table 4), which are mostly composed of seeds of *Malva* sp., *Chenopodium murale* and *Amaranthus* sp. (Morales 2010). These taxa are uncommon in or totally absent from the silos at El Álamo-Acusa, where we have recovered a large number of taxa that have not been previously identified in pre-Hispanic domestic sites, such as *Spergularia fallax*, *E. regis-jubae* and *Fumaria* sp., among others. Harvesting techniques used by the pre-Hispanic population did not usually include weeds, because ears

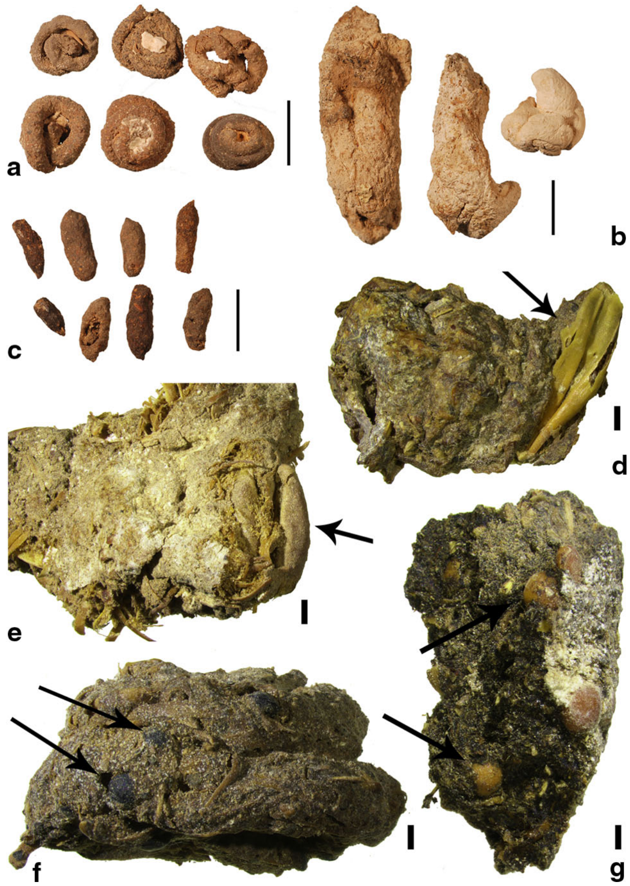


Fig. 8 Animal droppings from El Álamo-Acusa: **a** birds (cf. Columbidae), **b** birds (cf. *Turdus* sp.), **c** rat/lizard (*Rattus* sp./*Gallotia stehlini*), **d** bird dropping with *Hordeum* grain, **e** indeterminate dropping with *Triticum* grain, **f** bird dropping with *Chenopodium murale* seeds, **g** bird dropping with *Ficus* seeds; scale 10 mm (*thin bar*) and 1 mm (*thick bar*)

were mostly collected individually, so we conclude that the wild plants in the silos at El Álamo-Acusa should not be considered as ancient remains, but modern intrusions. Nevertheless it is possible that some weeds were ancient remains stored in the silos with the crops, but always as a minor component of the crop plants stored there (see "Harvesting", below).

Ancient stores

In spite of these problems of contamination by modern intrusions, radiocarbon dates on *Hordeum*, *Triticum*, *L. novocanariensis* leaf and *S. granarius* remains (Table 2) confirm that some of the finds were the remains of the plants originally stored in the silos. This is certainly the case for cereals and *L. novocanariensis* leaf, and we assume that this could be the same for the pulses, *V. faba*, *Lens* and *Pisum*, *Ficus* and the gathered wild plants *P. canariensis* and *Ph. canariensis*.

For cereals, the remains consisted of rachis segments and articulated hulls, with seeds and culm nodes being scarce. Recovery of basal rachis segments still attached to the straw suggests that whole ears were stored in the silos. Identification of culm nodes also points to the presence of some cereal straw. The ratios of rachis segments to seeds for both *Hordeum* and *Triticum* are high (Table 5), since only two complete grains were found. Ratios of rachis segments to grains are a useful way of showing whether a crop represents a by-product, a final product, or complete ears (Van der Veen 2007). High ratio values at El Álamo-Acusa suggest that these samples may be characterized as a by-product from early processing stages (Van der Veen 2007). However, as we have stated previously, articulated sets of *Hordeum* hulls showing holes made by beetles and the presence of grains and hulls in the animal droppings indicate that the small number of complete grains found in the silos does not represent the original quantity stored there. The occurrence of *Sitophilus granarius* in all the silos indicates that grain was indeed stored there, since it only develops and feeds on cereal grains (Plarre 2010). Animal droppings also contained grains and hulls, confirming that seeds were originally present in the silos.

Therefore, the cereals in the silos at El Álamo-Acusa represent the remains of ancient stored foodstuffs. We postulate that complete cereal ears were initially stored in the silos, and that when the site was abandoned, some of the ears were still left there. Later, insects and animals ate the seeds and left only the unpalatable parts, such as the rachis segments or the hulls and glumes. This hypothesis may explain the absence of grains and the presence of chaff. Alternatively, this assemblage could also be interpreted as the remains of fodder, for chaff was commonly used to feed domestic animals; but we think that the inaccessible location of the granary, the occurrence of grains in the animal droppings, and the high numbers of grain weevils in the silos all point to the storage of grains for human consumption.

In the case of pulses, we assume they are part of the original content of the silos because these three species are common in pre-Hispanic settlement sites in Gran Canaria (Table 4; Morales 2010, p 147). Most pulse remains were composed of detached hila and fragments of the testa, but no cotyledons were found except the lentils inside the pod. As with the cereals, this is probably due to the actions of beetles and animals, which had eaten the seeds and left the most unpalatable parts.

Ficus remains, also common in domestic sites (Morales 2010, p 161), were extremely abundant in the samples and they included a large number of seeds as well as fruit fragments and peduncles. We assume that figs were originally stored as complete fruits, but later insects and animals consumed most of them. We could only find one complete fig, but this also showed holes made by insects (Fig. 5),

Table 4 Numbers of crops and wild plant remains in archaeological sites from Gran Canaria (Morales 2010), including ancient and modern remains from El Álamo-Acusa; given are numbers of seeds unless otherwise noted

	La Cerera	El Tejar	Ermita de San Antón	Lomo los Melones	Cueva Pintada	Lomo los Gatos	El Álamo-Acusa
Site type	Cave dwelling	Ritual dwelling	Kitchen midden	Dwelling food proc.	Village dwelling	Midden	Granary
Preservation	charred	charred	charred	charred	charred	charred	desiccated
Age cal BP	1,650 ± 40 1,370 ± 40	1,280 ± 80 640 ± 40	920 ± 70 750 ± 50	710 ± 40 560 ± 40	610 ± 40 430 ± 40	450 ± 40 430 ± 40	980 ± 30 540 ± 30
Sediment volume (l)	780	617	69	491	737	207	14
Seed density (l^{-1})	1.17	0.21	1.42	5.86	4.59	2.38	836.85
Cultivated plants							
Hordeum vulgare ssp. *vulgare,* grain	880	92	17	212	1,465	245	2
H. vulgare ssp. *vulgare*, rachis	3	3	2	4	90	.	5,795
Triticum aestivum/durum, grain	2	3	2	3	216	49	2
Triticum durum, rachis	.	.	.	.	1	.	403
Cereal node	.	.	.	.	1	.	7
Lens culinaris	1	.	21	.	7	.	61
Pisum sativum	1	.	.	.	3	.	1
Vicia faba	.	.	.	.	2	.	14
Ficus carica, seed/fruit fragment	25/	32/	53/	2,658/	1,581/1	108/9	4,458/8
Wild gathered plants							
cf. *Adenocarpus foliolosus*	.	.	.	.	1	.	.
cf. *Laurus novocanariensis*	.	.	.	.	.	.	3
Neochamaelea pulverulenta	.	.	3	.	3	3	.
Phoenix canariensis	2	3	.	1	2	21	4
Pinus canariensis	.	.	.	.	.	.	8
Pistacia atlantica	.	1	.	.	1	.	.
Plocama pendula	.	.	.	1	.	55	.
Retama rhodorhizoides	.	.	.	.	1	.	.
Rubus sp.	.	.	.	.	1	.	.
Visnea mocanera	.	.	.	3	4	3	.
Weeds							
Aizoon canariense	.	.	.	2	14	.	8
Ajuga iva	.	.	.	12	.	.	.
Amaranthus sp.	1	.	1	6	650	1	.
Anagallis arvensis	.	.	.	1	33	.	16
Apiaceae	.	.	.	.	.	.	24
Asphodelus sp.	.	.	.	.	2	.	.
Asteraceae, seed/flower head	3/	.	.	.	5/	.	93/2
Atriplex sp.	.	.	.	3	1	1	.
Avena sp., spikelet	.	.	.	.	1	.	2
Bituminaria bituminosa	.	.	.	.	.	.	29
Boraginaceae	.	.	.	.	.	.	31
Brassicaceae	.	.	.	.	.	.	55
Bromus sp.	.	1	.	.	.	.	5
Calendula arvensis	.	.	.	.	.	.	23
Chenopodium murale	.	1	.	8	237	7	28
Emex spinosa	.	1	.	.	.	.	1
Euphorbia regis-jubae	.	.	.	.	.	.	73
Fumaria sp.	.	.	.	.	.	.	20
Galium sp.	.	1	.	.	3	.	2
Heliotropium ramosissimum	.	.	.	26	.	.	.
Hippocrepis sp.	.	.	.	.	.	.	1
Linum sp.	.	.	.	.	1	.	.
Lathyrus clymenum	.	.	.	.	.	.	1
Malva parviflora	7	12	44	10	255	4	10
Medicago sp., fruit	.	.	.	.	.	.	2
Mesembryanthemum nodiflorum	.	.	.	.	54	.	.
Opuntia sp.	.	.	.	.	.	.	73
Oxalis pes-caprae, tuber	.	.	.	.	.	.	10
Patellifolia patellaris	.	.	.	1	.	5	.
Phalaris sp.	2	1	.	1	131	.	26
Plantago sp.	.	1	.	1	15	.	15
Poaceae	.	.	.	.	3	.	20
Raphanus raphanistrum, pod	.	.	.	.	.	.	43
Rumex sp.	2	1	.	.	4	.	5
Sherardia arvensis	1	.	.	.	7	1	12
Silene gallica	2	2	.	9	85	1	60
Silene vulgaris	.	.	.	.	8	.	8
Silybum marianum	.	.	.	.	.	.	20
Sisymbrium sp.	.	.	.	.	21	.	48
Small seeded legume	3	.	1	15	15	6	73
Solanum alatum/nigrum	.	1	4	3	31	.	5
Solanaceae	.	.	.	.	.	.	9
Spergularia fallax	.	.	.	.	.	.	172

Table 5 Ratios of main plant components at the silos from El Álamo-Acusa (*according to Van der Veen 2007); "−" not enough values for calculating ratios; "+" values of ratios near 0; "^" grain refers to set of hulls

Silo	1	2	3	4	5	6	8	9	10	11	12	AC	SS	Total	Interpretation
Hordeum, rachis segments/grains^	0.5	4	11	3	12	8	9	21	6	10	100	22	2	6	by-product from early processing stage*
Triticum, rachis segments/grains	-	2	179		8		16	4	25	89	28	16	42	206	by-product from early processing stage*
No. of crop items/l sediment	71	312	2,440	1,621	241	109	671	90	750	2,243	1,540	505	1,348	852	rapid/single deposition*
No. of insects/grains^	+	2	+	+	2	2	0.5	18	0.5	0.5	7	8	0.5	0.5	spoiled grain

which had eaten the flesh of the fruit but left the seeds and peduncles, which are hard and unpalatable. Fruit fragments were only present in a few silos, while seeds were common in all them.

In relation to wild gathered plants, *L. novocanariensis* leaf fragments were radiocarbon dated to cal. AD 1030–1210, confirming that this plant was originally stored in the silos. In addition, this tree mainly grows in the laurel forest on the northern side of the island, several kilometres distant from the granary.

For *P. canariensis* and *Ph. canariensis*, there are both archaeological and ethnohistorical records for the consumption of these plants by the pre-Hispanic population of the Canaries that suggest that they belonged to the food stores (Morales 2010; Morales and Gil 2014). In addition, we have identified fragments of cone scale and rachilla, which suggest that whole pine cones and bunches of palm dates were brought to the silos, which are too large and heavy to have been introduced by birds, rats or lizards.

In any case, we cannot be sure that all these remains are ancient and it is possible that some of the plants mentioned above are modern intrusions, especially in the case of pulses and wild plants since they have not been radiocarbon dated. However ongoing work in other granaries of Gran Canaria seems to confirm this same set of plants in most of the silos.

Plant remains in silos compared with plant remains in settlement sites of pre-**Hispanic** Gran Canaria

These results from El Álamo-Acusa are important for a better understanding of how the harvesting, storage and processing of crops were carried out in pre-Hispanic times. We are now able to compare macro-botanical assemblages from settlement sites with the ones from granaries, and to study the links between both types of sites. However, we must consider that preservation conditions and sampling are not consistent between sites, and conclusions resulting from this comparison are thus limited.

Although the range of plants is not homogeneous in all the silos, it is characterized by the presence of cereals, pulses, figs and wild plants in almost every one (Fig. 9). As we have stated previously, there is a moderate negative correlation ($r = -0.304$) between the amount of crops in each silo and the volume of animal droppings, suggesting that differences in the numbers of plants are the result of animal activities, among other reasons. *Hordeum* is the most common plant, constituting 51 % of the total if only rachis segments are considered, and it is present in all the samples. *Ficus* is also very frequent, with 40 % of the total, and it has been recovered from all the samples. However, figs are mostly preserved as seeds and they cannot be directly compared to cereals, since one fig may contain hundreds of seeds. These data suggest that these two food plants were the most important crops, even though we must keep in mind that *Ficus* may be overrepresented. Conversely, *Triticum*, pulses and wild plants are not so frequent and they have not been identified in each silo. These results indicate that cereals, pulses, figs and wild gathered plants were stored in the same silos simultaneously, probably in baskets or other containers of plant material, as remains of the former have been found abundantly in other pre-Hispanic sites (Morales 2003). It is also possible that cereals and pulses were grown simultaneously, and were harvested and stored together.

We think the first hypothesis is more plausible, as the pattern of crops in silos is similar to the assemblages of charred macro-botanical remains collected from dwelling and cooking structures in settlement sites in Gran Canaria (Morales 2010). Analysis carried out at several sites on this island that are dated between the 4 and 15th century AD indicates that *Hordeum* and *Ficus* are the most frequent plant remains (Morales 2010). *Triticum*, pulses and wild plants are rare at these sites, and they are present in similar proportions to the range of plants identified from the silos at El Álamo-Acusa, in spite of different preservation conditions (Table 4). These data are confirmed by ethnohistorical texts, which emphasize *Hordeum* and *Ficus* as the staple foods of the indigenous population of Gran Canaria at the time of European contact (Abreu-Galindo [1602] 1977; Morales-Padrón [1500/1525] 1993), and also by dietary studies on human bones that show important skeletal markers of high carbohydrate food intakes (Delgado-Darias et al. 2005).

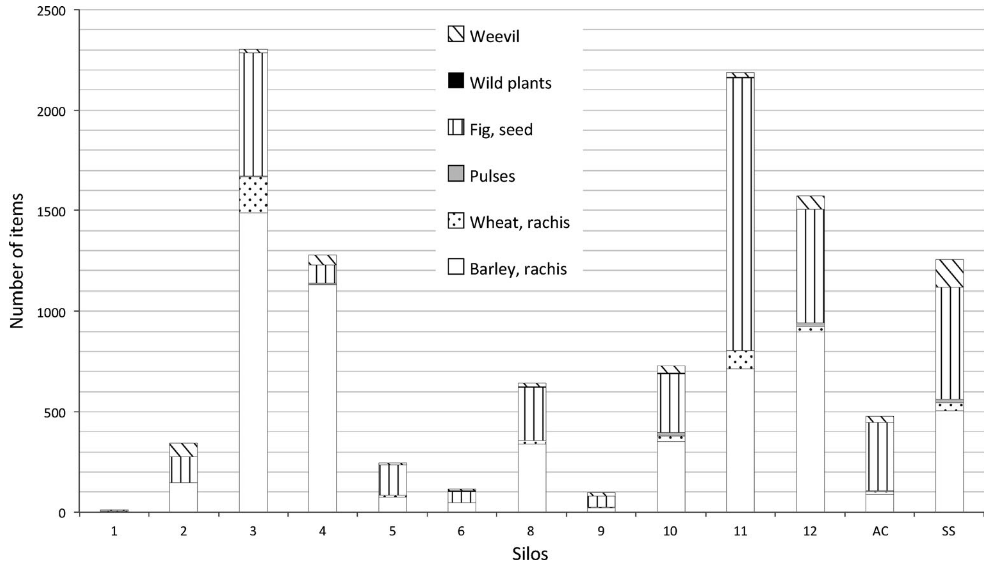


Fig. 9 Graph showing the frequency of main ancient plant components from the silos at El Álamo-Acusa. For cereals, only rachis segments are recorded, and for figs only seeds/ endocarps are recorded (*AC* adjacent cave, *SS* stone structure)

However, we must point to the fact that in domestic sites from Gran Canaria few rachis segments of *Hordeum* and *Triticum* are found, grains being the most frequently found (Table 4). Very little evidence of early crop processing has been found at settlements, and seed assemblages from there are interpreted as the result of fine-sieving and cooking activities (Morales 2010). Therefore, it is possible that cereals were mostly processed immediately after storage. This would have been carried out near the granaries but not in the granary itself, as there is no space for that. After being processed, cereal grains would have been taken to settlements in a semi-clean state, and this may explain the scarcity of chaff at these sites.

Processing of plants for long-term storage

Harvesting

The excellent preservation of cereal ears in El Álamo-Acusa allows us to study harvesting techniques during the pre-Hispanic period in detail. All ears show regular cut marks on the straw that are located at a similar distance (2–20 mm) from the basal rachis (Fig. 6). To get this accuracy, the ears were probably harvested individually in the fields or they were separated from the plant after the harvest. In 1602, Abreu-Galindo, a Spanish monk who recorded some pre-Hispanic customs, commented that cereal ears were reaped individually in the field and threshed with wooden sticks, leaving the rest of the plant in the ground to feed the domestic animals (Abreu-Galindo [1602] 1977, p 160). This method is slower than other harvesting techniques, but it reduces grain losses between the fields and threshing yard, and it saves time during threshing and winnowing (Hillman 1985).

On the other hand, archaeobotanical assemblages from dwelling sites in Gran Canaria include cereal nodes and weeds. These remains do not support the hypothesis that ears were harvested individually in the field, for this technique would only result in remains of the ears, in the form of rachises, hulls, glumes and grains (Hillman 1984, 1985). We thus suggest that the pre-Hispanic population could also have harvested the cereals by uprooting the whole plant, which is a common technique in the Canaries nowadays (Morales 2010), especially in dry areas, and we have observed that weeds are frequently collected with crops, even plants with a prostrate or erect habit. In some cases, uprooted plants had a second harvest to separate the root from the rest of the plant, thus facilitating the threshing and reducing the number of stones on the threshing-floor (González-Urquijo et al. 2000).

Evidence from El Álamo-Acusa suggests that collecting the ears individually was the most common harvesting method for cereals, since basal rachises with cut marks are common in the samples. Weeds in the silos are considered to be modern intrusions, but we cannot rule out that some plants could have remained attached to the cereal ears, especially climbers such as *Galium* sp., *Fumaria* sp. and *Sherardia arvensis*. However, climbers are a minor component of the weed taxa from El Alamo-Acusa and other sites in Gran Canaria (Table 4). On the other hand, cereal culm nodes were also recovered from the silos, suggesting that people could have harvested the cereals by uprooting them and taking the whole plants to the granary. Culm nodes are rare, however, and consist of small sections of the straw only; these could have been put into the silos still attached to the basal rachis of the ears. We cannot exclude the hypothesis that some crops could also have been stored as semi-clean grains, including some weeds, but more studies will be necessary in order to test this, as pre-Hispanic harvesting methods seem to be complex and the evidence is still incomplete. We note that no trace of cereal cutting has been reported in use-wear analysis of stone tools from Gran Canaria. This is intriguing, as cut marks are clearly visible on the straw, but it is also true that use-wear analysis in Gran Canaria is currently limited to stones from only one settlement site, as granaries have not been sampled for this purpose so far (Rodríguez-Rodríguez 1998, 2009).

Processing plants for long-term storage

Storing cereals as ears had advantages for long-term storage as well. In this way, grains were naturally protected by the hulls and glumes. This method seems to be the same for pulses and wild fruits. We have found one entire pod of *Lens* and some indeterminate pod peduncles. Peduncles link the pod with the plant and usually remain attached to the pod when this type of fruit is harvested. Therefore, it is likely that pulses were stored in their pods to avoid insect infestation. It is worth remembering here that the lentils identified in the pod were the only undamaged ones from the silos at El Álamo-Acusa. However, pods were also consumed by the animals visiting the site, since most of the lentils were damaged and only detached hila were recorded.

In the case of figs, the whole fruits were stored. Ethnohistorical records by the first Spaniards confirm that pre-Hispanic people dried figs in order to store and use them all the year around (Abreu-Galindo [1602] 1977, p 161). For *Ph. canariensis*, the identification of rachilla fragments suggests that dates were stored still attached to the bunch. Like figs, ethnographic records of *Ph. canariensis* consumption in the recent past indicate that dates were dried and stored (Morales 2010, p 169). In the case of *P. canariensis*, the presence of seed scales indicates that the seeds were stored inside the cones. In order to collect pine nuts, cones are usually gathered while they are still closed and unripe (Lanner 1981). In this way seeds can be stored undamaged inside the cone for a long time. When it is time to consume the pine nuts, the cones are laid out in the sun or put in the fire, as low humidity causes the opening of the scales (Dawson et al. 1997). After this, pine nuts are eaten raw or are pounded to produce flour.

All the methods of storage that we have recorded aimed to protect the seeds. Pre-Hispanic people did not try to maximize the storage space in the silos by processing the harvest completely and eliminating the unpalatable parts of the food plants. Instead, they tried to store them in the way they naturally occur on the plant, although some plants were also stored after some kind of processing such as cleaning and drying. Unprocessed cereals are reported to store better, as hulls and glumes protect the grains, especially in hulled species (Alonso i Martínez 1999; Meurers-Balke and Lüning 1992; Sigaut 1988). *T. durum* grains are protected by a multilayered epidermis and are usually stored without chaff (Alonso i Martínez 1999; Meurers-Balke and Lüning 1992), but evidence from El Álamo-Acusa indicates that pre-Hispanic people tried to protect the grains as long as possible and stored *T. durum* with the glumes and still attached to the ear.

Insect infestation and insect repellents

Ethnohistorical accounts mention the frequent use of granaries by the indigenous people of Gran Canaria, emphasizing that cereals were stored in them for several years with no damage (Morales-Padrón [1500/1525] 1993, p 373). Recent molecular studies in desiccated archaeological *Triticum* grains recovered from the large site of Barranco de Guayadeque, Gran Canaria, which includes dwellings, cemeteries and granaries, have confirmed the preservation of ancient DNA in the seeds, underlining the extremely good quality of pre-Hispanic storage techniques (Oliveira et al. 2012).

However, infestation by weevils is one of the main problems in the long-term storage of grains. It has been estimated that before chemical insecticides were used systematically, weevils damaged around 10–20 % of the stored grain, and in certain conditions they could spoil the whole harvest (Buckland 1990). This was a common problem in the El Álamo-Acusa silos, as is proved by the state of preservation of *Hordeum*, which in most cases only leaves the hulls remaining, as well as the presence of *Sitophilus granarius* in the samples. Granary weevil is one of the most common insects infesting stored grains in the Old World (Buckland 1990; Panagiotakopulu 2001) and it is especially important since it is completely synanthropic and only lives and reproduces on grains stored by humans, as it is unknown in the wild (Plarre 2010). It is understood that *S. granarius* spread with domesticated plants from the early Neolithic period, but there is no agreement about its place of origin (Plarre 2010). It has been identified at Neolithic sites in Germany and Macedonia (Büchner and Wolf 1997; Hubbard 1979), and more abundantly in Pharaonic Egypt (Panagiotakopulu 2001) and Bronze Age Crete (Panagiotakopulu and Buckland 1991). Remains from El Álamo-Acusa are the first occurrence of *S. granarius* in the Canary Islands. Therefore it is quite probable that this grain pest was brought there by the first colonizers, who introduced these beetles with their cereals.

In order to keep weevils away from the stored grains people have traditionally used several inorganic products such as sulphur, natron or salt, but it is also common to use certain plants to dispel or kill the insects (Lefébure 1985; Panagiotakopulu et al. 1995). These insecticide plants are characterized by having strong smells and tastes, such as

Coriandrum sativum (coriander), *Allium cepa* (onion), *Ruta graveolens* (rue) and *Laurus nobilis* (bay laurel) among others, but none of them have been identified in archaeological stores so far (Panagiotakopulu et al. 1995). From the silos at El Álamo-Acusa we have recovered fragments of cf. *L. novocanariensis* leaves that we interpret as a result of the use of this plant to repel insects from the grain. Radiocarbon dates on leaf fragments indicate that *L. novocanariensis* was part of the original content of the silos and ethnobotanical data confirms that it was used for this purpose until recently (Rodilla et al. 2008). Biochemical analyses indicate that oils present in the leaves inhibit the feeding of insects, are a strong antifungal agent, and also inhibit seed germination (Rodilla et al. 2008). These properties are very useful for the long-term storage of grains as they repel insects and keep the seeds in dormancy.

Finally, one might argue that these plants were not successful in repelling the insects, as weevils were quite common in the silos. But we think this is also because the granary was abandoned and the maintenance of silos neglected. The fumigant action of repellent plants decreases after a short time and needs repetition in order to maintain its toxicity (Rajendran and Sriranjini 2008). Radiocarbon dates suggest that the granary was used until the 15th century AD and this is the time when the Spaniards conquered Gran Canaria and the pre-Hispanic society collapsed. Dates from Silo 12 (*S. granarius*) and Silo 8 (*L. novocanariensis*) are slightly earlier than *Hordeum* and *Triticum* remains from silos 3 and 4. Silo 12 and 8 are closer to the cliff and access to them is difficult and risky, so it is possible that people stopped using these silos earlier. Nevertheless, it is quite likely that samples from silos 3 and 4 at El Álamo-Acusa belong to the last stores in this granary.

Conclusions

The Canary Islands and northwest Africa are both semi-arid regions where the rains are often irregular and failed harvests are common during dry years. Long-term storage was thus an essential practice to cope with bad years. In order to protect their food reserves, pre-Hispanic people in Gran Canaria built communal granaries in inaccessible or fortified places, and stored their food in silos carved into the volcanic tuff rock.

This study shows that in spite of the presence of some modern plants, pre-Hispanic silos still retain part of their original content, that is, the remains of ancient stored foods. Radiocarbon dates indicate that the communal granary of El Álamo-Acusa was used at least between AD 1000 and 1500. The silos contained cereals, pulses, and both cultivated and wild fruits that were stored with the natural protection of hulls, pods and floral structures. The identification of grain weevils and insect repellent plants in the same contexts suggests that these beetles were a serious problem in long-term grain storage. However, the excellent preservation of the plant remains indicates that storage techniques were outstanding and this was stated by the first Europeans who arrived in the archipelago, who pointed out that seeds were preserved in pre-Hispanic silos for several years and decades. This has also allowed the preservation of a unique archaeobotanical context that includes stored grains, weevils, and insect repellent plants.

Acknowledgments The research leading to these results has benefited from the Project HAR2010-19328 funded by the Ministry of Economy and Innovation of Spain and from the project PROID20100180 funded by the Canarian Research Agency, Spain (ACIISI). The authors are very grateful to Rachel Ballantyne and Pedro Oromí for support in identifying the insect remains; to Aaron González-Castro and Manuel Nogales for identifying the animal droppings; to Marijke van der Veen, Ferran Antolín and Maureen Mulligan for assistance with an earlier draft of this article; and the reviewers for helpful comments on the manuscript. Our special thanks are reserved for Quico Urdiales and Alisios Actividades for support in the field work; Tibicena for preparing the planimetry of the El Álamo-Acusa granary site, and Jose Molina for support with statistics.

References

Abreu-Galindo J [1602] (1977) Historia de la conquista de las siete islas de Canaria. Goya, Santa Cruz de Tenerife

Acebes-Ginovés JR, León-Arencibia MC, Rodríguez-Navarro ML, Del Arco-Aguilar M, García-Gallo A, Pérez de Paz PL, Rodríguez-Delgado O, Martín-Osorio VE, Wildpret W (2010) Pteridophyta, spermatophyta. In: Arechavaleta M, Rodríguez S, Zurita N, García A (eds) Lista de especies silvestres de Canarias. Hongos, plantas y animales terrestres 2009. Gobierno de Canarias, Tenerife, pp 119–172

Adam A (1978) L'agadir berbère: une ville manquée? Revue de L'Occident Musulman et de la Méditerranée 26:5–12

Alonso i Martínez N (1999) De la llavor a la farina. Els processos agrícolas protohistòrics a la Catalunya occidental. (Monographies d'Archéologie Méditerranéenne 4) UMR 154 du CNRS, Lattes

Arnay-de-la-Rosa M, Gámez-Mendoza A, Navarro-Mederos JF, Hernández-Marrero JC, Fregel R, Yanes Y, Galindo-Martín L, Romanek CS, González-Reimers E (2009) Dietary patterns during the early pre-Hispanic settlement in La Gomera (Canary Islands). J Archaeol Sci 36:1,972–1,981

Baiges JC, Espadaler X, Blanché C (1991) Seed dispersal in W Mediterranean *Euphorbia* species. Botanika Chronika 10: 697–705

Bazzana A (1996) Un *hish* valenciano: Shûn (Uxó) en la Vall d'Uixó (Castellón). Quaderns de Prehistòria i Arqueologia de Castelló 17:455–475

Bokbot Y, Cressier P, Delaigue M-Ch, Izquierdo R, Mabrouk S, Onrubia-Pintado J (2002) Enceintes refuges, gréniers fortifiés et qasabas: fonctions, périodisation et interprétation de la fortification en milieu rural présaharien. In: Ferreira Fernández IC (ed)

Mil anos de fortificações na Peninsula Iberica e no Magreb (500–1500). Actas do Simpósio Internacional sobre Castelos (Palmela 2000). Edições Colibri, Lisboa, pp 213–227

Büchner S, Wolf G (1997) Der Kornkäfer—*Sitophilus granarius* (Linné)—aus einer bandkeramischen Grube bei Göttingen. Archäol Korrbl 27:211–220

Buckland PC (1990) Granaries, stores and insects. The archaeology of insect synanthropy. In: Fournier D, Sigaut F (eds) La preparation alimentaire des cereals. Rapports présentés à la table ronde Ravello au Centre Universitaire pour les Biens culturels, 11–14 Avril 1988. (PACT 26) Rixensart, Belgium, pp 69–81

Cappers RTJ (2006) Roman food prints at Berenike: archaeobotanical evidence of subsistence and trade in the Eastern desert of Egypt. (Cotsen Institute of Archaeology, Monograph 55) Cotsen Institute, Los Angeles

Carretero MA, Roca V, Martín JE, Llorente GA, Montori A, Santos X, Mateos J (2006) Diet and helminth parasites in the Gran Canaria giant lizard, *Gallotia stehlini*. Revista Española de Herpetología 20:105–117

Cohen O, Plitmann U (1997) Dispersal strategies in the Apiaceae: the temporal factor and its role in dissemination. Lagascalia 19:423–438

Dawson C, Vincent JFV, Rocca AM (1997) How pine cones open. Nature 390:668

De Meulemeester J (2005) Granaries and irrigation: archaeological and ethnological investigations in the Iberian peninsula and Morocco. Antiquity 79:609–615

Delaigue MC, Onrubia-Pintado J, Amarir A (2006) Etnoarqueología de los graneros fortificados magrebíes: el agadir de Id Aysa (Amtudi, Marruecos). Etnoarqueología de la Prehistoria: más allá de la analogía. Treballs d'Etnoarqueologia 6:161–172

Delgado-Darias T, Velasco-Vázquez J, Arnay-de-la-Rosa M, Martín-Rodríguez E, González-Reimers E (2005) Prevalence of caries among the pre-Hispanic population from Gran Canaria. Am J Phys Anthropol 128:560–568

Despois J (1953) Greniers fortifiés de l'Afrique du Nord. Les Cahiers de Tunisie 1:38–58

Ferchiou S (1979) Conserves cerealières et role de la femme dans l′economie familiale en Tunisie. In: Gast M, Sigaut F (eds) Les techniques de conservation des grains à long terme, vol 1. CNRS, Paris, pp 190–197

Gil J (2011) Especies y variedades de plantas cultivadas tradicionalmente en la isla de Gran Canaria. Bases orales para su comprensión y estudio. AIDER, Gran Canaria

González-Reimers E, Arnay-de-la-Rosa M (1992) Ancient skeletal remains of the Canary Islands: bone histology and chemical analysis. Anthropol Anz 50:201–215

González-Urquijo JE, Ibáñez-Estévez JJ, Peña-Chocarro L, Gavilán-Ceballos B, Vera-Rodríguez JC (2000) El aprovechamiento de los recursos vegetales en los niveles neolíticos del yacimiento de los Murciélagos (Zuheros, Córdoba). Estudio arqueobotánico y de la función del utillaje. Complutum 11:171–189

Gutterman Y (1993) Seed germination in desert plants. Springer, Heidelberg

Gutterman Y (1994) Strategies of seed dispersal and germination in plants inhabiting deserts. Bot Rev 60:373–424

Hillman GC (1984) Interpretation of archaeological plant remains: the application of ethnographic models from Turkey. In: Van Zeist W, Casparie W (eds) Plants and ancient man: studies in palaeoethnobotany. Balkema, Rotterdam, pp 1–41

Hillman GC (1985) Traditional husbandry and processing of archaic cereals in recent time: the operations, products and equipment which might feature in Sumerian texts. Part II: the free threshing cereals. Bull Sumer Agric 2:1–31

Hubbard RNL (1979) Appendix 2: ancient agriculture and ecology at Servia. In: rescue excavations at Servia 1971–1973: a preliminary report. Ann Brit Sch Archaeol Athens 74:226–228

Lanner RM (1981) The pinon pine: a natural and cultural history. University of Nevada Press, Reno

Lefébure C (1985) Réserves céréalières et société: l′ensilage chez les marocains. In: Gast M, Sigaut F (eds) Les techniques de conservation des grains á long terme, vol 3. CNRS, Paris, pp 211–236

Louis A (1979) La conservation a long terme des grains chez les nomades et semi-sedentaires du sud de la Tunisie. In: Gast M, Sigaut F (eds) Les techniques de conservation des grains à long terme, vol 1. CNRS, Paris, pp 205–214

Maca-Meyer N, Arnay M, Rando JC, Flores C, González A, Cabrera V, Larruga JM (2004) Ancient mtDNA analysis and the origin of the Guanches. Eur J Hum Genet 12:155–162

Meunié J (1951) Greniers-citadelles au Maroc (deux volumes). Publications de l'Institut des Hautes Études Marocaines, Paris

Meurers-Balke J, Lüning J (1992) Some aspects and experiments concerning the processing of glume wheats. In: Anderson PC (ed) Préhistoire de l'agriculture: nouvelles approaches expérimentales et ethnographiques. CNRS, Paris, pp 341–362

Morales J (2003) Islands, plants and ancient human societies: a review of archaeobotanical works on the Canary Isles prehistory. In: Neumann K, Butler A, Kahlheber S (eds) Food, fuels and fields: progress in African archaeobotany. Heinrich-Barth-Institute, Cologne, pp 139–148

Morales J (2010) El uso de las plantas en la prehistoria de Gran Canaria: alimentación, agricultura y ecología. Cabildo de Gran Canaria, Gran Canaria

Morales J, Gil J (2014) Gathering in a new environment: the use of wild food plants during the first colonization of the Canary Islands, Spain (3–2nd BC to 15th AD). In: Chevalier A, Marinova E, Peña-Chocarro L (ed) Plants and people: choices and diversity through time. EARTH series, vol. 1. Oxbow, Oxford, pp 215-227

Morales-Padrón F [1500/1525] (1993) Canarias. Crónicas de su conquista. Cabildo Insular de Gran Canaria, Las Palmas de Gran Canaria

Newton C (2004) Plant tempering of Predynastic pisé at Adaïma in Upper Egypt: building material and taphonomy. Veget Hist Archaeobot 13:55–64

Oliveira HR, Civáň P, Morales J, Rodríguez-Rodríguez A, Lister DL, Jones MK (2012) Ancient DNA in archaeological wheat grains: preservation conditions and the study of pre-Hispanic agriculture on the island of Gran Canaria (Spain). J Archaeol Sci 39:828–835

Onrubia-Pintado J (1995) Magasins de falaise préhispaniques de la Grande Canarie. Viabilité et conditions de formulation d′une hypothèse de référence ethnoarchéologique. In: Bazzana A, Delaigue MC (eds) Ethnoarchéologie méditerranéenne, finalités, démarches et résultats. Casa de Velásquez, Madrid, pp 159–180

Onrubia-Pintado J (2003) La Isla de los Guanartemes. Territorio, sociedad y poder en la Gran Canaria indígena (siglos XIV–XV). Cabildo Insular de Gran Canaria, Las Palmas de Gran Canaria

Panagiotakopulu E (2001) New records for ancient pests: archaeoentomology in Egypt. J Archaeol Sci 28:1,235–1,246

Panagiotakopulu E, Buckland PC (1991) Insect pests of stored products from Late Bronze Age Santorini, Greece. J Stored Prod Res 27:179–184

Panagiotakopulu E, Buckland PC, Day P, Sarpaki A, Doumas C (1995) Natural insecticides and insect repellents in antiquity: a review of the evidence. J Archaeol Sci 22:705–710

Plarre R (2010) An attempt to reconstruct the natural and cultural history of the granary weevil, *Sitophilus granarius* (Coleoptera: Curculionidae). Eur J Entomol 107:1–11

Rajendran S, Sriranjini V (2008) Plant products as fumigants for stored-product insect control. J Stored Prod Res 44:126–135

Rodilla JM, Tinoco MT, Morais JC, Gimenez C, Cabrera R, Martín-Benito D, Castillo L, González-Coloma A (2008) *Laurus novocanariensis* essential oil: seasonal variation and valorization. Biochem Syst Ecol 36:167–176

Rodríguez-Rodríguez A (1998) Traceología de las obsidianas canarias. Resultados experimentales. El Museo Canario 53:21–58

Rodríguez-Rodríguez A (2009) Use-wear analysis on volcanic grainy rocks: problems and perspectives. The example of Canary Island material. In: De Araújo M, Clemente I (ed) Recent functional studies on non flint stone tools: methodological improvements and archaeological inferences. p 1–10. http://www.workshop-traceologia-lisboa2008.com

Rosenberger B (1985) Réserves de grains et pouvoir dans le Maroc précolonial. In: Gast M, Sigaut F (eds) Les techniques de conservation des grains à long terme, vol 3. CNRS, Paris, pp 237–268

Sigaut F (1988) A method for identifying grain storage techniques and its application for European agricultural history. Tools Tillage 6:3–32

Van der Pijl L (1982) Principles of dispersal in higher plants. Springer, Berlin

Van der Veen M (2007) Formation processes of desiccated and carbonized plant remains-the identification of routine practice. J Archaeol Sci 34:968–990

Van der Veen M (2011) Consumption, trade and innovation. Exploring the botanical remains from the Roman and Islamic ports at Quseir al-Qadim, Egypt. Verlag, Frankfurt

Velasco-Vázquez J, González-Reimers E, Arnay-de-la-Rosa M, Barros-López N, Martín-Rodríguez E, Santolaria-Fernández F (1999) Bone histology of prehistoric inhabitants of the Canary Islands: comparison between El Hierro and Gran Canaria. Am J Phys Anthropol 110:201–214

Velasco-Vázquez J, Martín-Rodríguez E, Alberto-Barroso V, Domínguez JC, León J (2001) Guía del patrimonio arqueológico de Gran Canaria. Cabildo Insular de Gran Canaria, Las Palmas de Gran Canaria

Zohary D, Hopf M, Weiss E (2012) Domestication of plants in the old world. The origin and spread of cultivated plants in West Asia, Europe and the Nile Valley, 4th edn. Oxford University Press, Oxford