Israel Journal of Plant Sciences
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tips20

Infested stored crops in the Iron Age I granary at Tel Hadar

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Published online: 22 Apr 2015.

Israel Journal of Plant Sciences, 2015
Vol. 62, Nos. 1–2, 86–97, http://dx.doi.org/10.1080/07929978.2015.1014261

Infested stored crops in the Iron Age I granary at Tel Hadar

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(*Received 11 August 2014; accepted 17 January 2015*)

Large quantities of charred seeds of field crops were found in a granary at early Iron Age (end of the eleventh century BCE) Tel Hadar, located at the eastern shore of the Sea of Galilee, Israel. They include mainly local naked wheat (*Triticum parvicoccum*), as well as bitter vetch (*Vicia ervilia*) and chickpea (*Cicer arietinum*) seeds. While the wheat was heavily infested by two major storage pest beetles – granary weevil (*Sitophilus granarius*) and a newcomer, the lesser grain borer (*Rhyzopertha dominica*) – the two pulses were much less infested. The presence of a large number of adults and larvae of *R. dominica* suggests that the granary was burned in mid or late summer. Seeds of the weed *Lolium temulentum* and several other weeds were also found.

Keywords: *Bruchus*; *Cicer*; Iron Age; *Palorus*; pest beetles; *Rhyzopertha*; *Sitophilus*; Tel Hadar; *Tenebroides*; *Tribolium*; *Triticum parvicoccum*; *Vicia ervilia*

Introduction

Tel Hadar, a small walled town and harbor, is located on the eastern shore of the Sea of Galilee (32°51′N, 35°39′E), in the long and narrow fertile strip of land that stretches between the Sea of Galilee and the Golan Heights. Its location, on one of the major routes from the Bashan to the Mediterranean coast, and its probable anchorage seem to be the major reasons for its prosperity during certain periods. The site was inhabited in the Late Bronze Age I and in Iron Age I and II (Kochavi 1989, 1996; Kochavi et al. 1992).

Six archaeological strata were excavated at Tel Hadar covering three periods: (1) the Late Bronze Age I (LB-I) (stratum VI) within the period of the sixteenth to fifteenth centuries BCE; (2) the Iron Age I (IA-I) (stratum V) in the twelfth century or early eleventh century BCE and continuing into the eleventh century BCE (stratum IV); and (3) the Iron Age II (strata III–I), ninth to eighth centuries BCE.

The nature of the settlement changed very much during its six phases of occupation. Stratum VI, the earliest phase of the settlement, was characterized only by several installations and silos. Still in stratum VI, during the LB-I occupation, but somewhat later than the earliest phase, Tel Hadar was a walled town, probably related to the political unit of Ashtarot. In stratum IV several public buildings were excavated, indicating that Tel Hadar was then a commercial center. In stratum III, the settlement was characterized by private buildings, suggesting that the site was part of the hinterland of Bethsaida that became the most important settlement of the region (Kochavi 1989, 1996; Arav 1995). However, the houses were not as dense as in strata II and I (Kochavi 1989, 1996; Kochavi et al. 1992).

Here I describe the crops found in a burnt early Iron Age granary excavated from stratum V that include mainly local naked wheat (*Triticum parvicoccum*), as well as bitter vetch (*Vicia ervilia*) and chickpea (*Cicer arietinum*). The wheat was heavily infested by two major storage pest beetles: granary weevil (*Sitophilus granarius*) and the lesser grain borer (*Rhyzopertha dominica*). Seeds of the weed *Lolium temulentum* and several other weeds were also found. The amount of grain finds, their excellent preservation and the rich weed and insect finds are unique for that period and allow a deep look into both the grain fields and storage of the early phase of the Iron Age.

Materials and methods

Large quantities of grains which had been stored in the Pillared Building complex at Tel Hadar were found in the granary. The site was excavated during the 1989 and 1991 seasons under the direction of the late Esti Yadin and the late Professors Pirchiya Beck and Moshe Kochavi from the Sonia and Marco Nadler Institute of Archaeology, Tel-Aviv University. It was dated by the pottery assemblage to the end of the eleventh century BCE and the culture belongs to the Iron Age I. The grains were excavated

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This paper has been contributed in honor of Professor Daniel Zohary

Table 1. Two subsamples, each 100 cc.

Plants							
Latin name	Organ	1	%	2	%	Total	%
Useful plants							
Triticum parvicoccum	Uninfested grain	**4320**	83.0	**1524**	79.1	**5844**	82.0
Triticum parvicoccum	Infested grain	**421**	8.1	**291**	15.1	**712**	10.0
Triticum parvicoccum	Rachis internode	**10**	0.2	**1**	0.1	**11**	0.2
Hordeum vulgare s.I.	Grain	**6**	0.1	**4**	0.2	**10**	0.1
Vicia ervilia	Seed	**2**		**28**	1.5	**30**	0.4
Linum usitatissimum	Seed			**4**	0.2	**4**	0.1
Weeds							
Lolium temulentum	Grain	**269**	5.2	**49**	2.5	**318**	4.5
Lolium rigidum	Grain	**124**	2.4	**6**	0.3	**130**	1.8
Cephalaria syriaca	Fruit	**26**	0.5	**16**	0.8	**42**	0.6
Bupleurum lancifolium	Fruit	**11**	0.2	**2**	0.1	**13**	0.2
Malva sp.	Seed	**5**	0.1	**1**	0.1	**6**	0.1
Vitex sp.	Fruit	**2**				**2**	
Phalaris sp.	Grain	**1**				**1**	
Bromus sp.	Grain	**1**				**1**	
cf. *Silene italica/rubella*	Seed	**1**				**1**	
Gramineae	Grain			**1**	0.1	**1**	
Unidentified	Seed	4	0.1			**4**	0.1
Total		**5203**	100	**1927**	100	**7130**	100
Pest insects							
Storage pests	Stage	1	%	2	%	Total	%
Rhyzopertha dominica	Adult	**32**	39.0	**6**	18.2	**38**	33.0
Rhyzopertha dominica	Larva	**44**	53.7	**25**	75.8	**69**	60.0
Rhyzopertha dominica	Pupa	**1**	1.2			**1**	0.9
Sitophilus granarius	Adult	**3**	3.7			**3**	2.6
Sitophilus granarius	Larva			**1**	3.0	**1**	0.9
Tenebroides mauritanicus	Larva	**1**	1.2			**1**	0.9
Tribolium castaneum	Adult			**1**	3.0	**1**	0.9
Tribolium castaneum	Larva	**1**	1.2			**1**	0.9
Total		**82**	100	**33**	100	**115**	100

in the field from a six-celled silo and an adjacent building for archaeobotanical processing. Many buckets with charred cereal seeds were excavated and because the bottom of the six-celled silo was covered by a thick layer of practically pure charred plant remains, there was no need for floating or sieving. Wood charcoals were picked manually, separated from the bulk of charred seeds and studied in another laboratory. A large sample of charred seeds was sent to the archaeobotanical laboratory, Faculty of Life Sciences, Bar-Ilan University, Ramat-Gan, Israel.

The largest quantity, about half a cubic meter, of charred threshed grains of small-grain naked wheat had been preserved in Cell 334. The fire there was so intense – about 1200°C – that it melted the wall bricks (Kochavi 1989). Small samples of that store were collected from the excavated seed bulk by hand. Most of the charred material was well preserved, enabling the identification of the crop plants, the weeds and the pest beetles (Table 1). In order to facilitate the processing, the charred material was first passed through a series of sieves with 2, 1, 0.5 and 0.25 mm mesh. The wheat grains were accumulated in the largest sieve, but most of the insect material was found in the smallest mesh sieves, partly because the adults were found incomplete. The largest store of wheat was infested by a variety of pest beetles that were identified by Dr D.G.H. Halstead, Old Windsor, UK. In addition to the charred archaeological materials, *R. dominica* beetles were raised in the laboratory for better understanding of its mode of wheat grain infestation.

Results

The large quantity of about half a cubic meter of seeds preserved in Cell 334 belonged to the small-grain naked wheat *Triticum parvicoccum*. Much smaller volumes of this wheat were found and sampled from the other six cells of the granary. In addition, seeds of flax (*Linum usitatissimum*, one cell), and two pulses – bitter vetch (*Vicia ervilia*, two cells) and chickpea (*Cicer arietinum*) in an adjacent building (one cell) – were found.

The wheat bulks were infected by weeds, mainly by darnel (*Lolium temulentum*, Figure 1), but also by Syrian scabious (*Cephalaria syriaca*), false thorow-wax (*Bupleurum lancifolium*) and a few other species, which are presented by small numbers (Table 1).

The largest store of wheat was also infested by a variety of pest beetles (Figures 2 and 3), mainly adults, but also larvae and pupae of the lesser grain borer (*Rhyzopertha dominica*, Figures 4–7), as well as by some adults and a few larvae of the granary weevil (*Sitophilus granarius*, Figure 8), red flour beetle (*Tribolium castaneum*) (including one larva, Figures 9–11), as

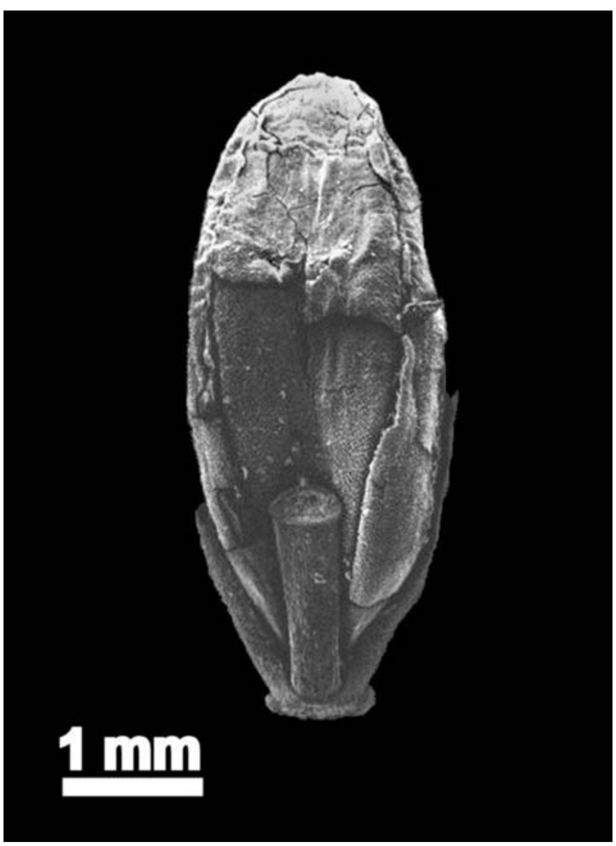

Figure 1. The weed *Lolium temulentum*, dispersal unit of a fertile floret, ventral view. The upper husk is partly covered on both sides by the margins of the lower husk. The rachilla node exhibits on its upper part the abscission zone from which the upper floret of the spikelet had been separated.

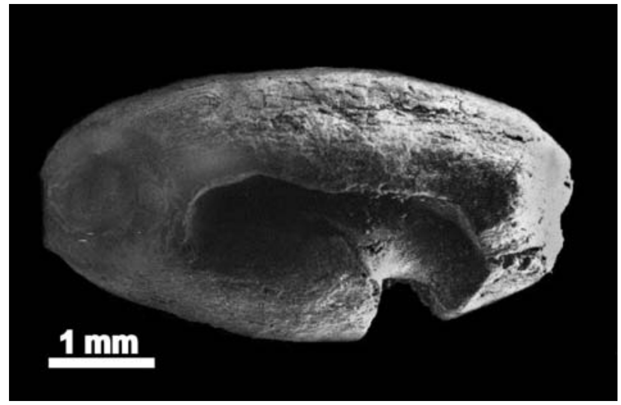

Figure 2. *Triticum parvicoccum*, charred grain, dorsal view. The deep tunnel and its exit are clearly seen. The embryo is well preserved.

well as small-eyed flour beetle (*Palorus ratzeburgii*, Figure 12) and cadelle (*Tenebroides mauritanicus*, Figure 13) as secondary pests (Table 1). In addition, a considerable amount of bitter vetch and some chickpea seeds were found to be typically holed by field weevil (*Bruchus* spp.) infestation.

Pest insect remains

*Lesser grain borer (*Rhyzopertha dominica*)*

The lesser grain borer belongs to the family Bostrichidae, which are principally wood borers, and is 2–3 mm long. Their brownish cylindrical bodies appear to be divided into two distinct parts by a constriction between the pronotum (the large dorsal plate of the prothorax, behind the head) and the elytra (the hard wings that cover the flying wings). When viewed from above (dorsal view), the head is completely covered by the pronotum, the front margin of which has numerous tubercules or projections

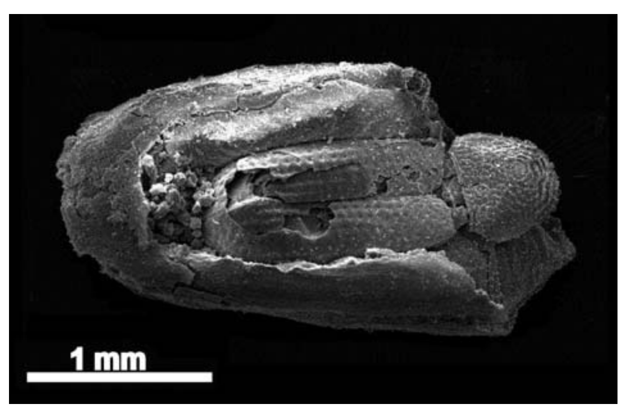

Figure 3. *Triticum parvicoccum*, charred grain infested by an adult of *Rhyzopertha dominica*, dorsal view. Most of the grain was consumed and tunneled by a larva. Part of a long tunnel is seen on the left side. Fecal pellets remained on two spots. The embryo side is damaged.

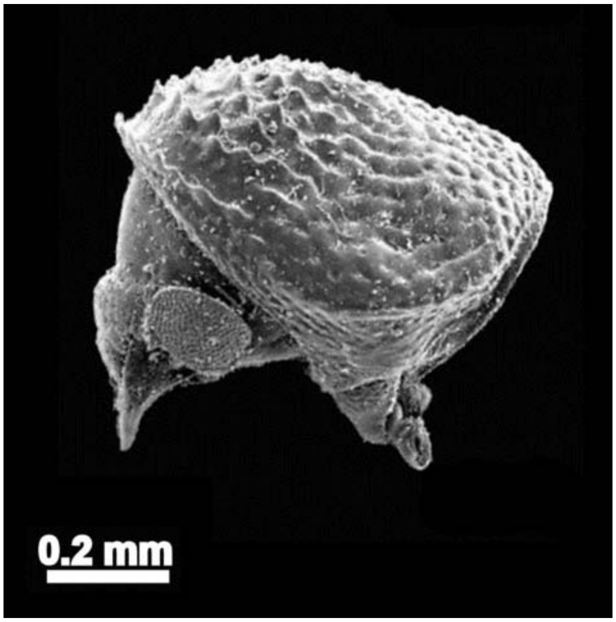

Figure 4. Prothorax and head of adult of *Rhyzopertha dominica*, side view. The front of the pronotum is covered by tubercules and small projections. The head is facing downwards, forming with the prothorax an angle of almost 90°. Head with compound eyes and pointed, strong mouthparts (mandibles). Part of the left foreleg is still preserved.

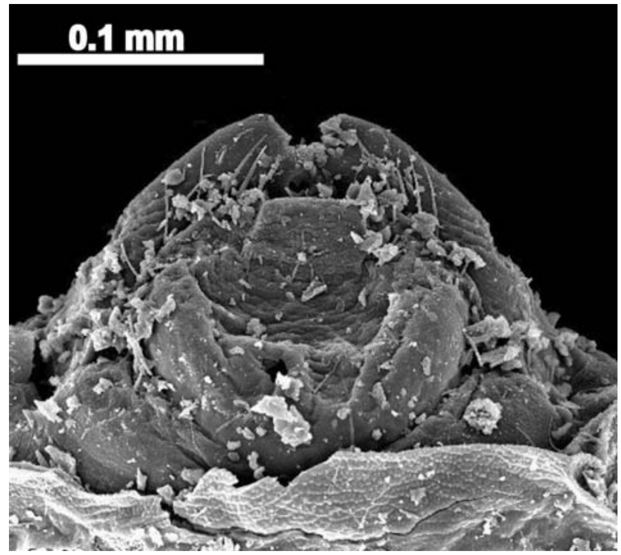

Figure 6. Head of *R. dominica* larva, magnification of Figure 5. The strong mouthparts supported by the hard head enable the boring within the wheat grain. Epidermis cells of the head and prothorax, and bristles of the mouthparts are seen. Small particles of the grain endosperm are scattered on the head surface.

(Figure 4). It has well-developed flight wings that enable the adults to migrate readily from one granary to another. The larvae are white and parallel-sided, i.e. they do not taper at the ends. They undergo 3–5 molts (generally 4). The head capsule is small relative to the size of the body (Figures 5–7). The pupa exhibits the characteristic depressed head and enlarged prothorax of the adult. Neither eggs nor young larvae, especially the first instar, could be found, apparently due to their small size.

R. dominica occurs mostly in tropical and subtropical regions of the world. The optimal conditions for its development are 34°C and 70% relative humidity. The minimum temperature for its infestation is about 20°C. However, it is exceptional in being able to develop on food with very low (14%) moisture content (Haines 1991, p. 25). The species has been found at other sites in Israel and elsewhere (Kislev 1991). Its origin appears to be tropical. Two records are reported from Tutankhamun's tomb and Amarna, Egypt, dated to the fourteenth century BCE, as well as from Kahun, dated to the nineteenth century BCE (Zacher 1937; Panagiotakopulu 1998, 2001; Panagiotakopulu et al. 2010). In Israel, the Beth-Shean single find dated to the Middle Bronze IIB (ca. 1750–1650 BCE) is hitherto the earliest record (Simchoni et al.

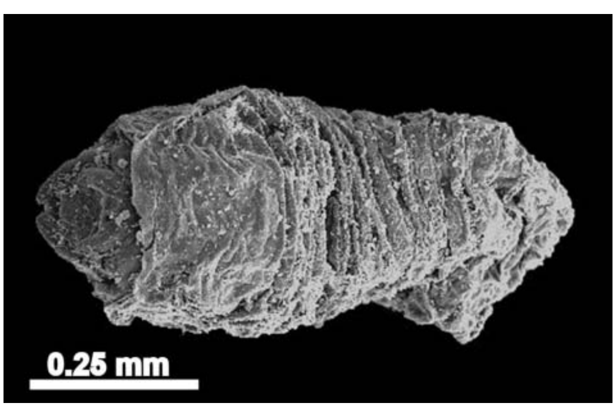

Figure 5. Larva of *R. dominica*, third instar, dorsal view. Behind the head (on the left), the large prothorax and the segmented body can be observed.

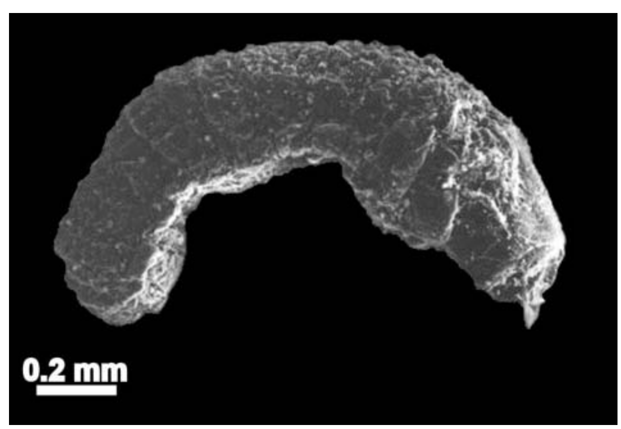

Figure 7. Larva of *R. dominica*, fourth instar, side view. The curved body is characteristic to this stage. The head is on the right.

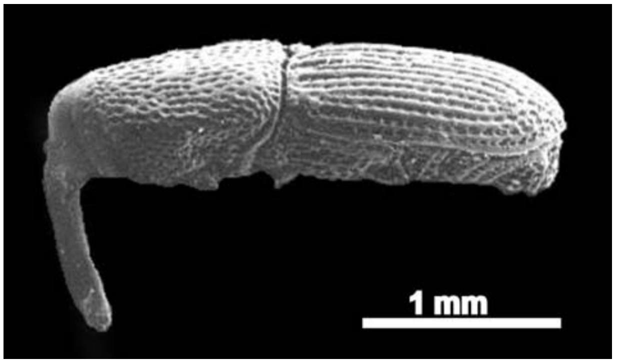

Figure 8. Adult of *Sitophilus granarius*, side view. The basal part of the head is spherical; the rest is elongated, with a small, curved fissure of the (missing) antenna. The rostrum is long and narrow, typical to females. The pronotum is covered by oval pits. The basal parts of the three pairs of legs were preserved. The large meso- and metathorax as well as the segmented abdomen are covered by the elytra.

2007). A later appearance in the archaeological records is a single specimen reported from Santorini dated to 1628 (or 1530) BCE (Panagiotakopulu & Buckland 1991).

*Granary weevil (*Sitophilus granarius*)*

Granary weevils, 3–4.5 mm long, are uniformly blackish to reddish beetles. The adults are long-lived, surviving from several months to one year. Like all members of the family Curculionidae, they are easily distinguished from other pests by their head capsule, which is elongated into a snout, with tiny but powerful mouthparts on the tip. The

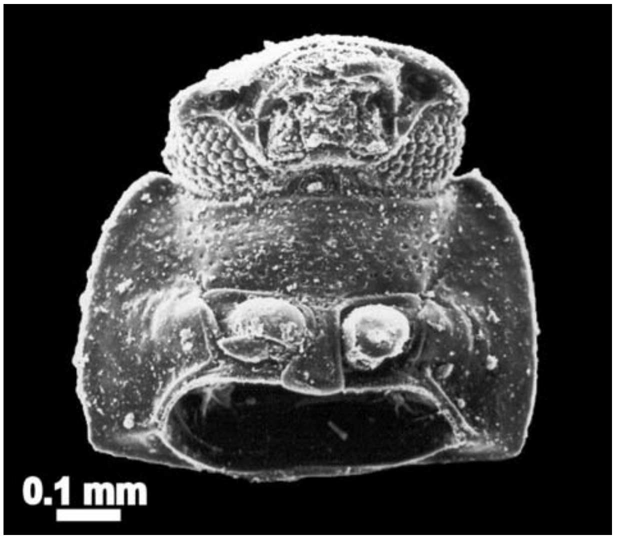

Figure 9. Head and prothorax of an adult *Tribolium castaneum*, ventral view. The width of each eye equals the distance between them. In front of the eyes are two cavities of the (missing) antennae. The mouthparts are median. Parts of both forelegs are preserved. The transverse cavity exhibits the connection to the (missing) hind part of the beetle.

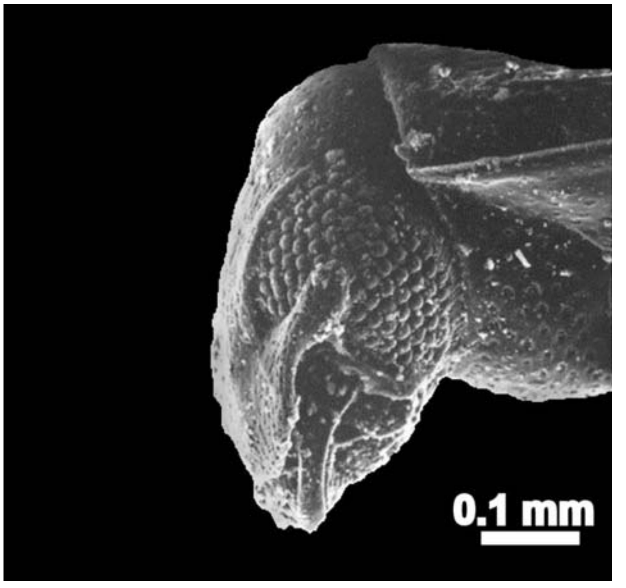

Figure 10. The same *T. castaneum* (Figure 9), side view. The head faces downwards, forming with the prothorax an angle of almost 90°. The large eye is U-shaped opening forewards, partly divided by the genal canthus. Below, mouthparts (left mandible) and the antenna cavity are seen one under the other.

pronotum of this species is characterized by its oval-shaped pits (Figure 8). They do not have functional wings.

The larvae are legless and the body tapers at both ends. The newly hatched larva usually tunnels towards the center of the wheat kernel until it reaches the crease which partly divides it lengthwise into two halves, then it tunnels back and forth along the crease. When granary weevil larvae are about half-grown they cut a passage through the crease and occupy the center of a wheat kernel. This is not the case with the two related major pests, namely rice weevil (*S. oryzae*) or maize weevil (*S. zeamais*), which rarely cross the crease.

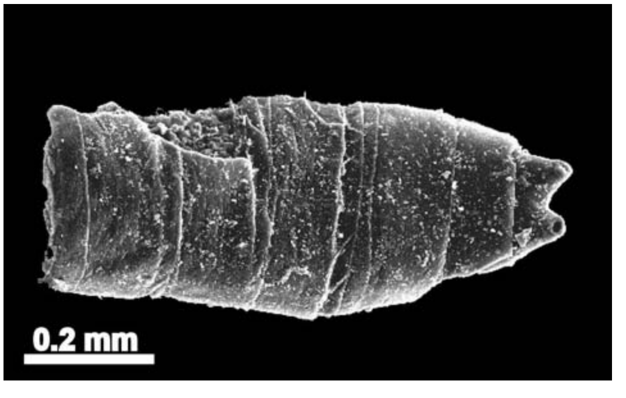

Figure 11. Early larval instar of *T. castaneum*, dorsal view. Only the abdomen is preserved, except the two fore segments. The urogomphi are partly broken. The larva was identified to this species because of the adult finds.

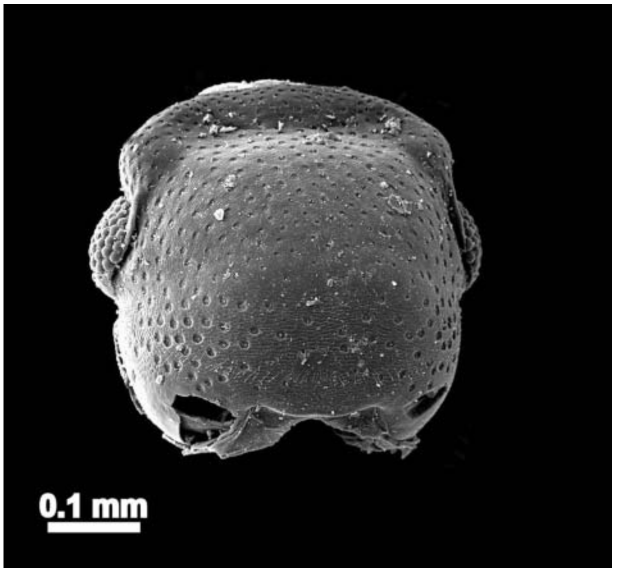

Figure 12. Head of an adult of *Palorus ratzeburgii*, dorsal view. Both small eyes can be observed. On top, parts of its mouthparts.

Granary weevils may complete their development from egg to adult in about five weeks. As each female is capable of laying several hundred eggs, an enormous increase in population is possible within a few weeks. Under less favorable conditions, however, this development period may be extended to several months.

S. granarius is distributed throughout the temperate regions of the world. The optimum conditions for its development are similar to those for tropical species: about 30°C and 70% relative humidity. However, it is successful in temperate regions because it can develop in temperatures down to 11°C (Haines 1991, p. 47). The species was reported from contemporary local archaeological sites, Ḥorbat Rosh Zayit and Ashkelon (Kislev & Melamed 2000; Weiss et al. 2011), from the Middle Age Canary Islands (Morales et al. 2014), as well as dating back to the Neolithic period (Kislev 1991; Kislev et al. 2004). In Israel its remains are found quite often, although today the species is very rare. The number of specimens (only three adults and a single larva in two of the samples) found in Tel Hadar, is almost 1/30 that of *R. dominica* (38 adults and 69 larvae, Table 1; see also Table 2).

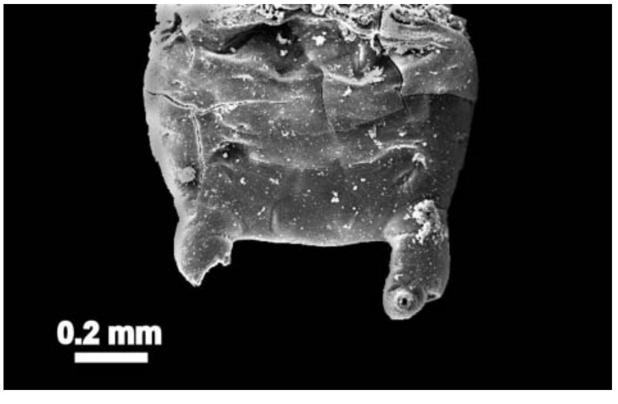

Figure 13. *Tenebroides mauritanicus*, two-tailed last abdominal segment of a larva (urogomphi), dorsal view. They are shorter and thicker than those of *Tribolium castaneum* (compare to Figure 11).

Table 2. One subsample, 1000 cc.

Pest insects			
Storage pests	Stage		%
Palorus ratzeburgii	Adult	**2**	1.1
Rhyzopertha dominica	Adult	**56**	30.3
Rhyzopertha dominica	Larva	**112**	60.5
Rhyzopertha dominica	Pupa	**6**	3.2
Sitophilus granarius	Adult	**6**	3.2
Tenebroides mauritanicus	Larva	**1**	0.5
Tribolium castaneum	Adult	**2**	1.1
Total		**185**	100

*Red flour beetle (*Tribolium castaneum*)*

The red flour beetle belongs to the family Tenebrionidae, is flat, reddish-brown, 2.3–4.4 mm long and has functional wings. It is readily recognized by its large U-shaped eyes which are partly divided into two halves by the expanded, horizontal side margins of the head (genal canthus; Figures 9, 10). In *T. confusum*, the related store beetle, the side margins divide the eyes almost completely. The larvae are typically tenebrionid, having a distinctly banded appearance, and possess two upwardly curved pointed projections (urogomphi) at the end of the body (Figure 11).

T. castaneum is capable of living on a wide range of commodities, especially flour but also on detritus of plant or animal origin. When it is a secondary pest on cereal grains, it has a preference for the embryo. To some extent it also feeds on other insects as a predator. It does not multiply rapidly on dry cereal grains if they are undamaged and free of grain fragments. It is thus considered to be a minor or secondary pest which is introduced only after the store had been infested by major pests. However, the species is one of the most abundant and destructive insects infesting flour and other prepared cereal products. Their populations may increase rapidly because the female deposits 400 or more eggs at a daily rate of 6–12 eggs. The progeny of a single pair could reach the staggering total of over one million in 150 days.

Apart from eating them, this pest also damages the grains by contaminating them with their dead bodies, cast skins and fecal pellets. In addition, the adults have odoriferous glands on the thoracic and abdominal segments, which secret a pungent, irritating liquid containing quinones (Haines 1991, 72f).

T. castaneum is thought to have originated in India, but is now found throughout all tropical, subtropical and warm temperate areas of the world. The species is known from a few archaeological sites in Israel and elsewhere (Kislev 1991; Kislev & Simchoni 2007). The earliest finds are from grains or flour dated to the Sixth Dynasty, 2300 BCE (*Tribolium* spp.) (Andres 1931 cited by Levinson & Levinson 1985) and in Tutankhamun's tomb in Egypt, dated to 1347–1336 BCE (Zacher 1937). The Tel Hadar find is the earliest in Israel.

*Small-eyed flour beetle (*Palorus ratzeburgii*)*

The small-eyed flour beetle (Tenebrionidae), 2.4–3.0 mm long, is so named because it has small eyes compared to other species of the genus (Figure 12). It is also recognized by the following characters: pronotum widest near the apex; and supra orbital carinae very strongly developed, distinct from apex to base of eye (Halstead 1967b). *Palorus* is rather similar to *Tribolium* in shape and behavior, but its eyes differ in that they are round and undivided by expanded side margins of the head. It infests stored wheat, wheat residues and various cereal products. They are not good flyers.

P. ratzeburgii belongs to the group of minor pests that include an appreciably larger number of species that may become damaging locally and occasionally may approach the status of a major pest. Frequently, large populations develop in grain or in cereal products which have deteriorated because of high moisture and poor sanitation (Halstead 1967a).

It has a cosmopolitan distribution, probably because it can develop under a wide range of temperatures and is tolerant of low humidity. Biological and systematic evidence indicate North Africa as being the area of origin. The under-bark habitat in Europe is reported as the natural one. Sometimes they recolonize the natural habitat by moving from stored products. Two adults were found at Tel Hadar (Table 2). The species is known from a few other archaeological sites in Israel and elsewhere (Haines 1991, p. 78; Kislev 1991; Kislev & Simchoni 2007). The Tel Hadar find is apparently the earliest one reported.

*Cadelle (*Tenebroides mauritanicus*)*

Cadelle (Trogossitidae), 5–11 mm long, is one of the largest insect pests that attack stored grain and its products. Its larvae burrow into the wood and structure of empty farm granaries and remain in their galleries until the arrival of newly harvested grain. Both adult and larval stages feed on stored products of plant and animal origins. It also eats the larvae and frass of other insects found at stored-grain facilities. The larva is characterized by two short horns (urogomphi) attached to the posterior end of the body (Figure 13) (Sinha & Watters 1985, p. 205). The larval remains of *Tenebroides mauritanicus* were also found at Iron Age Ḥorbat Rosh Zayit (Kislev & Melamed 2000).

*Field weevils (*Bruchus *spp.)*

Species of this genus belong to field pests rather than store pests. Field weevils of the family Bruchidae all feed on seeds, especially on those of Leguminosae. The females lay their eggs on the seed pod, to which they are firmly stuck. Upon hatching, the larvae bore into the pod and then into the seed and feed upon the cotyledons. They complete their development within a single seed. They are able to avoid the toxins present in the pod wall and seed coat by not ingesting them as they bore into the seed, so that all feeding takes place within the seed cotyledons. They prepare their point of eventual escape from the seed before pupation by chewing away at the cotyledon to leave an area of the seed testa as a window through which the adult can eventually push its way out. Most species have one generation in a year, and the damage they cause is restricted to that which takes place in the field before harvest and in the immediate post-harvest period. None of the species is able to multiply in store, and therefore they are never major storage pests.

A considerable number of bitter vetch seeds were infested by *Bruchus* in Cell 408. In addition, a few infested cotyledons of chickpea were found. It should be kept in mind that it is easier to detect infested seeds when they are charred rather than fresh. The missing seed coat, which is almost always removed in charred pulses, reveals the empty tunnel made by the larva when the adult escaped. Several species of *Bruchus* are important field pests of bitter vetch and chickpea (Haines 1991, 30f; Kislev 1991). The remains of a single beetle of *Bruchus* sp. was found in a grass pea (*Lathyrus sativus*) seed at Iron Age Ashkelon (Weiss et al. 2011). However, no actual insect remains of *Bruchus* were found here.

Discussion

Apparently, the granary's function was to store annual crops rather than fruits. It stored naked wheat, chickpea, bitter vetch and flax. Although the variety of crops stored is small, they represent most of the main field crops in the region at the time. Wheat was the most important, while pulses and flax were secondary. Some missing crops should be mentioned here, such as emmer (*T. dicoccum*), barley (*Hordeum vulgare*), lentil (*Lens culinaris*) and horse bean (*Vicia faba*). It is suggested that some of them had been stored elsewhere. The find of chickpea in the adjacent building may support this assumption.

The small-grain naked wheat (*Triticum parvicoccum*) is now an extinct wheat species found abundantly in archaeological sites in the Near East and the Mediterranean basin, and was the prevailing naked wheat in prehistoric and early historic times. It is assumingly tetraploid and the grain is characterized by its small dimensions. During the Roman period it was apparently replaced by macaroni wheat (*T. durum*), which has larger grains (Kislev 1980a). The common grain length in Tel Hadar is about 5 mm, but a considerable number of grains, especially in Cell 289, are smaller (2–3 mm). It seems that the smaller wheat grains can hardly support the normal development of the major pest's larvae. Indeed, a rather high level of infestation is evident in Cell 334, where 4.6%, 8.9% and 16.0% of infested wheat grains were observed in three 100 cc subsamples. Apparently, this is the earliest record of heavily infested wheat.

Chickpea (*Cicer arietinum*) is well recognized by its angular seeds, and especially by the blunt oblique point at one end formed by the radicle of the germ which is often found broken when charred. It is adapted to Mediterranean climate, and grows generally in the post-rainy season on moisture stored in the soil. The seed protein content is about 20%, and may constitute a meat substitute in peasant communities. It is rather commonly found in archaeological sites of the Near East since the Neolithic period (Zohary et al. 2012, p. 87).

Bitter vetch (*Vicia ervilia*) seeds are pyramidal-rounded with triangular planes. As its name implies, its seeds are bitter and toxic to humans, but the poisonous substance can be partly removed by soaking in water. Since the Iron Age this vetch has been utilized primarily as an animal feed, as it is regarded as very inferior for human consumption and is only eaten by the poor, or in times of famine (Kislev 1994; Zohary et al. 2012, p. 92). Some seeds which were infested by *Bruchus* are easily recognized by the typical chamber made by its larva.

Flax (*Linum usitatissimum*) seeds were also found. The seeds are oval, 4–6 mm long × 2–3 mm broad when fresh, lenticular in form and somewhat beaked at one end. The dimensions of 50 charred seeds from Cell 348 are 3.9–4.7 × 1.8–2.6 × 0.8–1.6 mm, 4.27 × 2.14 × 1.24 mm on average. The mature flax fruit is a rounded capsule which contains 10 seeds. In most cultivated varieties the capsule is almost completely indehiscent, and the seeds are released by threshing. Flax is cultivated today for two products: the oily linseeds, which contain 30–40% oil and about 20% protein (used for human and animal food and for technical purposes), and its stem bast fibers from which linen is manufactured. Both these important qualities were appreciated by humans from prehistoric periods onwards. Its remains are common in Levantine sites and elsewhere (Kislev et al. 2011). No insect damage was observed in this crop species.

Several weed species were identified in the wheat store. Darnel (*Lolium temulentum*) or rye-grass grains, covered by their persistent husks, imitate wheat grains in size and shape. They follow the crop during threshing, winnowing and sieving either into the kitchen or in seeds kept for sowing in the next year. It is interesting to note that among the very small wheat grains in Cell 289, the darnel grains were also considerably smaller. It is a particularly obnoxious weed because a fungus (*Alternaria lolii temulenti* or *Loliomyces temulentus*), which is toxic to humans and animals, is sometimes harbored under the seed coat. The fungus, when incorporated in wheat flour, can cause serious illness to those eating bread made from it. It is a common weed in traditional and ancient fields of the Near East, e.g. Tell Keisan dated to the Iron Age I, as well as of Europe, and favors calcareous soils in particular (Kislev 1980b, 1983).

More than 500 beetle species associated with stored products have been found over the world. Apart from the major pests, which are of considerable economic importance, many species regularly occur because they are general scavengers, predators or mold-feeders. Other species are found due to their association with wood, having come from dunnage, structural timbers, etc., and a few because they were harvested accidently with cereals and other crops (Haines 1991).

Insects usually have four clearly distinct stages in life: from egg through larva and pupa to adult. Typically, an insect egg hatches to produce a larva which is a worm-like, segmented animal usually with three pairs of minute legs at its front end. During development, larvae pass through stages called instars. In most cases the form of each instar differs little from that of the others except in size, although the first instar is usually distinguished from subsequent ones by the hatching spines known as egg-bursters. The segmental nature of the thorax (three segments) and the abdomen (10 segments, the tenth is perianal) is usually apparent. Frequently, a pair of dorsal spines or processes (urogomphi) is present in the last obvious (ninth) abdominal segment (Halstead 1967a). By passing their developmental life inside a kernel, the defenseless larvae are protected from most enemies, as well as from sudden changes in temperature and moisture.

The insect larva eats vigorously and grows rapidly. Most insects, such as beetles, at the end of their larval life turn into a rest stage called a pupa. Inside the pupa skin, the larva is largely broken down and dissolved into a more or less disorganized mass of cells. Their mass of cells is gradually formed into a new, complete adult insect with wings, six legs, distinct head, thorax and abdomen, and a pair of antennae and two large eyes on the head. The young of most insects are either smaller than the adults or very different in appearance (compare Figure 5 to Figure 4, and Figure 9 to Figure 11). The adult insect does not grow and, therefore, has very little need to eat. In fact, some adult insects do not eat at all, but the majority of them eat a little, particularly females when they lay a large number of eggs.

Rhyzopertha dominica, *Sitophilus granarius* and *Tribolium castaneum* belong to the 11 most destructive major pest beetles of stored grains in the world today. The latter feeds on a wide range of durable commodities, such as groundnuts, nuts, coffee, cocoa and dried fruits, and is found as a secondary pest on cereals, having a preference for the embryo. Under hot, dry conditions, *R. dominica* is able to develop at a much faster rate than *S. granarius*. However, the latter has a greater advantage under cooler, more humid conditions. Commodities infested by *R. dominica* rarely become moldy. It would seem that this species does not raise the moisture content of the food to the same extent as *S. granarius*, which can cause a considerable increase (Haines 1991, 24f, 47f, p. 194).

Benefits and hazards of grain storage

The various stored crops at Tel Hadar exhibit different types of damage caused by pest beetles. Cereals were infested by store pests, pulses by field pests, and flax seeds were undamaged. In the following lines mainly damage made by store pests is discussed.

Because grain production is seasonal and consumption is continuous, a safe storage place must be provided for the greater part of the grain produced until it is needed. Storage facilities take many forms, ranging from piles of unprotected grain on the ground, underground pits or containers, piles of bagged grain, to storage bins of many sizes, shapes and types of construction. Safe storage must maintain grain quality and quantity. This means protecting it from the weather, molds and other microorganisms, from the addition of moisture, destructively high temperatures, insects, rodents and birds, from objectionable odors and contamination, as well as safeguarding against theft and unauthorized distribution.

Good storage practices aim to maintain the conditions in the grain that will preserve its marketing and processing qualities at as high a level as possible. It can be maintained that destruction begins when storage begins, with the rate of quality loss depending on the storage conditions. If all outside contamination of grain in storage can be prevented, the destruction rate is slowest where the grain is coolest and driest, as the growth rate of insects depends mainly on temperature (Bailey 1982). The effects of grain storage on the milling properties of wheat have also been studied. The post-harvest maturation (and accompanying improvement) is about one to two months in wheat. In the maturation process, germinability, gluten strength and elasticity increase. These changes are accompanied by increased bread-making potential (Pomeranz 1982).

All cereal grains are relatively easy to store. Their value as a food for mankind rests quite largely on their prominence in storage. Furthermore, the success of agriculture depends on the durability of dry cereal grains. When a site or a whole region suffers from a shortage of cereals by the end of the season, there will be very little prolonged storage and the dry grains are unlikely to give any trouble. However, the need for perennial storage in order to smooth out fluctuations in supply from season to season may result in damaged grains.

Cereal grains are the dormant resting stage of the plant which bears them. Although they are alive, respire and produce heat, water and carbon dioxide, these processes are at a very low ebb. It is the combined effect of their continued life which enables them to resist decomposition by microorganisms, and the very low level of that life which makes cereal grains such pre-eminently stable bodies to store (Oxley 1948). Some optimists argue that whatever happens to grain in storage, it is never seriously damaged. This is because pest insects in a grain store are difficult to detect by ordinary inspection. Many insects which infest cereals spend part of their life within the grains. Moreover, some types of insect infestation develop deep in a bulk and may have done considerable damage by the time they come to the surface and are first noticed. Very often insects do not come to the surface until they are driven there by the heat which they have themselves caused (Oxley 1948).

Fortunately, only a few insects cause serious damage to seeds of cereal products in good condition. Stored-product insects may be divided into two groups: major pests and minor pests. Major pests comprise those species responsible for most of the insect damage to stored grains and their products. They are particularly well adapted to life in the stringent environment imposed by a bin of grain. There are a few species that develop inside kernels and comprise the “hidden infestation” in a grain mass. Weevils deposit their eggs inside the kernels; lesser grain borers deposit eggs outside the kernels into which their newly hatched larvae promptly tunnel. There is little evidence of their presence inside the kernels until they emerge as adult beetles; kernels appear to be sound and undamaged even though the germ, endosperm or both may have been consumed (Cotton & Wilbor 1982).

Insect damage usually takes the form of hollowing out of the grains by the larvae that live inside them until maturity. Apart from this direct damage there are less direct effects, such as webbing of the grains together into small bundles, contamination with dead and rotting larvae bodies and the production of very large quantities of dry excrement which appear as excessive dust. Both larvae and beetles produce an inordinate quantity of fecal pellets. Larvae inside the kernels push their pellets and some particles of starchy endosperm out of the kernels through their entrance holes so that in heavy infestation large quantities of fecal pellet dust accumulates in the grain mass. The pellets have a sweetish, musty odor that characterizes lesser grain-borer infestation (Oxley 1948).

Ecology of grain infestation

The development of pest insects in the special conditions of bulk grain follows different lines from those of free-living insects. The dominant features of a bulk of grain which are responsible for the special type of infestation which develops are the large size, the low thermal conductivity and the inter-granular humidity. In the course of development in bulk grain, insect infestation changes the environment in three ways:

(1) rise in temperature,
(2) change in humidity,
(3) production of carbon dioxide and reduction of oxygen concentration.

The development of an insect causes a rise in temperature which increases its rate, thus initiating a self-accelerating process from the moment that the infestation has established itself in the bulk. The higher temperature produced by the larvae hasten their own development. The size of the temperature rise will be closely related to the population density. Any slight difference in the original density or rate of laying eggs or in local conditions of humidity becomes enormously exaggerated and typical patchy development of infestation in pockets is produced (Oxley 1948). As long as the temperatures are just below the optima for development and metabolism, multiplication is most rapid at the thermal center of a developing infestation. Hence the temperature continues to rise to levels which are highly unfavorable to the insects (38−42°C). Because the larvae of grain pest beetles live within the grain, they are unable to leave an unfavorable region and eventually they die. The hot region is surrounded, however, by a falling temperature gradient in which ideal conditions for development are present. The ideal conditions are valid for humidity as well, as movement of water occurs from the hot center to the cooler periphery. In this region of ideal conditions, development is very rapid, so that rapid extension of the infested area is encouraged. This fact, coupled with the tendency for all free-living insects to migrate from excessively hot, dry conditions to cooler and damper regions, is probably a major factor in promoting the spread of infestations once they are well established. The grains are heated by the body heat of the larvae until most of them are killed. However, the remainders survive and are driven to the surface of the bulk where they appear very suddenly and unexpectedly (Oxley 1948).

Sampling of grain infestation

Good sampling of modern grain infestation is very important for economic reasons. Obtaining a sample truly representative of the lot of grain is an essential part of grain grading. If the sample obtained is not representative, no amount of care in making the determination for grading factors will establish the true grade for the lot involved. A representative sample is achieved by proper sampling technique, and correctly composing the subsamples and reducing them to the proper size for grading.

Grain conveyed in trucks is often sampled with a probe (trier). The compartmented portion of the probe, with the slots closed, is completely inserted in the grain at an angle of about 10° from the vertical. Then, with the slots facing upward, it is opened, moved up and down in two short motions so that all of the compartments are filled, then closed and withdrawn. The contents are then placed full-length on a sampling canvas. This procedure is repeated until the required number of probes from the appropriate locations in the trucks has been obtained.

Factors that determine grade in grain (dockage, foreign material, damage, and the like) are seldom evenly distributed. This is the basis of the major problems associated with sampling (Parker et al. 1982). To illustrate the difficulty of obtaining a representative sample for insect infestation in an ancient store, two samples of 100 cc (and one more sample of 1000 cc, merely for pests), each, taken from the small-grain wheat found in Cell 334, were processed for crop admixture, weeds, insect pests and insect damage (Tables 1, 2).

Conclusions

The presence of a large number of adults and larvae of *R. dominica* suggests that the population of the pest has increased rapidly during the summer. It is suggested, therefore, that the granary was burned in mid or late summer.

It is assumed that in the Bronze Age, especially in the warmer places, humans could cope with *S. granarius* which had been common and active in the Near East for millennia. A Biblical record of perennial storage comes from Egypt: “And he [Joseph] gathered up all the food of the seven years, which were in the land of Egypt, and laid up the food in the cities . . . And Joseph gathered corn as the sand of the sea, very much, until he left numbering, for it was without number” (Genesis 41, 48−49). *S. granarius* was known in Egypt already from the tomb of Queen Ichetis, in the Step Pyramid at Saqqara, dated to 2600 BCE (Howe 1972). This is not the case with *R. dominica*, which is rarely recorded there before the fourteenth century BCE (see above). It is suggested that Joseph succeeded to store corn for seven years because *R. dominica* had not yet established in the region. Alternatively, among the suggestions for pest control made in the Ebers Papyrus (ca. 1600 BCE) are thorough washing with an aqueous soda solution as well as the application of pest repellents such as cat and bird fat, as well as the ash of gazelle dung, to the grain containers and granary surface (Levinson & Levinson 1985).

The introduction and spread of *R. dominica*, *T. castaneum* and *P. ratzeburgii* to the region, which took place from the end of Middle Bronze to Iron Age I, produces evidence that humans have changed their concepts about insect infestation. At least, several cardinal facts connected with stored foods and food storing should be mentioned.

(1) The number of major pests was doubled. In the Iron Age I, a new pest, namely *R. dominica*, joined the old one, *S. granarius*. For the first time there is evidence that it was a major pest, because of the find of large numbers of adults and larvae, as well as the large number of infested grains.
(2) The newcomer pest has different abilities compared to the native pest, e.g. well-developed flight wings that enable its easy migration from one granary to another. Therefore, avoidance of self-infestation by moving crops from one granary to another could no longer help much.
(3) The two pest beetles require different ecological conditions for a rapid population increase and hence for causing severe damage. While *S. granarius* was more active in humid and cold seasons (winters) or regions, *R. dominica* developed faster in dry summers and/or in warm and dry regions. Therefore, it became impossible to store cereal grain safely, especially in dry and warm places, without taking the risk of sharing the food with beetles. Moreover, the threat of *R. dominica* to the economies of Egypt and other hot regions should be taken in consideration.
(4) It seems that the old tradition of storing crop grains in dry and warm conditions, which was effective against the damage of *S. granarius*, did not help when *R. dominica* was introduced. New devices should have been invented for keeping the food away from the pests. The infestation rate in Cell 334 exhibits that this was not the case at Tel Hadar.
(5) The introduction of *T. castaneum* apparently increased the range of commodities ready to be infested by pest beetles to flour, bread and all kinds of baked cereals. Therefore, it was no longer safe to store processed cereal foods for long times.
(6) The finds of *P. ratzeburgii* and *T. castaneum* among the wheat grains produce additional evidence that the store was infested for a considerable time. So, there is additional evidence that at least in this case humans probably did not succeed in avoiding the damage.

Fortunately for that period, stored pests of pulses were not known in our region. All kinds of pulses – chickpea and bitter vetch found in Tel Hadar, as well as local lentil and horse bean – could be stored for long periods without significant damage because they could not be infested by store pest beetles. The first evidence for their introduction (e.g. *Callosobruchus maculatus*) to the Near East and Europe is very late, at the end of the Middle Ages, probably when the routes and international trade to India became more popular (Kislev 1991).

Acknowledgments

Thanks to Dr Y. Langsam for his technical assistance in the SEM photographs, and to Dr Y. Melamed and M. Marmorstein for the help with the identifications.

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