

1 Unprecedented yet gradual nature of first millennium CE intercontinental
2 crop plant dispersal revealed in ancient Negev desert refuse

3 Daniel Fuks^{1*}, Yoel Melamed², Dafna Langgut,³ Tali Erickson-Gini⁴, Yotam Tepper^{5,6}, Guy
4 Bar-Oz⁶, Ehud Weiss²

5 ¹ McDonald Institute for Archaeological Research, Department of Archaeology, University of Cambridge,
6 Cambridge CB2 3ER, UK

7 ² Archaeobotany Lab, Martin (Szusz) Department of Land of Israel Studies and Archaeology, Bar-Ilan
8 University, Ramat-Gan 5290002, Israel

9 ³ Laboratory of Archaeobotany and Ancient Environments, Institute of Archaeology & The Steinhardt Museum
10 of Natural History, Tel Aviv University, Tel Aviv 69978, Israel

11 ⁴ Southern Region, Israel Antiquities Authority, Omer Industrial Park 84965, Israel

12 ⁵ Central Region, Israel Antiquities Authority, Tel-Aviv 61012, Israel

13 ⁶ School of Archaeology and Maritime Cultures, University of Haifa, Haifa 3498838, Israel

14 * Corresponding author: df427@cam.ac.uk

15 ORCiDs

16 DF: <https://orcid.org/0000-0003-4686-6128>

17 DL: <https://orcid.org/0000-0002-4824-1044>

18 GBO: <https://orcid.org/0000-0002-1009-5619>

19 EW: <https://orcid.org/0000-0002-9730-4726>

20 YT: <https://orcid.org/0000-0002-5564-1652>

21

22 *Abstract*

23 Global agro-biodiversity has resulted from processes of plant migration and agricultural
24 adoption. Although critically affecting current diversity, crop diffusion from antiquity to the
25 middle-ages is poorly researched, overshadowed by studies on that of prehistoric periods. A
26 new archaeobotanical dataset from three Negev Highland desert sites demonstrates the first
27 millennium CE's significance for long-term agricultural change in southwest Asia. This
28 enables evaluation of the "Islamic Green Revolution" (IGR) thesis compared to "Roman
29 Agricultural Diffusion" (RAD), and both versus crop diffusion since the Neolithic. Among
30 the finds, some of the earliest *Solanum melongena* seeds in the Levant represent the proposed
31 IGR. Several other identified economic plants, including two unprecedented in Levantine
32 archaeobotany (*Ziziphus jujuba*, *Lupinus albus*), implicate RAD as the greater force for crop
33 migrations. Altogether the evidence supports a gradualist model for Holocene-wide crop

34 diffusion, within which the first millennium CE contributed more to global agro-diversity
35 than any earlier period.

36 *Introduction*

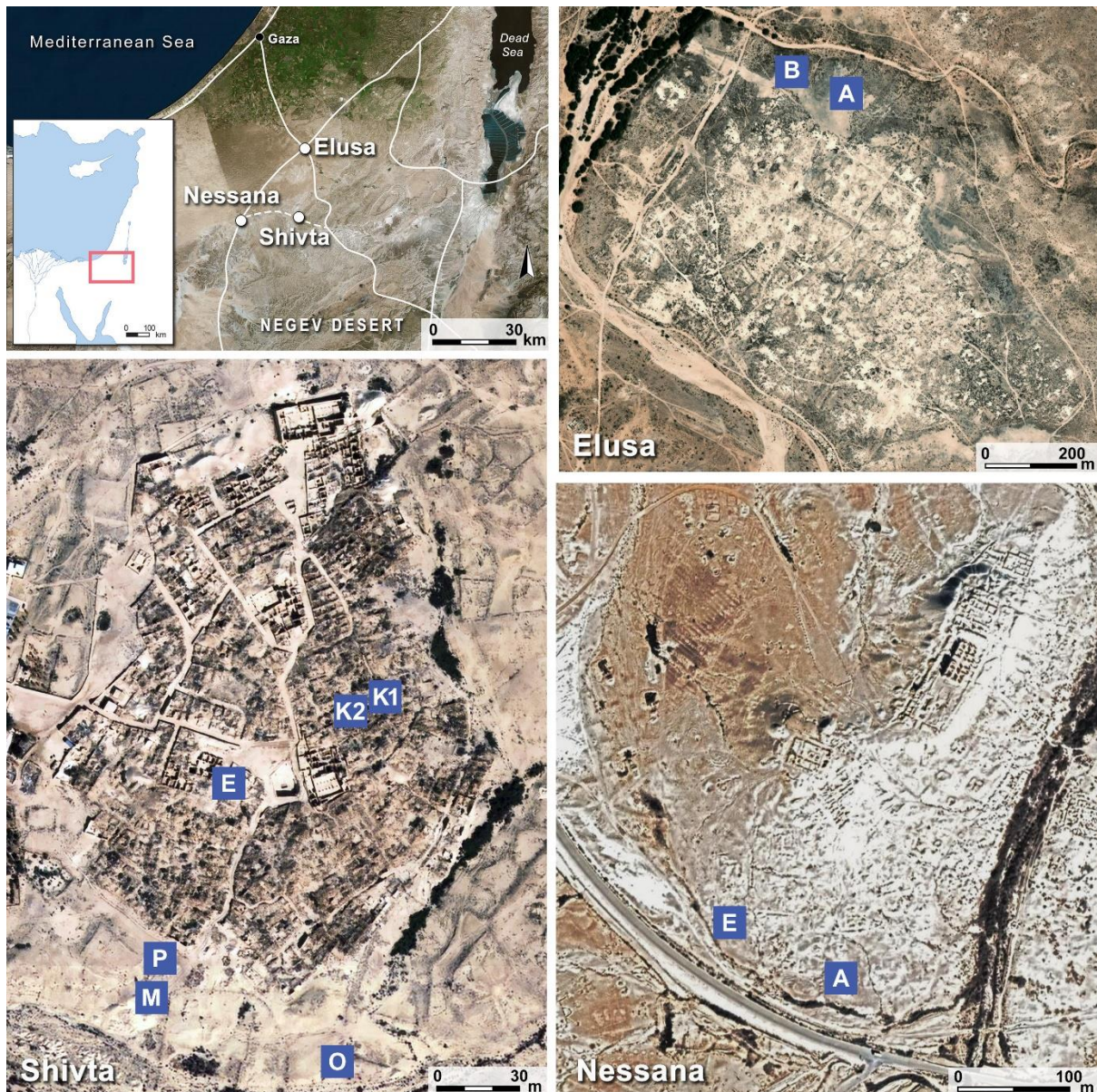
37 Crop diversity has long been recognized as key to sustainable agriculture and global food
38 security, encompassing genetic resources for agricultural crop improvement geared at
39 improving yields, pest resistance, climate change resilience, and the promotion of cultural
40 heritage. Global genetic diversity of agricultural crops is a product of their dispersal from
41 multiple regions and much research has attempted to reconstruct these trajectories [1-3]. As
42 part of this effort, archaeobotanical research on plant migrations across the Eurasian
43 continent has been a central theme in recent decades, especially with reference to “food
44 globalization” and the “Trans-Eurasian exchange” [4-8]. Yet, as is true for archaeology-based
45 domestication research in general, most studies of crop dispersal and exchange have focused
46 on prehistoric origins and developments, to the near exclusion of more recent crop histories
47 directly affecting today’s agricultural diversity [9-15]. One of the most influential, and
48 contested, chapters in the later history of crop diffusion is the ‘Islamic Green Revolution’
49 (IGR) [16,17]. According to Andrew Watson, the IGR involved a package of sub-/tropical,
50 mostly east- and south Asian domesticates which, as a result of the Islamic conquests, spread
51 into Mediterranean lands along with requisite irrigation technologies ca. 700–1100 CE. This
52 allegedly involved some 17 domesticated plant taxa (**Supplementary Table 1**), including
53 such economically significant crops as sugar cane, orange and banana [16]. However, critics
54 have argued that many of the proposed IGR crops were, and still are, of minor economic
55 significance, while others were previously cultivated in the Mediterranean region, particularly
56 under Roman rule, or else arrived much later [17-19]. Indeed, there is considerable evidence
57 for crop diffusion immediately preceding and during the Roman period in the eastern
58 Mediterranean, 1st c. BCE– 4th c. CE. During this time, several east- and central Asian crops,
59 including some of those on Watson’s IGR list, were introduced to the Mediterranean region,
60 along with agricultural technologies [17-21]. From this period on, a growing fruit basket is
61 evident in sites and texts of the eastern Mediterranean region [22-25]. These include several
62 tree-fruits (**Supplementary Table 2**) apparently reflecting the Greco-Roman passion for
63 grafting and its pivotal role in the dispersal of temperate fruit crops from Central Asia to the
64 Mediterranean and Europe [3,26]. Yet Roman arboricultural diffusion is but a subset of
65 Roman agricultural diffusion (hereafter, RAD), which also includes non-arboreal crops
66 (including cannabis, muskmelon, white lupine, rice, sorghum) and various agricultural

67 techniques diffused by the Romans into the eastern Mediterranean [21,27-35]. Not all crops
68 in motion during this period took hold in local agriculture. In some cases, as has been claimed
69 for rice in Egypt, initial Roman-period importation of the new crops ultimately led to local
70 cultivation in the Islamic period [36]. In other cases, Roman introductions were subsequently
71 abandoned [37], or failed to diffuse beyond elite gardens until much later [38]. Limited
72 adoption in local agriculture is also a feature of some proposed IGR crops, as Watson
73 admitted regarding coconut and mango [16]. Thus, a cursory consideration of proposed IGR
74 and RAD crops in the eastern Mediterranean reveals that the balance between the two is
75 about even and perhaps weighted toward RAD (**Supplementary Tables 1-2**). This sort of
76 comparison is valuable for evaluating the IGR thesis and attaining improved understandings
77 of crop exchange and dispersal in the first millennium CE, but a higher-resolution micro-
78 regional approach is needed to rigorously gauge these developments. Systematic evaluation
79 of relative Islamic and Roman contributions to agricultural dispersal has been attempted for
80 Iberia [35,39]. In the eastern Mediterranean, archaeobotanical studies in Egypt [36], northern
81 Syria [40], and Jerusalem [25,41-42] have also yielded evidence for IGR introductions
82 framed against Roman agricultural diffusion, but these have not yet been considered
83 holistically.

84 The exceedingly rich plant remains from relatively undisturbed Negev Highland middens
85 (**Fig. 1-2**; [43-45]) provide a significant new addition to the evidence for Levantine and
86 Mediterranean crop diffusion, informing upon changes in the local economic plant basket
87 over the 1st millennium CE. The Negev Highlands also offer an ideal test case for the
88 geographical extent of crop dispersal, as a desert region on the margins of the settled zone,
89 which practiced vibrant runoff farming and engaged in Mediterranean and Red Sea trade
90 networks of Late Antiquity [46-50]. Archaeobotanical finds from the Negev Highlands,
91 mainly from Byzantine sites (5th-7th centuries CE), have been reported in previous studies
92 [43-44,51-59], including those deriving from organically rich middens at Elusa, Shivta, and
93 Nessana, excavated as part of the recent NEGEVBYZ project [53-59]. We present below the
94 first complete dataset of identified plant remains from the Late Antique Negev Highland
95 middens dated to the local Roman, Byzantine and early Islamic periods (2nd-8th centuries
96 CE). We then analyze this data to assess the evidence for Roman and Early Islamic crop
97 diffusion in the southern Levant, comparing with earlier introductions. These include the
98 southwest Asian Neolithic ‘founder crops’, Chalcolithic-Early Bronze Age tree fruit

99 domesticates, and Bronze-Iron Age introductions (**Supplementary Tables 1-3**). This analysis
100 offers Holocene-scale insights on the dynamics of crop diffusion.

101 *Figure 1. Study sites and middens*



102

103 *The study sites – Shivta, Elusa and Nessana – roughly span the Negev Highlands region of the Negev desert.*
104 *The excavated middens are marked on the aerial photos above. Middens are lettered as named in the 2015-2017*
105 *excavations (see also Table 2).*

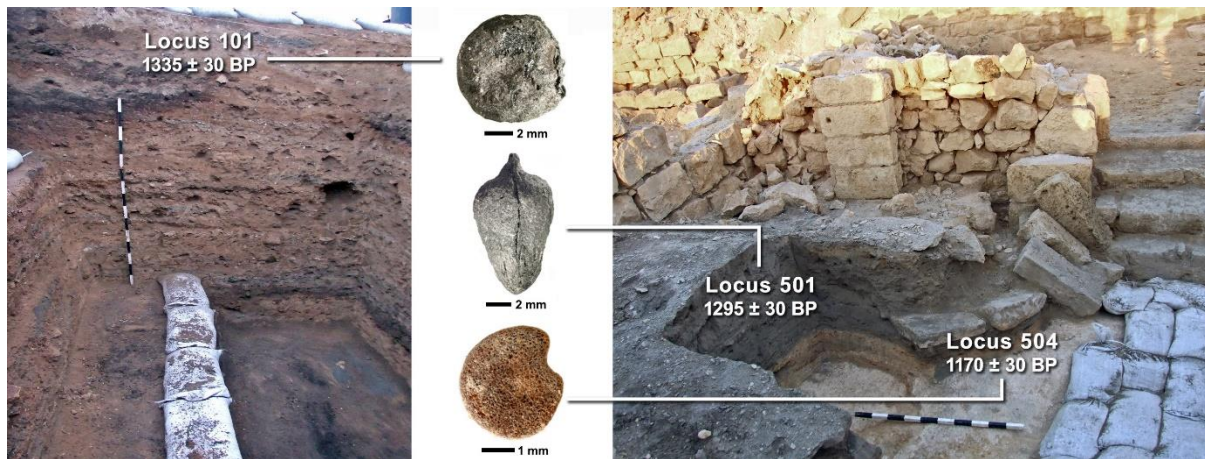
106

107 *Results*

108 Roughly 50,000 quantifiable macroscopic plant parts were retrieved from fine-sifted flotation
109 and dry-sieved sediment samples of the middens of Elusa, Shivta and Nessana, excluding
110 charcoal and in addition to a roughly equal number retrieved from wet-sieving (see
111 **Supplementary Information**). These mostly carpological remains were identified to a total

112 144 distinct plant taxa (**Supplementary Table 4**). Nearly half of the identified specimens
113 derived from six Shivta middens; one quarter from three Elusa middens and one quarter from
114 two Nessana middens. Preservation quality varied somewhat within and between middens
115 and samples, but all middens yielded rich concentrations of charred seeds and other organic
116 remains, including many exceptionally preserved specimens. Identified species were
117 classified as either domestic or wild and the former grouped by functional category
118 (**Supplementary Table 4**). Most of the 120 wild taxa have ethnographically documented
119 uses, whether for forage or fodder, crafts or fuel, food or spice, medicine or recreation.
120 Nearly all of them grow wild in the Negev Highlands today and we cannot determine for
121 certain which were deliberately used on site. Twenty-three domesticated food plant types
122 were identified, including cereals, legumes, fruits, nuts, and one vegetable. Like the other
123 domesticates, we consider the presence of Nile acacia (*Vachellia nilotica* [L.] Willd. ex
124 Delile) in the assemblage to be the result of deliberate import or cultivation, along with other
125 exotic trees previously identified by charcoal and pollen from the study sites. We focus on
126 these 24 plants as indicators of local foodways and global crop diffusion. Their
127 presence/absence by period in the Negev Highland middens appears in **Table 1**, and orders of
128 magnitude by midden context for fine-sifted archaeobotanical samples appear in **Table 2** (see
129 **Supplementary Information** for sifting and sampling strategy). The latter enable
130 categorization of the Late Antique Negev Highland domesticates as staples, cash crops, and
131 luxury/supplementary foods, setting the stage for analysis of the local manifestation of long-
132 term crop diffusion. This analysis is further augmented by identified charcoal and pollen data
133 from the study sites (**Supplementary Tables 5-6**) which raise the number of distinct plant
134 taxa identified in the NEGEVBYZ project to over 180. Among the charcoal/pollen taxa not
135 identified by seed and fruit remains are three fruit trees: sycamore fig (*Ficus sycomorus* L.),
136 doum palm (*Hyphaene thebaica* [L.] Mart.), and hazelnut (*Corylus* sp.).

137 **Figure 2. First finds from the Negev Highlands middens**



138
 139 Section photos of Nessana midden A (left) and Shivta midden E (right) are shown with select Loci and their
 140 uncalibrated radiocarbon dates (photographed by: Yotam Tepper), from which seeds of *Lupinus albus* (center
 141 top), *Ziziphus jujuba* (center middle), *Solanum melongena* (center bottom) were found. These seeds represent
 142 some of the earliest of their species found in the southern Levant (photographed by Daniel Fuks).

143

144 **Table 1. Presence/absence of domesticated species in Negev Highland middens by period**
 145 (carpological remains)

Plants/centuries CE		1 st -3 rd	4 th -mid-5 th	mid-5 th -mid-6 th	mid-6 th -mid-7 th	7 th	mid-7 th -8 th
Functional category	Latin name						
Cereals	<i>Hordeum vulgare</i>	✓	✓	✓	✓	✓	✓
	<i>Triticum turgidum</i> s.l.	✓	✓	✓	✓	✓	✓
	<i>Triticum aestivum</i>				✓	✓	✓
Legumes	<i>Lens culinaris</i>	✓	✓	✓	✓	✓	✓
	<i>Vicia ervilia</i>	✓	✓	✓	✓	✓	✓
	<i>Vicia faba</i>					✓	✓
	<i>Lathyrus clymenum</i>					✓	✓
	<i>Lupinus albus</i>					✓	
	<i>Trigonella foenum-graecum</i>		✓			✓	✓
Fruits	<i>Vitis vinifera</i>	✓	✓	✓	✓	✓	✓
	<i>Ficus carica</i>	✓	✓	✓	✓	✓	✓
	<i>Olea europaea</i>	✓	✓	✓	✓	✓	✓
	<i>Phoenix dactylifera</i>	✓	✓	✓	✓	✓	✓
	<i>Punica granatum</i>		✓	✓	✓	✓	✓
	<i>Ceratonia siliqua</i>		✓		✓	✓	✓
	<i>Prunus persica</i>		✓		✓	✓	✓
	<i>Prunus</i> subgen. <i>Cerasus/Prunus</i>						✓
	<i>Ziziphus jujuba</i>						✓
Nuts	<i>Prunus amygdalus</i>				✓	✓	✓
	<i>Pinus pinea</i>					✓	✓
	<i>Pistacia vera</i>						✓
	<i>Juglans regia</i>						✓
Vegetable	<i>Solanum melongena</i>					✓	✓
Other	<i>Vacchelia nilotica</i>		✓	✓			

146

147 Seed quantities and ubiquity point to barley (*Hordeum vulgare* L.), wheat (*Triticum*
148 *turgidum/aestivum*), and grapes (*Vitis vinifera* L.) as the main cultivated crops, which were
149 clearly calorific staples. Their local cultivation is attested to by cereal processing waste
150 (rachis fragments, awn and glume fragments, culm nodes and rhizomes) and wine-pressing
151 waste (grape pips, skins, and pedicels). In addition, lentil (*Lens culinaris* [L.] Coss. &
152 Germ.), bitter vetch (*Vicia ervilia* [L.] Willd.), fig (*Ficus carica* L.), date (*Phoenix dactylifera*
153 L.), and olive (*Olea europaea* L.) should also be counted as staples based on seed quantities
154 and ubiquity (**Tables 1-2**). They were likely cultivated locally. Significantly, all identified
155 staples were among the southwest Asian Neolithic founder crops and early fruit domesticates
156 which formed a stable part of Levantine diets by the Early Bronze Age (3300–2000 BCE).

157 Grapes were previously shown to be the primary cash crop of the Byzantine Negev
158 Highlands—particularly in the mid-5th to mid-6th c. CE—based on their changing relative
159 frequencies [54]. Yet, we cannot rule out the possibility of cereal cultivation for export in
160 some periods. One modern example is the export of Negev barley to Britain for beer
161 production in the 19th century [60]. Interestingly, free-threshing hexaploid bread wheat
162 (*Triticum aestivum* L.)—a more market-oriented wheat species identifiable archaeologically
163 by indicative rachis segments—appears in the Negev Highlands only after the mid-6th c.
164 (**Table 2**). This corresponds with the period of decline in viticulture [54].

165 In the ‘luxuries and supplements’ category we include potentially important and desirable
166 dietary components which were minor and apparently nonessential in local consumption or
167 agriculture. These include several food crops poorly represented in the local assemblages:
168 fava bean (*Vicia faba* L.), fenugreek (*Trigonella foenum-graecum* L.), Spanish vetchling
169 (*Lathyrus clymenum* L.), and white lupine (*Lupinus albus* L.) among the legumes; peach
170 (*Prunus persica* [L.] Batsch), plum/cherry (*Prunus* subgen. *Cerasus/Prunus*), carob
171 (*Ceratonia siliqua* L.) and jujuba (*Ziziphus jujuba* Mill.) among the tree-fruits; almond
172 (*Prunus amygdalus* Batsch), walnut (*Juglans regia* L.), stone pine (*Pinus pinea* L.), pistachio
173 nut (*Pistacia vera* L.) and hazel (*Corylus* sp.) among the nuts; the aubergine (*Solanum*
174 *melongena* L.) as a unique summer vegetable (**Fig. 2-3**); and supplementary wild edibles such
175 as beet (*Beta vulgaris* L.), coriander (*Coriandrum sativum* L.), and European bishop (*Bifora*
176 *testiculata* [L.] Spreng.) (**Supplementary Table 4**). Any of these could have been cultivated
177 in Negev Highland runoff farming [47, 59], or on site [61].

178 Another important ancient economic plant found in the assemblages is the Nile acacia, which
179 does not grow today in the Negev. Previous archaeobotanical finds of Nile acacia in the
180 Levant all come from Roman-period sites in the Dead Sea rift valley, which Kislev [62]
181 interpreted as a component of the ancient flora in this region of Sudanian vegetation
182 penetration. However, this was also an important region for desert-crossing camel caravan
183 commerce. Nile acacia seed finds from Elusa (**Fig. 3**) are the first from outside the
184 phytogeographic region of Sudanian vegetation, but they remain within the ancient caravan
185 trade routes connecting the Red Sea and the Mediterranean. Therefore, we consider Nile
186 acacia seeds to represent a Roman-period introduction to the Levant, whether as objects of
187 cultivation or of trade at the Negev desert route sites. Other exotic trees used for quality wood
188 and craft were identified by pollen and/or charcoal, including: cedar of Lebanon (*Cedrus*
189 *libani* A.Rich.), European ash (*Fraxinus excelsior* L.), and boxwood (*Buxus sempervirens*
190 L.). Cedar was identified by both charcoal and pollen, suggesting local garden cultivation
191 (see Langgut et al. 2021 [59] and **Table 3**).

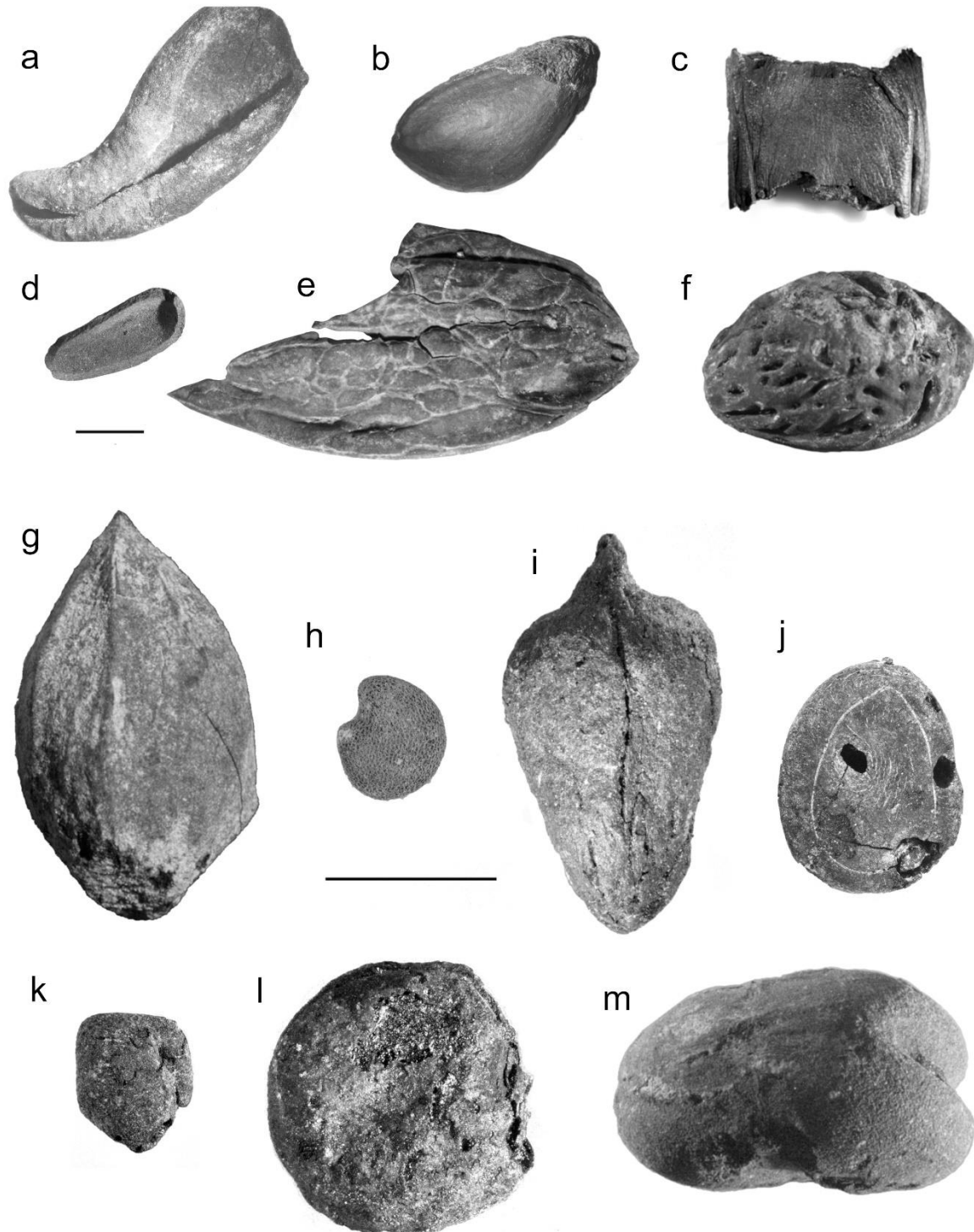
192 Table 2. Domesticated plant seeds order of magnitude by period, site, and area (from fine-sift)

Century CE	1 st - 3 rd	4 th - mid-5 th	mid-5 th - mid-6 th		mid-5 th - mid-7 th		mid-6 th - mid-7 th		early 7 th		7 th - 8 th	mid-7 th -8 th			
Site	SVT	HLZ	HLZ	SVT	NZN	NZN	SVT	SVT			NZN	NZN	SVT		
Area (midden)	P	A4	A1	M	A	A	O	K2	E	A	E	K1	K2	E	
Samples	5	14	19	14	7	5	12	3	3	27	10	13	13	12	
Vol. (L)	15	85	85	42	21	15	36	9	9	84	33	39	39	36	
Plant species															
<i>Hordeum vulgare</i>	XX	XXX	XXX	XX	XXX	XX	XX	XXX	XXX	XXX	XXX	XXX	XXX	XXX	XXX
<i>Triticum</i> sp.	XX	XX	XX	XX	X	X	X	XX	XX	XX	XXX	XXX	XXX	XXX	XXX
<i>Lens culinaris</i>		XX	XX	X	XX		X	X	X	X	XX	XX	X	X	
<i>Vicia ervilia</i>	X	X	X	X	X	X	X	X	XX	X	XX	XX	X	XX	
<i>Trigonella foenum-graecum</i>		X							X	X	X	X	X		
<i>Lathyrus clymenum</i>										X		X			
<i>Lupinus albus</i>												X			
<i>Vitis vinifera</i>	X	XX	XX	XX	XX	X	XX	XX	X	XXX	XXX	XXX	XXX	XX	
<i>Ficus carica</i>	X	XXX	XXX	XX	X	X	XX	X	X	XX	X	X	XX		
<i>Olea europaea</i>		X		X	X	X	X	X		X	XX	X	X	X	
<i>Phoenix dactylifera</i>	X	X	X	X	X		X	X	X	X	XX	XX	X	X	
<i>Punica granatum</i>		rind		rind	X	rind	X	rind		X	XX	X	X	X	
<i>Cerantonia siliqua</i>										X		X	pistil		
<i>Prunus amygdalus</i>										X		X	X	X	
<i>Prunus persica</i>		X					X			X		X			
<i>Pinus pinea</i>										X	X				
<i>Solanum melongena</i>										X				X	
<i>Vachellia nilotica</i>		X	X		X										

193

194 Sites abbreviated as: SVT-Shivta; HLZ-Elusa; NZN-Nessana; for midden locations see Figure 1. Orders of
 195 magnitude presented as $1 \leq X < 10 \leq XX < 100 \leq XXX < 1000$. See **Supplementary Information** for sifting and
 196 sampling strategy.

197 *Figure 3. Select plant remains from the Negev Highland middens*



198
199 (a) charred almond (*Prunus amygdalus* Batsch.) exocarp; (b) charred pistachio (*Pistacia vera* L.) drupe; (c)
200 charred carob (*Ceratonia siliqua* L.) pod fragment; (d) uncharred stone pine (*Pinus pinea* L.) outer seed coat
201 fragment; (e) uncharred walnut (*Juglans regia* L.) endocarp of the thin-shelled variety (f) charred peach (*Prunus*
202 *persica* [L.] Batsch) endocarp; (g) charred cherry/plum (*Prunus* subgen. *Cerasus/Prunus*) endocarp; (h)
203 uncharred aubergine (*Solanum melongena* L.) seed; (i) charred jujuba (*Ziziphus jujuba* Mill.) endocarp; (j)
204 charred *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. seed; (k) charred fenugreek (*Trigonella foenum-*
205 *graecum/berythea*) seed; (l) charred white lupine (*Lupinus albus* L.) seed; (m) charred fava bean (*Vicia faba*
206 L.). Scale bars = 5mm; all photos in grayscale (photographed by: Daniel Fuks and Yoel Melamed).

207 Complementing the seed/fruit remains presented above, palynological and anthracological
 208 analyses support local cultivation of grapevine, fig, olive, date, pomegranates, carob, and the
 209 *Prunus* genus, which includes almond, peach, plum and/or cherry [59]. Based on stone pine
 210 seed coats, and the identification of Pinaceae pollen (= pine other than the local Aleppo pine),
 211 it is plausible that stone pine was cultivated locally, albeit on a small scale (**Table 3**). Pollen
 212 evidence also supports local cultivation of hazel – another domesticated unattested in the
 213 southern Levant before the Roman period (**Tables 3, 5; Supplementary Tables 5-6**).

214

215 *Table 3. Combined evidence for fruit/nut trees*

Taxon	Common name	Seeds/Fruit			Charcoal			Pollen		
		SVT	NZN	HLZ	SVT	NZN	HLZ	SVT 1	SVT 2	SVT 3
<i>Vitis vinifera</i>	grapevine	+	+	+	+	+	-	+	+	+
<i>Olea europaea</i>	olive	+	+	+	+	-	+	+	+	+
<i>Ficus carica</i>	common fig	+	+	+	+	+	+	-	-	-
<i>Phoenix dactylifera</i>	date palm	+	+	+	+	-	-	+	+	+
<i>Ceratonia siliqua</i>	carob	+	+	+	-	-	-	+	-	+
<i>Punica granatum</i>	pomegranate	+	+	+	-	+	-	-	-	-
<i>Prunus</i> spp.	almond/peach/plum	+	+	+	+	+	-	-	-	-
<i>Pinus</i> spp.	pine	+	+	-	+	+	+	+	+	+
<i>Corylus</i> sp.	hazel	-	-	-	-	-	-	+	-	+
<i>Ficus sycomorus</i>	sycomore fig	-	-	-	-	+	+	-	-	-
<i>Hyphaene thebaica</i>	doum palm	-	-	-	+	+	-	-	-	-
<i>Juglans regia</i>	walnut	+	-	-	-	-	-	-	-	-
<i>Pistacia vera</i>	pistachio	+	-	-	*	*	-	-	-	-
<i>Ziziphus jujuba</i>	jujuba	+	-	-	*	*	-	-	-	-

216

217 *Carpological, anthracological and palynological evidence for fruit- and exotic trees in the*
 218 *study sites. Assessment of local cultivation is based on the combination of proxies and*
 219 *especially pollen to include grapevine, fig, olive, date, pomegranate, carob, hazelnut, cedar*
 220 *and the Prunus genus (potentially including almond, peach, plum and/or cherry). Local*
 221 *cultivation of stone pine may also plausibly be inferred. SVT1= South reservoir, Shivta; SVT*
 222 *2 = North reservoir, Shivta; SVT3 = North church garden, Shivta; + indicates presence; -*
 223 *indicates absence; *indicates charcoal identified to genus, including possible local wild*
 224 *species. Prunus spp. includes Prunus dulcis and Prunus domestica/cerasus endocarp/exocarp,*
 225 *and Prunus spp. charcoal. Pinus spp. includes Pinus pinea seed coats, Pinus halepensis*
 226 *charcoal, and Pinus sp. pollen.*
 227

228 Overall, the later-period middens were more concentrated in plant remains, and it is in the
 229 Early Islamic period middens where we find most of the rare domesticated species, RAD
 230 crops included (**Table 1**). This appears to be related to taphonomy, and therefore absence of
 231 RAD crops in the Byzantine middens should not be taken as evidence of their absence (see
 232 **Supplementary Information**). Samples containing the unique finds of white lupine and
 233 jujuba – which are unprecedented in southern Levantine archaeobotany – were dated to the
 234 Umayyad or early Abbasid period (mid-7th – late 8th c. cal. CE at 2 σ ; see **Fig. 1; Table 4** and
 235 **Supplementary Information**). However, textual studies have identified these species in
 236 Roman-period texts of the southern Levant [22]. The sample from Shivta containing
 237 aubergine seeds was dated to the Abbasid period (772-974 cal CE at 2 σ), supporting previous
 238 finds from Abbasid Jerusalem [25,40-41].

239 *Table 4. Radiocarbon dating of select loci*

Radiocarbon Lab. no.	Site	Locus	Basket	Special find	Material dated	Uncal BP	Cal. CE (1 σ)	Cal. CE (2 σ)
Poz-141223	Nessana	101	1040-1	white lupine	charred barley seed	1335 \pm 30	654 (46.4%) 682	647 (61.0%) 708
							745 (18.3%) 760	730 (34.5%) 775
							768 (3.6%) 771	
Poz-141225	Shivta	504	5029	aubergine	charred barley seed	1170 \pm 30	776 (9.7%) 788	772 (73.9%) 901
							825 (49.0%) 894	916 (21.6%) 974
							928 (9.6%) 945	
Poz-141226	Shivta	501	5108	jujuba	charred barley seed	1295 \pm 30	670 (33.4%) 704	659 (95.4%) 775
							739 (34.9%) 772	

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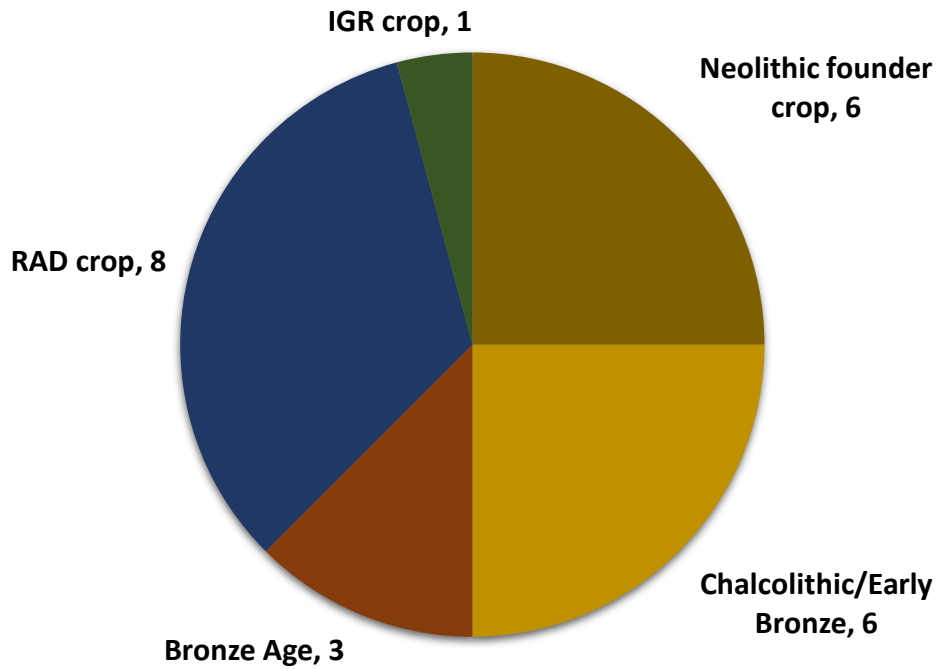
241 Considering together the domestic plants evident in the Negev Highlands according to their
 242 period of first attestation in the southern Levant – archaeobotanically and historically – offers
 243 a window onto processes of long-term crop diffusion (**Table 5**). While their quantities and
 244 ubiquities indicate that RAD and IGR crops were initially of minor significance, they make
 245 up over a third of the domesticates' species diversity (**Fig. 4; Table 5**). All the more
 246 surprising considering the Negev Highlands' desert and present-day peripheral status, this
 247 new data reveals for the first time the extent of western influence on local agriculture and
 248 trade (**Fig. 5**).

249 *Table 5. Earliest archaeobotanical evidence in the southern Levant for domestication/introduction*
 250 *of Negev Highland domesticated plants*

Latin name	Period	Tag	Approx date	Reference
<i>Hordeum vulgare</i>	PPNB	Founder crop	9 th mill. BCE	Zohary et al. 2012 [3]
<i>Lens culinaris</i>	PPNB	Founder crop	9 th mill. BCE	Caracuta et al. 2017 [74]
<i>Vicia ervilia</i>	PPNB	Founder crop	9 th mill. BCE	Caracuta et al. 2017 [74]
<i>Vicia faba</i>	PPNB	Founder crop	9 th mill. BCE	Caracuta et al. 2017 [74]
<i>Triticum turgidum</i> s.l. (free-threshing)	PPNB	Founder crop	7 th mill. BCE	Feldman and Kislev 2007 [75]
<i>T. aestivum</i> (free-threshing)	NA	Founder crop	NA	Zohary et al. 2012 [3]
<i>Olea europaea</i>	Chalcolithic/E. Bronze	Early fruit domesticate	5 th mill. BCE	Langgut et al. 2019 [76]
<i>Ficus carica</i>	Chalcolithic/E. Bronze	Early fruit domesticate	5 th mill. BCE	Weiss 2015 [77]
<i>Vitis vinifera</i>	Chalcolithic/E. Bronze	Early fruit domesticate	5 th mill. BCE	Weiss 2015 [77]
<i>Phoenix dactylifera</i>	Chalcolithic/E. Bronze	Early fruit domesticate	5 th mill. BCE	Weiss 2015 [77]
<i>Punica granatum</i>	Chalcolithic/E. Bronze	Early fruit domesticate	5 th mill. BCE	Melamed 2002 [78]
<i>Prunus amygdalus</i>	Chalcolithic/E. Bronze	Early fruit domesticate	5 th mill. BCE	Zohary et al. 2012 [3]
<i>Lathyrus clymenum</i>	Middle Bronze	Bronze Age introduction	19 th -18 th c. BCE	Kislev et al. 1993 [79]
<i>Juglans regia</i>	Middle Bronze	Bronze Age introduction	18 th c. BCE	Langgut 2015 [80]
<i>Trigonella foenum-graecum</i>	Late Bronze Age IIA	Bronze Age introduction	14 th c. BCE	Weiss et al. 2019 [81]
<i>Prunus persica</i>	Nabatean	RAD crop	1 st c. BCE	Kislev and Simchoni 2009 [82]
<i>Vachellia nilotica</i>	Nabatean	RAD crop	1 st c. BCE	Kislev 1990 [62]
<i>Ceratonia siliqua</i>	Hellenistic-Roman	RAD crop	1 st c. BCE	Zohary et al. 2012 [3]
<i>Pinus pinea</i>	Hellenistic-Roman	RAD crop	1 st c. BCE	Kislev 1988 [83]
<i>Prunus</i> subgen. <i>Cerasus/Prunus</i>	Roman	RAD crop	1 st c. CE	Tabak 2006 [84]
<i>Pistacia vera</i>	Roman	RAD crop	2 nd c. CE	Hartman and Kislev 1998 [85]
<i>Corylus</i> sp.	Roman	RAD crop	2 nd c. CE	Kislev and Simchoni 2006 [23]; Langgut et al. 2021 [59]
<i>Lupinus albus</i>	Early Islamic	RAD crop	7 th c. CE	this paper
<i>Ziziphus jujuba</i>	Early Islamic	RAD crop	7 th c. CE	this paper
<i>Solanum melongena</i>	Early Islamic	IGR crop	7 th c. CE	Amichay et al. 2019 [25]; this paper

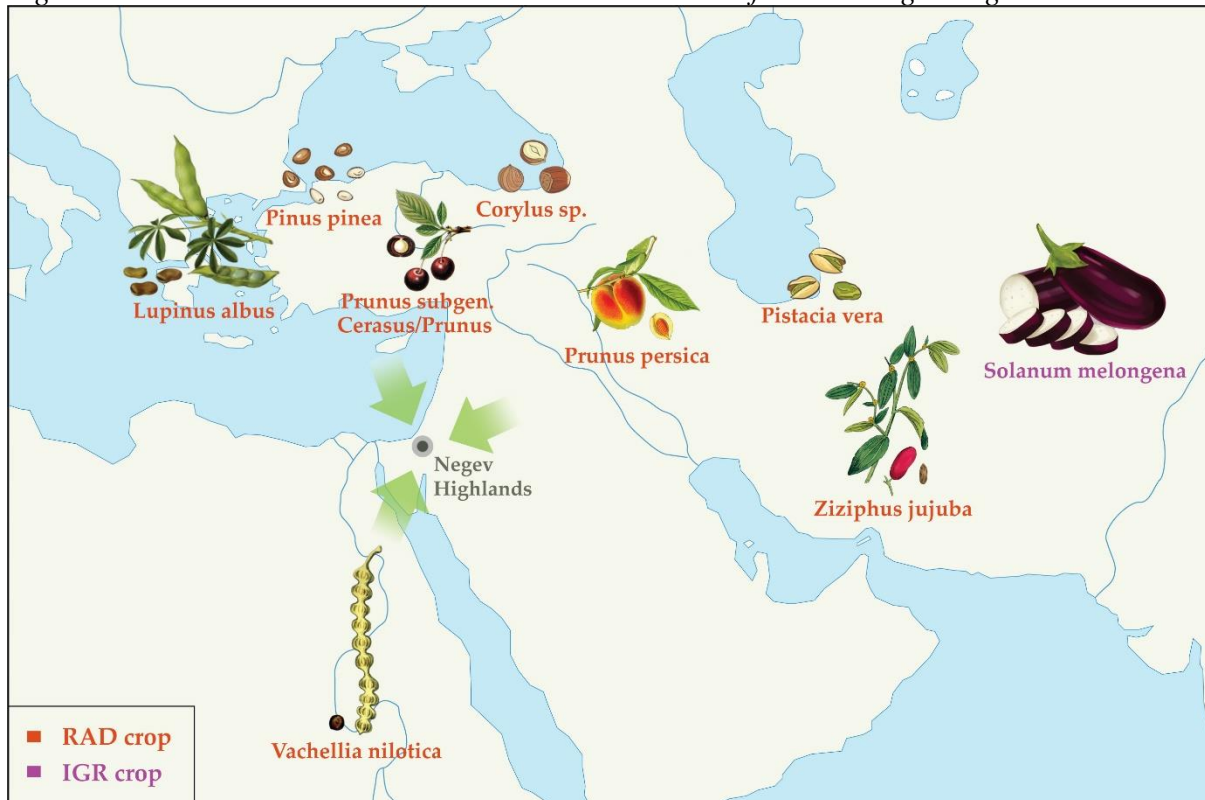
251 *Note: The earliest evidence for Prunus subgen. Cerasus/Prunus refers to plum (Prunus subgen. Prunus) only. Cherry (Prunus*
 252 *subgen. Cerasus) has yet to be identified in the southern Levantine archaeobotanical record.*

253 *Figure 4. Negev Highlands crop basket by period of introduction to the southern Levant*
254 *(based on carpological remains)*



255

256 *Figure 5. First mill. CE southern Levantine introductions found in Negev Highland middens*



257

258 *Schematic representation of directions of first millennium CE crop diffusion into the southern Levant based on*
259 *plants attested to in the Negev Highland middens. RAD crops are labeled red; IGR crops purple.*

260

261 *Discussion*

262 The critical mass afforded by the new, systematically retrieved and identified plant remains
263 from Late Antique Negev Highland trash mounds allows not only reconstructions of local
264 plant economy, but also insights on the dispersal of crop plants over the last 11.5 ky. Of the
265 Negev Highland plant remains, only the aubergine is an IGR crop (**Table 5; Fig. 4-5**).
266 Together with finds from Abbasid Jerusalem, seeds found in the Negev Highland middens are
267 among the earliest archaeobotanical finds of this plant in the Levant and are roughly
268 contemporary with the earliest textual references to aubergine [16,22]. Significantly,
269 aubergine is the only summer crop in the Negev Highlands plant assemblage. In other regions
270 of the southern Levant, summer crops were certainly cultivated in the Roman period [20,63],
271 but the Early Islamic introduction of aubergine is consistent with Watson's claim that
272 summer cultivation expanded in this later period [16,64]. Ultimately, widespread adoption of
273 summer-winter crop rotation in the Mediterranean region effected changes in people's diets
274 and work routines. Yet these changes clearly did not occur overnight. To be fair, the Early
275 Islamic assemblages from the Negev Highlands do not offer enough of a time perspective to
276 fully gauge the effects of Early Islamic crop introduction on their own as they span only the
277 first 200-300 years of Islam. Yet it is also possible that finds from the 7th-8th century middens
278 represent Byzantine agronomic traditions and techniques. Regardless, had crop introductions
279 been inundating and pervasive during the Early Islamic period, we expect they would have
280 been more apparent in Negev Highland crop diversity.

281 By contrast, the Negev Highlands crop basket highlights the influence of RAD, particularly
282 on arboriculture. Of the 24 domestic plants identified by carpological remains, seven were
283 introduced to the southern Levant during the 1st c. BCE to the 4th c. CE: pistachio nut, stone
284 pine, peach, plum/cherry, jujuba, Nile acacia, white lupine, plus carob which is a local wild
285 species but was apparently not fully domesticated until the Classical period (**Table 5**). Jujuba
286 and white lupine are unprecedented in southern Levantine archaeobotany, but they are known
287 from Roman-period texts and the archaeobotany of neighboring regions [65-68]. Considering
288 pollen remains, hazelnut is an additional RAD species identified in the Negev Highlands, that
289 was also found in Herod's garden at Caesarea, probably as an imported ornamental [69]. The
290 fact that the RAD plant remains are more prevalent in the Early Islamic phase (**Table 1-2**) is
291 likely the result of overall better preservation and plant richness in this phase. Therefore, we
292 understand them to be part of the general Late Antique Negev Highlands domestic plant
293 assemblage, noting that their earliest secure archaeobotanical records in the southern Levant

294 as a whole derive mostly from the 1st c. BCE to the 2nd c. CE (**Table 5**). We acknowledge that
295 some RAD species are first attested to at the end of the Hellenistic period of the southern
296 Levant in the 1st c. BCE. We nonetheless consider them RAD crops in view of chronological
297 proximity and their entrenchment in local agriculture and culture during the Roman period.
298 Allowing for gaps in the archaeobotanical record, partially compensated by textual
299 references, it is still fair to say that the RAD plants—which comprise a significant proportion
300 of species diversity in the Late Antique Negev Highland basket of domestic plants—were
301 introduced to the southern Levant over a relatively short period in Holocene history.

302 The snapshot presented here of the Negev Highlands' microregional crop basket supports and
303 significantly enhances previous evidence for 1st millennium CE crop diffusion. Together with
304 the archaeobotany of sites from southern Jordan [70] and Jerusalem [25,41], the Negev
305 Highland plant remains attest to Roman and Byzantine agricultural influence on the spread of
306 fruit crops such as peach, pear, plum, jujuba, apricot, cherry, pistachio nut, pine nut, and
307 hazelnut, among others, and to Abbasid introduction of aubergines in the southern Levant.

308 Altogether, this evidence suggests that RAD was a greater force in the agricultural history of
309 the first millennium CE than the IGR, which is also the current consensus from Iberia [39].

310 The significance of RAD is evident in the archaeobotany of additional regions, such as Italy,
311 northwest Europe and Britain [34,38,68]. However, we should not dismiss the IGR on these
312 grounds alone, since several of the proposed IGR crops are less likely to leave identifiable
313 macroscopic traces (e.g., sugar cane, colocasia), and there is textual evidence for Early
314 Islamic crop diffusion and agricultural development [22]. Hence it may be appropriate and
315 productive to consider RAD and IGR part of the same process of first millennium CE
316 agricultural development, as indicated by Early Islamic expansion of Roman and Byzantine
317 crop introductions. Clearly the first millennium CE was an unprecedented period of change in
318 local crop-plant species diversity in the eastern Mediterranean and beyond. The multi-
319 regional evidence suggests that the multi-empire combination of Roman-Byzantine and
320 Umayyad-Abassid regimes was a major force for crop diffusion, with a likely role for
321 developments in the Sassanid empire underrepresented in current research. Yet the evidence
322 presented here demonstrates that even the combined forces underlying first millennium CE
323 crop diffusion affected, but did not immediately transform, people's diets. At least until the
324 end of that millennium, inhabitants of the Levant and Mediterranean region continued to rely
325 primarily on long tried and tested Neolithic founder crops and early fruit domesticates.
326 Indeed, this situation widely persisted until the latter second millennium CE.

327 The new microregional data presented above supports an emerging multi-regional picture of
328 both an unprecedented period for plant migrations and food diversity in the first millennium
329 CE as well as gradual and incomplete local adoption. This is evident from Late Antique
330 Negev Highlands archaeobotanical assemblages within which plants first attested to in the
331 southern Levant during this period account for one third of the domesticated plant species
332 diversity – more than any other period represented in the assemblage. Among these crops,
333 only the aubergine represents an Early Islamic introduction, suggesting that Roman
334 Agricultural Diffusion (RAD) was a greater force for intercontinental movement of crop
335 plants than the proposed Islamic Green Revolution (IGR). However, both RAD and IGR
336 plant species are very rare in the Negev Highlands assemblages, indicating slow
337 incorporation into local foodways and agriculture. These findings present a window to a
338 wider perspective on the last 11.5 millennia of southwest Asian crop diffusion, in which the
339 first millennium CE is unprecedented for the diversity of plant species in motion yet
340 consistent with a long-term pattern of gradual local adoption.

341 *Materials and Methods*

342 Eleven middens from the three sites, Elusa, Shivta and Nessana, were excavated at
343 approximately 10 cm spits to ensure chronological control. An intensive sampling-and-sifting
344 strategy was followed to ensure optimal retrieval of plant remains (see **Supplementary**
345 **Information**). Fine-sifted samples (see **Supplementary Information**) were sorted using an
346 Olympus SZX9 stereo microscope and analyzed in the Bar-Ilan University Archaeobotany
347 Lab. Course sifted samples were sorted by volunteers and archaeology students during the
348 excavation and thereafter. Seed finds from the course sifting were examined and rare
349 specimens taken to the Bar-Ilan University Archaeobotany Lab for identification. All
350 identifications were made with reference to the Israel National Collection of Plant Seeds and
351 Fruits at Bar-Ilan University. To confirm identification, the jujuba (*Ziziphus jujuba* Mill.)
352 endocarp was scanned using a Bruker SkyScan 1174 desktop micro-CT scanner
353 (**Supplementary Videos 1-2**). Identification criteria for this and other select specimens
354 appear in the **Supplementary Information**. Information on previous archaeobotanical
355 records of cultivated species was retrieved from the cited literature and lab records, as well as
356 from online databases of archaeobotanical finds [71-73]. For palynological analysis, sediment
357 samples from the middens were collected. However, all samples showed pollen barrenness,
358 probably because of oxidation. Pollen from the reservoir and the northern church at Shivta

359 did contribute additional taxa, as did wood and charcoal analyses. Results of pollen and wood
360 analyses published by Langgut et al. [43,59] are summarized in **Supplementary Tables 5-6**.

361 The excavations' stratigraphic, ceramic, and radiocarbon analyses enabled differentiation of
362 five chronological phases obtained from the middens [43,54]: Roman (ca. 0–300 CE), Early
363 Byzantine (ca. 300–450 CE), Middle Byzantine (ca. 450–550 CE), Late Byzantine (ca. 550–
364 650 CE) and Umayyad (ca. 650–750 CE), which was adjusted slightly based on radiocarbon
365 dates presented herein. This enabled detection of trends within the Byzantine period as well
366 as broader chronological comparisons. These periods are each represented by between one
367 and four middens, and some middens span two periods (see **Table 2**). Grouping the seed/fruit
368 crop remains into broad periods of introduction to the southern Levant was used to provide a
369 general sketch of crop diffusion's local influence in time.

370 *Data Availability*

371 Only securely identified plant taxa are reported in the results of this study. All relevant data
372 are included in the manuscript and supplementary materials. The investigated plant remains
373 are currently stored in the Israel National Collection of Plant Seeds and Fruits at Bar-Ilan
374 University and may be accessed by request to the authors.

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396 *Competing interests*

397 The authors declare that there are no competing interests associated with this submission.

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644 *Supplementary Tables*

645 *Supplementary Table 1. Proposed IGR crops (according to Watson 1983 [16])*

Category	Latin name	English common name
cereal	<i>Sorghum bicolor</i> (L.) Moench.	sorghum
cereal	<i>Oryza sativa</i> L.	rice
cereal	<i>Triticum durum</i> Desf.	hard wheat
textile	<i>Gossypium arboreum/herbaceum</i> L.	Old World cotton
tree fruit	<i>Citrus aurantium</i> L.	sour orange
tree fruit	<i>Citrus limon</i> L.	lemon
tree fruit	<i>Citrus aurantifolia</i> Swing.	lime
tree fruit	<i>Citrus grandis</i> L.	shaddock
tree fruit	<i>Musa sapientum/paradisica</i> L.	banana/plantain
tree fruit	<i>Cocos nucifera</i> L.	coconut
tree fruit	<i>Mangifera indica</i> L.	mango
vegetable	<i>Citrullus lanatus</i> (Thumb.) Mansf.	watermelon
vegetable	<i>Spinacia oleracea</i> L.	spinach
vegetable	<i>Cynara cardunculus</i> L. var. <i>scolymus</i>	artichoke
vegetable	<i>Colocasia antiquorum</i> Schott.	colocasia
vegetable	<i>Solanum melongena</i> L.	eggplant
condiment	<i>Saccharum officinarum</i> L.	sugar cane

646 *Supplementary Table 2. Proposed RAD crops (see main text for discussion and sources)*

Category	Latin name	English common name
cereal	<i>Oryza sativa</i> L.	rice
cereal	<i>Sorghum bicolor</i> (L.) Moench.	sorghum
legume	<i>Lupinus albus</i> L.	white lupine
textile	<i>Cannabis sativa</i> L.	cannabis
tree fruit/nut	<i>Ceratonia siliqua</i> L.	carob
tree fruit/nut	<i>Morus nigra</i> L.	black mulberry
tree fruit/nut	<i>Prunus persica</i> (L.) Batsch	peach
tree fruit/nut	<i>Pyrus communis</i> L.	pear
tree fruit/nut	<i>Prunus domestica</i> L.	plum
tree fruit/nut	<i>Prunus armeniaca</i> L.	apricot
tree fruit/nut	<i>Prunus avium/cerasus</i>	cherry
tree fruit/nut	<i>Pistacia vera</i> L.	pistachio nut
tree fruit/nut	<i>Pinus pinea</i> L.	pine nut
tree fruit/nut	<i>Corylus avellana</i> L.	hazelnut
tree fruit/nut	<i>Ziziphus jujube</i> Mill.	jujuba
tree fruit/nut	<i>Citrus x limon</i> (L.) Osbeck	lemon
tree fruit/nut	<i>Cocos nucifera</i> L.	coconut
vegetable	<i>Cucumis melo</i> convar. <i>melo</i>	muskmelon

647

648 *Supplementary Table 3. Pre-1st mill. CE Eastern Mediterranean introductions/domestications*

Period	Category	Latin name	English common name
Neolithic	cereal	<i>Triticum monococcum</i> L. subsp. <i>monococcum</i>	einkorn wheat
Neolithic	cereal	<i>T. turgidum</i> L. subsp. <i>dicoccum</i> (Schrank) Thell.	emmer wheat
Neolithic	cereal	<i>Hordeum vulgare</i> subsp. <i>vulgare</i>	barley
Neolithic	cereal	<i>Lens culinaris</i> L.	lentil
Neolithic	legume	<i>Pisum sativum</i> L.	pea
Neolithic	legume	<i>Cicer arietinum</i> L. subsp. <i>arietinum</i>	chickpea
Neolithic	legume	<i>Vicia ervilia</i> (L.) Willd.	bitter vetch
Neolithic	legume	<i>Vicia faba</i> L.	fava bean
Neolithic	fiber/oil	<i>Linum usitatissimum</i> L.	flax
Chalcolithic-Early Bronze	tree fruit/nut	<i>Olea europaea</i> L.	olive
Chalcolithic-Early Bronze	tree fruit/nut	<i>Vitis vinifera</i> L.	grapevine
Chalcolithic-Early Bronze	tree fruit/nut	<i>Ficus carica</i> L.	fig
Chalcolithic-Early Bronze	tree fruit/nut	<i>Ficus sycomorus</i> L.	sycomore
Chalcolithic-Early Bronze	tree fruit/nut	<i>Phoenix dactylifera</i> L.	date
Chalcolithic-Early Bronze	tree fruit/nut	<i>Punica granatum</i> L.	pomegranate
Chalcolithic-Early Bronze	tree fruit/nut	<i>Prunus amygdalus</i> Batsch.	almond
Bronze-Iron Age	tree fruit/nut	<i>Juglans regia</i> L.	walnut
Bronze-Iron Age	tree fruit/nut	<i>Citrus medica</i> L.	citron
Bronze-Iron Age	cereal	<i>Panicum miliaceum</i> L.	broomcorn millet
Bronze-Iron Age	cereal	<i>Setaria italica</i> (L.) P. Beauv.	foxtail millet
Bronze-Iron Age	legume	<i>Lathyrus clymenum</i> L.	Spanish vetchling
Bronze-Iron Age	legume	<i>Lathyrus sativus/cicera</i> L.	grass pea
Bronze-Iron Age	legume	<i>Trigonella foenum-graecum</i> L.	fenugreek
Bronze-Iron Age	condiment/oil	<i>Papaver somniferum</i> L.	opium poppy
Bronze-Iron Age	condiment/oil	<i>Nigella sativa</i> L.	black cumin
Bronze-Iron Age	condiment/oil	<i>Sesamum indicum</i> L.	sesame
Bronze-Iron Age	vegetable	<i>Citrullus lanatus</i> (Thunb.) Matsum. & Nakai	watermelon

649

650 *Based primarily on Zohary et al. 2012 [3], this list includes only species whose evidence for domestication/introduction is*
 651 *clear. This and the preceding Supplementary tables are not meant as exhaustive lists but rather as a basis against which the*
 652 *Negev Highlands crop plant assemblage can be compared.*

653 *Supplementary Table 4. Carpological¹ plant remains from Negev Highland middens*

Category	Latin name	Common name
Cereals	<i>Hordeum vulgare</i> subsp. <i>hexastichum</i> (hulled)	six-row hulled barley
	<i>Hordeum vulgare</i> subsp. <i>distichum</i> (hulled)	two-row hulled barley
	<i>Triticum turgidum</i> s.l. (free-threshing)	free-threshing tetraploid wheat
	<i>Triticum aestivum</i> (free-threshing)	free-threshing hexaploid wheat
Legumes	<i>Lens culinaris</i>	lentil
	<i>Vicia ervilia</i>	bitter vetch
	<i>Vicia faba</i>	broad beans
	<i>Lathyrus clymenum</i>	Spanish vetchling
	<i>Lupinus albus</i>	white lupine
	<i>Trigonella foenum-graecum</i>	fenugreek
Fruits	<i>Vitis vinifera</i>	common grape
	<i>Ficus carica</i>	common fig
	<i>Phoenix dactylifera</i>	date palm
	<i>Olea europaea</i>	European olive
	<i>Punica granatum</i>	pomegranate
	<i>Ceratonia siliqua</i>	carob
	<i>Prunus persica</i>	peach
	<i>Prunus</i> subgen. <i>Cerasus/Prunus</i>	plum/cherry
	<i>Ziziphus jujuba</i>	jujuba
	Nuts	<i>Prunus amygdalus</i>
<i>Pinus pinea</i>		stone pine
<i>Pistacia vera</i>		pistachio nut
<i>Juglans regia</i>		Persian walnut
Vegetable	<i>Solanum melongena</i>	aubergine
Wild	<i>Vachellia nilotica</i> ²	Nile acacia
	<i>Adonis dentata</i>	toothed pheasant's eye
	<i>Aizoon hispanicum</i>	Spanish aizoon
	<i>Ajuga iva</i>	herb ivy
	<i>Ammi majus/visnaga</i>	bishop's weed
	<i>Anagallis arvensis</i>	scarlet pimpernel
	<i>Anagyris foetida</i>	Mediterranean stinkbush
	<i>Andrachne telephioides</i>	bastard orpine
	<i>Anthemis pseudocotula</i>	chamomile
	<i>Arnebia decumbens</i>	Arabian primrose
	<i>Asphodelus tenuifolia/fistulosus</i>	onionweed
	<i>Astragalus hamosus/arpilobus</i>	milkvetch
	<i>Atriplex glauca</i>	waxy saltbush
	<i>Avena barbata</i>	slender wild oat
	<i>Avena sterilis</i>	animated oat
	<i>Bassia muricata</i>	smotherweed
	<i>Bellevalia</i> sp.	Roman squill
	<i>Beta vulgaris</i>	beet
	<i>Bifora testiculata</i>	European bishop
	<i>Brachypodium distachyon</i>	purple false brome
<i>Bromus</i> type	brome (type)	

¹ Includes taxa identified by other preserved plant parts, e.g. perianth, rachis fragments, segmented stems/leaves.

² We take this Egyptian wild plant to have been cultivated or imported into the Negev Highlands (see Results).

<i>Buglossoides tenuiflora</i>	corn gromwell
<i>Bupleurum lancifolium</i>	lanceleaf thorum wax
<i>Calendula</i> sp.	calendula
<i>Cardaria draba</i>	hoary cress
<i>Carrichtera annua</i>	Ward's weed
<i>Carthamus</i> sp.	thistle
<i>Caylusea hexagyna</i>	
<i>Centaurea</i> sp.	knapweed
<i>Cephalaria joppensis</i>	Jaffa scabious
<i>Chenopodium murale</i>	nettleleaf goosefoot
<i>Cichorium endivia</i>	endive
<i>Citrullus colocynthis</i>	colocynth
<i>Convolvulus</i> cf. <i>arvensis</i>	bindweed
<i>Coriandrum sativum</i>	coriander
<i>Coronilla</i> cf. <i>repanda</i>	
cf. <i>Crassula</i> / <i>Sedum</i>	stonecrops
<i>Cutandia memphitica/dichotoma</i>	cutandia grass
<i>Cynodon dactylon</i>	Bermuda grass
<i>Daucus</i> / <i>Torilis</i>	wildcarrot/hedgeparsley
<i>Echiochilon fruticosum</i>	bushy bugloss
<i>Echium</i> cf. <i>angustifolium</i>	bugloss
<i>Emex spinosa</i>	devil's thorn
<i>Erucaria microcarpa</i>	pink mustard
<i>Erucaria pinnata</i>	pink mustard
<i>Euphorbia falcata</i>	sickle spurge
<i>Fagonia</i> sp.	fagonbush
<i>Fumaria parviflora</i>	fineleaf fumitory
<i>Galium aparine</i>	cleavers
<i>Gastrocotyle hispida</i>	hairy bugloss
<i>Glaucium arabicum</i>	horned poppy
<i>Glebionis coronaria</i>	garland chrysanthemum
<i>Gypsophila capillaris</i>	desert baby's breath
<i>Gypsophila pilosa</i>	Turkish baby's breath
<i>Haplophyllum</i> cf. <i>tuberculatum</i>	plant of the mosquito
<i>Hedysarum spinosissimum</i>	spiny sulla
<i>Heliotropium</i> sp.	heliotrope
<i>Hippocrepis unisiliquosa</i>	single-flowered horseshoe vetch
<i>Hordeum glaucum</i>	wall barley
<i>Hordeum marinum/hystrix</i>	sea/Mediterranean barley
<i>Hordeum vulgare</i> subsp. <i>spontaneum</i>	wild barley
<i>Hyoscyamus reticulatus</i>	henbane
cf. <i>Lathyrus aphaca</i>	yellow vetchling
cf. <i>Lathyrus blepharicarpos</i>	ciliate vetchling
<i>Lathyrus hierosolymitanus</i>	Jerusalem vetchling
<i>Lathyrus marmoratus</i> cf. <i>Vicia narbonensis</i> wild cf. <i>edible</i>	vetchling cf. purple broad vetch
<i>Lathyrus</i> sect. <i>cicercula</i>	vetchling
cf. <i>Lavandula coronopifolia</i>	stagshorn lavender
Lithospermeae	
<i>Lolium rigidum</i>	rigid ryegrass
<i>Lolium temulentum</i>	darnel ryegrass

<i>cf. Lotus peregrinus</i>	bird's foot trefoil
<i>Malva aegyptica</i>	Egyptian mallow
<i>Malva parviflora</i>	cheeseweed mallow
<i>Medicago astroites</i>	medick
<i>Medicago polymorpha/marina</i>	bur clover/sea medick
<i>Medicago tuberculata</i>	medick
<i>Melilotus sulcatus</i>	furrowed melilot
<i>Mesembryanthemum nodiflorum</i>	slenderleaf iceplant
<i>Moltkiopsis ciliata</i>	callous-leaved gromwell
<i>Neslia apiculata</i>	ball mustard
<i>Nonea echioides/melanocarpa</i>	monkswort
<i>Papaver</i> sp.	poppy
<i>Peganum harmala</i>	wild rue
<i>Phalaris minor</i>	small canary grass
<i>Phalaris paradoxa</i>	Mediterranean canary grass
<i>Picris</i> sp.	oxtongue
<i>cf. Pinus halepensis</i>	cf. Aleppo pine
<i>Pistacia atlantica</i>	atlas pistachio
<i>Plantago chamaepsyllium/notata</i>	plantain
<i>Plantago ovata</i>	blond plantain
<i>Pteranthus dichotomus</i>	
<i>Pulicaria incisa</i>	
<i>Raphanus raphanistrum</i>	wild radish
<i>Rapistrum rugosum</i>	annual bastardcabbage
<i>Reseda muricata</i>	mignonette
<i>cf. Rhus coriaria</i>	cf. elm-leaved sumach
<i>Rumex</i> sp.	dock
Salsoleae	saltwort
<i>Scorpiurus muricatus</i>	prickly scorpion's-tail
<i>Silene colorata/decipiens</i>	catchfly
<i>Solanum villosum/nigrum</i>	hairy/black nightshade
<i>Spergula fallax</i>	spurry
<i>Suaeda</i> sp.	seepweed
<i>Tamarix aphylla</i>	athel tamarisk
<i>Teucrium capitatum</i>	cat-thyme germander
<i>Thesium humile/bergeri</i>	bastard toadflax
<i>Thymelaea</i> cf. <i>passerina/gussonei</i>	mezereon/sparrow-wort
<i>Thymelaea hirsuta</i>	shaggy sparrow-wort
<i>Trifolium campestre/glanduliferum</i>	field/glandular clover
<i>Trifolium</i> sp.	clover
<i>Trigonella arabica</i>	Arabian fenugreek
<i>Vaccaria hispanica</i>	cow cockle
<i>Verbascum</i> sp.	mullein
<i>Vicia hybrida/sericocarpa</i>	vetch
<i>Vicia palaestina/sativa</i>	Palestine/common vetch
<i>Vicia peregrina/narbonensis</i>	wandering/purple broad vetch
<i>Vicia sativa</i>	common vetch
<i>Vicia villosa/tenuifolia</i>	hairy/fine-leaved vetch
<i>Zilla spinosa</i>	spiny zilla

654 *Supplementary Table 5. Identified wood and charcoal taxa from Shivta, Nessana and Elusa*

Category	Taxon	English common name	SVT	NZN	HLZ
Fruit trees	<i>Ficus carica</i>	common fig	+	+	+
	<i>Ficus sycomorus</i>	Sycomore fig	-	+	+
	<i>Hyphaene thebaica</i>	doum palm	+	+	-
	<i>Olea europaea</i>	olive	+	-	+
	<i>Phoenix dactylifera</i>	date palm	+	-	-
	<i>Prunus</i> spp. (<i>dulcis/armeniaca</i>)	plum/apricot	+	+	-
	<i>Punica granatum</i>	pomegranate	-	+	-
	<i>Vitis vinifera</i>	grapevine	+	+	-
Exotic trees	<i>Buxus sempervirens</i>	boxwood	+	+	-
	<i>Cedrus libani</i>	cedar of Lebanon	+	+	-
	<i>Fraxinus excelsior</i>	European ash	-	+	-
Desert trees and shrubs	<i>Calotropis procera</i>	apple of Sodom	+	+	-
	<i>Capparis spinosa</i>	caper bush	+	-	-
	<i>Fagonia mollis</i>	fagonia	-	+	-
	<i>Juniperus phoenicea</i>	Phoenician juniper	+	+	-
	<i>Lycium</i> spp.	boxthorn	+	+	+
	<i>Moringa peregrina</i>	Ben tree	+	-	-
	<i>Pistacia atlantica</i>	Persian turpentine	+	+	-
	<i>Populus/Salix</i>	poplar/willow	-	+	-
	<i>Retama raetam</i>	white broom	+	+	+
	<i>Rhamnus</i> spp.	buckthorn	+	+	+
	<i>Salsola tetrandra</i>	saltwort [tetrandra]	+	-	-
	<i>Salsola vermiculata</i>	Mediterranean saltwort	+	+	-
	<i>Tamarix</i> spp.	tamarisk	+	+	+
	<i>Ziziphus/Paliurus</i>	jujube/Jerusalem thorn	+	+	+
<i>Zygophyllum dumosum</i>	bushy bean caper	+	+	-	
Mediterranean trees and shrubs	<i>Crataegus</i> spp.	hawthorn group/Maloideae	+	+	+
	<i>Cupressus sempervirens</i>	Italian cypress	+	+	+
	<i>Myrtus communis</i>	true myrtle	-	+	-
	<i>Pinus halepensis</i>	Aleppo pine	+	+	+
	<i>Pistacia palaestina</i>	terebinth	+	+	+
	<i>Platanus orientalis</i>	oriental plane	-	+	+
	<i>Quercus calliprinos</i>	Kermes oak	+	-	+
	<i>Vitex agnus-castus</i>	chaste tree	-	+	-

655 *Data for Shivta and Nessana derive from Langgut et al. 2021, Table 1 [59]; Data for Elusa are based*
 656 *on Bar-Oz et al. 2019, Table S8 [43].*

657 *Supplementary Table 6. Identified pollen from Shivta reservoirs and garden*

Taxon	English common name	S reservoir	N reservoir	N church
<i>Artemisia</i>	sagebrush	+	+	+
<i>Asphodelus</i>	asphodels	-	+	+
Asteraceae Asteroideae type	aster-like	+	+	+
Asteraceae Cichorioideae type	dandelion-like	+	+	+
Brassicaceae	mustards	+	+	+
<i>Bunium</i> type	cabbage family	+	+	+
<i>Calendula</i>	marigold	+	-	-
<i>Carduus</i>	plumeless thistles	-	-	-
<i>Carthamus</i>	distaff thistle	+	-	+
Caryophyllaceae	pinks	-	+	+
<i>Cedrus</i>	cedar	+	+	+
<i>Centaurea</i>	knapweeds	-	+	+
<i>Ceratonia siliqua</i>	carob	+	-	+
Cerealina	cereals	+	+	+
Chenopodiaceae	chenopods	+	+	+
<i>Cistus</i>	rock rose	+	+	-
<i>Corylus</i>	hazel	+	-	+
<i>Crocus</i>	crocus	-	+	-
Cyperaceae	sedges	+	+	+
<i>Ephedra</i>	Mormon-tea	+	+	+
Fabaceae	legumes	+	+	+
<i>Ferula</i> type		-	+	+
<i>Fraxinus</i>	ash	+	+	+
<i>Geranium</i>	cranesbill	+	+	+
Juniperus/Cupressus	juniper/cypress	+	+	+
<i>Lemna</i>	duckweeds	-	+	-
Liliaceae	lilies	+	+	+
Malvaceae	mallows	-	+	+
<i>Myrtus communis</i>	true myrtle	-	-	+
<i>Nymphaea</i>	water lilies	+	+	+
<i>Olea europaea</i>	olive	+	+	+
<i>Phoenix dactylifera</i>	date palm	+	+	+
Pinaceae	pine family	-	+	+
<i>Pinus</i>	pine	+	+	+
Plantaginaceae	plantains	+	+	+
Poaceae	grasses	+	+	+
Polygonaceae	knotweeds	+	+	+
<i>Potamogeton</i>	pondweed	-	+	-
Ranunculaceae	buttercup	-	+	-
<i>Rumex</i>	docks	-	-	+
<i>Salix</i>	willow	+	+	+
<i>Scilla</i>	squills	-	+	-
<i>Sparganium</i>	bur-reeds	-	-	+
<i>Tamarix</i>	tamarisk	-	-	+
Thymelaeaceae	sparrow-wort	+	+	+
<i>Ulmus</i>	elm	-	+	-
<i>Vitis vinifera</i>	grapevine	+	+	+
<i>Zygophyllum</i>	bean-caper	-	-	+

658 **Supplementary Information**

659 *Field and laboratory extraction methods*

660 Eleven middens from the three sites, Elusa, Shivta and Nessana, were excavated at
661 approximately 10 cm height intervals to ensure chronological control (Figure 1 of main text).
662 Loci and baskets were assigned by a combination of stratigraphy and sediment features
663 during excavation. A three-pronged sifting strategy was adopted to maximize retrieval of
664 artifacts and biological remains, while enabling complementary resolutions of analysis. All
665 excavated material was sifted at one of three different levels, corresponding to sieve sizes: (1)
666 Most excavated sediment was dry screened on site through 5 mm sieves. (2) Wet screening
667 through 1 mm mesh was performed on two buckets (~20 l) from each excavated locus-basket.
668 (3) One additional bucket from each locus-basket was set aside for fine screening. Selected
669 buckets of sample sediments were divided into 3-liter subsamples which were processed by
670 flotation or fine-mesh dry screening, and sieved using graduated sieves at 4 mm, 2 mm, 1
671 mm, 0.5 mm and sometimes 0.3 mm mesh sizes. One additional source of identified seeds
672 was an assemblage of dissected charred dung pellets from two of the middens (Dunseth et al.
673 2019).

674 For ease of reference, (1) and (2) above are collectively referred to as *course sift samples* and
675 (3) is referred to as *fine sift samples*. Due to the high volume of samples and the extremely
676 high concentration of seeds within them, a subsampling strategy based on sieve mesh size
677 was adopted for the fine sift samples. All flotation light fraction and heavy residues were
678 sorted at the ≥ 2 mm mesh size. Light fraction was studied at 1 mm and 0.5 mm mesh sizes
679 for select samples, such that at least three 1 mm samples and one 0.5 mm sample were sorted
680 for each period on each site. Fine sift samples were sorted using an Olympus SZX9 stereo
681 microscope. Course sifted samples were sorted by volunteers and archaeology students
682 during the excavation and thereafter. Seed finds from the course sifting were visually
683 examined with aid of a stereo microscope, and rare specimens taken to the Bar-Ilan
684 University Archaeobotany Lab for identification.

685 On-site screening through 5mm sieves enabled very large volumes of sediment to be screened
686 – nearly all excavated sediments were sifted in this way. As a result, course sifting
687 demonstrated the ubiquity of dates and olives in all sites and periods, which would have been
688 missed from fine sifting only. It also allowed for the discovery of less common large-seeded
689 species; cherry/plum, pistachio, walnut, jujuba, fava bean and white lupine would have been

690 missed entirely by exclusive fine sifting with its smaller sample volumes. This is reflected in
691 the shorter species list in Table 2 of the main text, which records fine-sift retrieval only, in
692 comparison with Table 1, which records course sift and fine sift retrieval. Since the same
693 positive bias for retrieval of large seeds by 5mm sieves applies to both olive pits and date
694 stones on one hand and those of cherry/plum, pistachio, walnut and jujuba on the other, this
695 level of sifting facilitated the distinction between staple fruit crops and luxury/supplementary
696 ones.

697 Wet screening through 1 mm mesh also allowed for processing of a greater sample volume
698 (up to 20 l per locus-basket) than for the fine sift samples (3 l per locus-basket), providing
699 additional qualitative and quantitative data for most of the major domesticated plant seeds.
700 Ratios of cereal grains to grape pips from wet screening and fine sifting were shown to be
701 equivalent, enabling wet-screened samples to complement fine-sifted samples in quantitative
702 analysis (Fuks et al. 2020). Wet screening through 1 mm mesh and sorting by volunteers is a
703 cost-effective method for discovering the main domesticated plant species on site, but it
704 provides incomplete coverage.

705 As long-recognized in archaeobotany, fine-mesh sifting enabled retrieval of a much wider
706 range of plants. Without it, we would have entirely missed the presence of fig drupelets on
707 site, let alone their high ubiquity. Evidence for crop processing, especially of cereals, derived
708 exclusively from the fine sifting, as did the vast majority of wild/weed seeds. In addition, the
709 subsampling strategy by mesh size proved highly effective in maximizing species retrieval
710 and quantitative comparison between contexts. Sorting 100% of fine sift sediments at the 2
711 mm+ mesh size enabled full recovery of all major domesticated species except figs.

712 Subsampling material retrieved from 1 mm and 0.5 mm sieves enabled a balance to be met
713 between constraints and coverage of small finds. These sieve sizes produced the bulk of
714 cereal rachis fragments, fig drupelets and remains of most identified wild/weed taxa.

715 Altogether, the above multi-pronged sifting strategy effectively maximized retrieval of plant
716 remains and contributed to the high diversity of identified taxa. This, together with the focus
717 on organically rich rubbish middens and a multi-site micro-regional approach produced a
718 dataset that is relevant on a macro-regional and Holocene-wide scale.

719

720 *Seed identification*

721 Identifications were performed with reference to the Israel National Collection of Plant Seeds
722 and Fruits at Bar-Ilan University. Cereal grain morphometry was employed to identify
723 candidates, using the Computerized Key of Grass Grains developed by Mordechai Kislev's
724 laboratory (Kislev et al. 1992; 1997; 1999). As aids to identification and analysis, local plant
725 guides were consulted, particularly the *Flora Palaestina* (Zohary and Feinbrun-Dothan,
726 1966–1986). Additional floras of Mediterranean, Irano-Turanian and Saharo-Arabian
727 phytogeographic regions were consulted as needed (Townsend and Guest 1966–1985;
728 Meikle, 1977, 1985; Zohary et al. 1980–1994; Feinbrun-Dothan et al. 1998; Turland, 1993;
729 Boulos, 1999–2005; Davis, 1966–2001; Danin, 2004). To confirm identification, the jujuba
730 (*Ziziphus jujuba*) endocarp was scanned using a micro-CT (Bruker desktop SkyScan 1174) at
731 the Laboratory of Bone Biomechanics, Hebrew University of Jerusalem (Supplementary
732 Videos 1-2).

733 Identification criteria for rare, domesticated plant specimens discussed in the main text are
734 summarized below:

735 *Aubergine (Solanum melongena L.)*

736 *S. melongena* and other *Solanum* seeds are laterally compressed, broadly oval-shaped and
737 under 5 mm in maximal length. *S. melongena* seeds are distinguished from wild *Solanum*
738 seeds of the southern Levant by their larger size, reticulated seed coat pattern, and the wide
739 ovoid hilum set in a recess in the seed's lateral outline (Van der Veen and Morales 2011: 93;
740 Amichay and Weiss 2020: 679). This includes *S. incanum* L. which was identified at
741 Byzantine Ein Gedi and is considered by some to be the wild progenitor of *S. melongena*
742 (Melamed and Kislev 2005). The latter two criteria also distinguish *S. melongena* from
743 domesticated *Capsicum* spp. Based on these criteria, we identified three definitive *S.*
744 *melongena* seeds from Umayyad Shivta (Area E, Locus 504, Basket 5029). Poor preservation
745 precludes definitive identification for an additional three fragmented seeds from Umayyad
746 Nessana (Locus 102) for which *S. melongena* nonetheless appears to be the only candidate
747 (SI Figure 1).



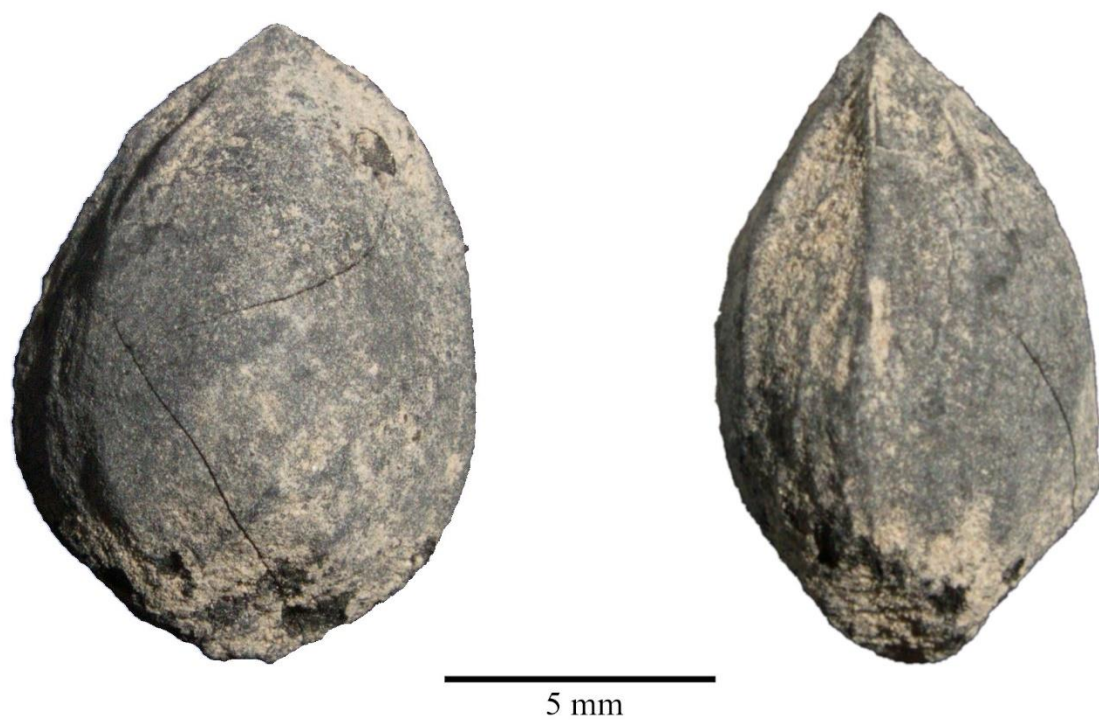
748

749 SI Figure 1. Left: *Solanum melongena* L. seed from Shivta (E 504-5029). Right: cf. *Solanum*
750 *melongena* from Nessana (A 102-1072-1).

751

752 *Cherry/plum (Prunus subgen. Cerasus/Prunus)*

753 A single ovoid endocarp with a pointed apex, elliptical base (5 mm by 2.5 mm), and smooth
754 surface was found in a course-sift sample from Umayyad Shivta (Area K1, Locus 165, Basket
755 1652; SI Figure 2). Its length from apex to base is 12.67 mm, width 9.33 mm, and breadth
756 7.67 mm. A ventral ridge runs down the length of the endocarp, from apex to base,
757 accompanied by two ridges on either side and at equal distance from the central ridge.
758 However, the right ventral ridge exists only on the top third of the endocarp while the left
759 ventral ridge is visible in the top two thirds. The dorsal side is marked by a single
760 longitudinal ridge. The above characteristics ruled out apricot, peach, and almond, and leave
761 cherry and plum as candidates (*Prunus* subgen. *Cerasus/Prunus*). Due to the wide variety of
762 plum and cherry cultivars (Depypere et al. 2007) not fully covered by the reference
763 collection, we did not identify to species.



764

765

766 SI Figure 2. *Prunus* subgen. *Cerasus*/*Prunus* endocarp from Shivta (K1 165-1652)

767

768

769 *Jujuba* (*Ziziphus jujuba* Mill.)

770 A single charred obconical-mucronate endocarp was found from Umayyad-period layers
771 from Shivta (Area E, Locus 501, Basket 5108). Micro-CT scanning (using a Bruker desktop
772 SkyScan 1174), demonstrated it to be spherically hollow with remnants of a partition (see
773 Supplementary Videos 1-2), confirming its status as a fruit endocarp. The external endocarp
774 dimensions (11.16 mm x 6.0 mm x 5.33 mm) and obconical with markedly narrowing apex
775 (SI Figure 3) are unique to certain varieties of *Ziziphus jujuba*. The specimen's pointed edges
776 tapered slightly and the external grooves characteristic of *Z. jujuba* are barely recognizable,
777 apparently the result of abrasion during or following charring. Remnants of the characteristic
778 v-shaped basal scar between the two endocarp halves (Jiang et al. 2013, their Fig. 6) are
779 barely visible, again likely due to abrasion. Species with similar endocarps include local wild
780 types of *Ziziphus* (*Z. spina-christi*, *Z. lotus*, *Z. nummalaria*), however these are always
781 spherical and never obconical-mucronate to the extent of *Z. jujuba* and the specimen at hand.



782

5 mm

783

SI Figure 3. *Ziziphus jujuba* Mill. endocarp from Shivta (E 501-5108)

784

785 *Nile acacia* (*Vachellia nilotica* (L.) P.J.H.Hurter & Mabb.)
786 *Vachellia* (syn. *Acacia*) is a genus in the Mimosoideae subfamily of the Fabaceae. Seeds of
787 Mimosoideae species native to the southern Levant are elliptical to ovate and compressed. On
788 each face of the seedcoat a conspicuous pleurogram delimits an ovate areole (Gunn 1984; Al-
789 Gohary and Mohamed 2007). The pleurogram may either be open-ended, i.e. U-
790 shaped/horseshoe-shaped, or closed, concentric to the seed contour. To identify seeds with
791 these traits found in the middens, we compared seeds of Mimosoideae species native to the
792 southern Levant, based on samples in the Israel National Collection of Plant Seeds and Fruits:
793 (i) *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb.) syn. *Acacia nilotica* (L.) Willd. ex Delile;
794 (ii) *Senegalia laeta* (R.Br. ex Benth.) Seigler & Ebinger syn. *Acacia laeta* R.Br. ex Benth.;
795 (iii) *Acacia pachyceras* O. Schwartz; (iv) *Vachellia tortilis* subsp. *raddiana* (Savi) Kyal. &
796 Boatwr. syn. *Acacia raddiana* Savi; (v) *Vachellia tortilis* (Forssk.) Galasso & Banfi syn.
797 *Acacia tortilis* (Forssk.) Hayne; (vi) *Faidherbia albida* (Delile) A.Chev.; and (vii) *Prosopis*
798 *farcta* (Banks & Sol.) J.F.Macbr. We observed that *V. nilotica* seeds are distinguished by the
799 following characteristics:

- 800 1) The pleurogram's border (linea fissura) is closed, creating an ovate areole (SI Figure
801 4).
- 802 2) The areole is largest, relative to seed size, in *V. nilotica*, i.e., the distance from the
803 linea fissura to the seed edge is shortest in this species (SI Table 1).
- 804 3) The areole's widest part is in the top third of the seed (SI Table 1; SI Figure 4).
- 805 4) A protrusion is present next to the hilum which we observed to be unique to *V.*
806 *nilotica* seeds among the above species.

807 *V. nilotica* seeds tend to be the largest of the above except for *P. farcta*, although interspecies
808 diversity leads to size overlap between *V. nilotica*, *A. pachyceras* and *V. tortilis* subsp.
809 *raddiana* (SI Table 1). *P. farcta* seeds are like *Vachellia* spp. seeds in shape but tend to be
810 larger than most *Vachellia* seeds and more ovate to pear-shaped. Their pleurograms are
811 visibly open. *V. nilotica* seeds were identified using a combination of criteria (1)-(4) above in
812 midden samples from Elusa (Area A1, Locus 1/10a; A4, L. 4/06a-4/07a; SI Figure 4).
813 Remains of *Vachellia* were identified also in other Negev Highland sites: One seed from
814 Nessana (A, L. 125, B. 1446) was identified as *Vachellia* sp., while a single seed from Shivta
815 (K1, L. 153, B. 1579) could only be identified as *Vachellia/Prosopis farcta* due to poor
816 preservation.



817

818 SI Figure 4. *Vachellia nilotica* (L.) Willd. ex Delile seed faces A and B from Elusa (A1/10a)

819

820 *SI Table 1. Some Acacia spp. seed measurements from the Israel National Collection of Plant*
 821 *Seeds and Fruits*

Species	Population	seed #	seed face (A/B)	seed length (mm)	seed width (mm)	areole length (mm)	areole width (mm)	(seed width-areole width)/seed width	(seed length-areole length)/seed length	max. areole width
<i>A. nilotica</i>	Elusa A, archaeological	1	A	7.5	6.0	6.0	4.2	0.30	0.20	a
<i>A. nilotica</i>	Elusa A, archaeological	1	B	7.5	6.0	6.1	4.1	0.32	0.19	a
<i>A. nilotica</i>	Elusa B, archaeological	2	A	5.7	4.7	5.3	3.6	0.23	0.07	a
<i>A. nilotica</i>	Luxor 1981	3	A	10.0	7.6	9.0	6.0	0.21	0.10	a
<i>A. nilotica</i>	Luxor 1981	3	B	10.1	7.7	8.9	5.6	0.27	0.12	a
<i>A. nilotica</i>	Luxor 1981	4	A	10.5	7.7	8.9	6.0	0.22	0.15	a
<i>A. nilotica</i>	Luxor 1981	4	B	10.5	7.7	8.8	6.0	0.22	0.16	a
<i>A. nilotica</i>	Luxor 1981	5	A	10.9	7.3	9.5	5.7	0.22	0.13	a
<i>A. nilotica</i>	Luxor 1981	5	B	10.6	7.0	9.5	5.0	0.29	0.10	a
<i>A. nilotica</i>	Luxor 1981	6	A	7.0	6.5	6.2	4.5	0.31	0.11	a
<i>A. nilotica</i>	Luxor 1981	6	B	7.0	6.4	6.0	4.5	0.30	0.14	a
<i>A. pachyceras</i>	Wadi Ram 26.2.95	7	A	9.2	6.9	6.2	3.2	0.54	0.33	c
<i>A. pachyceras</i>	Wadi Ram 26.2.95	7	B	9.1	6.7	6.6	3.2	0.52	0.27	c
<i>A. pachyceras</i>	Wadi Ram 26.2.95	8	A	10.5	8.0	7.4	4.2	0.48	0.30	a
<i>A. pachyceras</i>	Wadi Ram 26.2.95	8	B	10.5	8.0	7.8	3.9	0.51	0.26	a
<i>A. pachyceras</i>	Wadi Ram 26.2.95	9	A	10.6	6.5	7.9	3.5	0.46	0.25	b
<i>A. pachyceras</i>	Wadi Ram 26.2.95	9	B	10.4	6.4	7.8	3.6	0.44	0.25	b
<i>A. pachyceras</i>	Nahal Hayyun 15.3.71	10	A	8.1	5.7	5.0	2.7	0.53	0.38	a
<i>A. pachyceras</i>	Nahal Hayyun 15.3.72	10	B	8.0	5.7	5.1	2.5	0.56	0.36	a
<i>A. pachyceras</i>	Nahal Hayyun 15.3.73	11	A	8.5	5.8	6.4	3.3	0.43	0.25	b
<i>A. pachyceras</i>	Nahal Hayyun 15.3.74	11	B	8.5	5.8	6.3	3.2	0.45	0.26	b
<i>A. pachyceras</i>	Nahal Hayyun 15.3.75	12	A	7.7	6.2	6.0	3.6	0.42	0.22	b
<i>A. pachyceras</i>	Nahal Hayyun 15.3.76	12	B	7.5	6.2	6.0	3.6	0.42	0.20	b
<i>A. raddiana</i>	Moje Awad	13	A	7.9	5.8	5.4	3.5	0.40	0.32	e
<i>A. raddiana</i>	Moje Awad	13	B	7.9	5.7	5.2	3.5	0.39	0.34	e
<i>A. raddiana</i>	Moje Awad	14	A	9.7	6.5	7.0	3.8	0.42	0.28	d
<i>A. raddiana</i>	Moje Awad	14	B	9.6	6.5	7.0	4.0	0.38	0.27	c
<i>A. raddiana</i>	Moje Awad	15	A	8.1	5.9	5.5	3.8	0.36	0.32	c
<i>A. raddiana</i>	Moje Awad	15	B	8.0	6.0	5.7	3.5	0.42	0.29	c
<i>A. raddiana</i>	Ein Gedi 19.5.1917	16	A	8.0	5.5	5.9	3.5	0.36	0.26	c
<i>A. raddiana</i>	Ein Gedi 19.5.1917	16	B	8.0	5.5	5.6	3.4	0.38	0.30	c
<i>A. raddiana</i>	Ein Gedi 19.5.1917	17	A	8.0	5.3	5.9	3.5	0.34	0.26	c
<i>A. raddiana</i>	Ein Gedi 19.5.1917	17	B	8.1	5.4	5.5	3.4	0.37	0.32	c
<i>A. raddiana</i>	Ein Gedi 19.5.1917	18	A	8.0	5.4	5.9	3.5	0.35	0.26	c
<i>A. raddiana</i>	Ein Gedi 19.5.1917	18	B	8.0	5.4	5.8	3.4	0.37	0.28	c

822 *Table uses Acacia as used in the reference accessions; for synonyms see text above. Max. areole width is based on distance from hilum: a)*
 823 *upper third (from hilum); b) upper third-midway; c) midway; d) midway-lower third; e) lower third*

824

825 *Spanish vetchling (Lathyrus clymenum L.)*

826 Identification of *Lathyrus clymenum* was based on morphological similarity to ancient *L.*
827 *clymenum* seeds identified from Tel Nami by Kislev (1993). Diagrams and measurements
828 reported by Sarpaki and Jones (1990) for a large number of *L. clymenum* seeds from Late
829 Bronze Age Akrotiri and Knossos were also used.

830 The following generalized description refers to the identified *L. clymenum* seeds from Shivta
831 and Nessana: The seeds are laterally compressed, nearly rectangular circumstance. In lateral
832 view, the radicle lies on the short side, perpendicular to the long side where the hilum lies (SI
833 Figure 5). The radicle forms a somewhat planar face, especially by comparison with the other
834 sides of the seed. The dorsal side (parallel to that on which the hilum lies), is conspicuously
835 carinated, whereas the ventral side was only moderately carinated. The hilum occupies over
836 half the length of the ventral side. It begins at one end of the ventral side (near the radicle)
837 and ends just before the circular lens. The thin seed coat is neither perfectly smooth nor
838 tuberculate but appears grainy at magnification of ca. 40X.

839 *L. clymenum* seeds were identified at Nessana, midden A (106-1255 cf. 106-1257; 101-1032)
840 and several from midden K at Shivta (153-1588,1610; 158-1618; 166-1658; 169-1678,1703;
841 172-1689). The positions, shapes and relative sizes of the hilum and lens matched those of
842 the Tel Nami *L. clymenum* seeds and the depictions in Sarpaki and Jones (1990). The same is
843 true for seed coat thickness and texture, as well as the markedly carinated dorsal side. One
844 seed from Shivta (K1, 153-1588) measured below than the range of Tel Nami seed
845 dimensions (SI Table 2). However, its relative dimensions and clear morphology justified
846 unequivocal identification as *L. clymenum*.

847

848 *SI Table 2. Select L. clymenum seed measurements from Tel Nami*

Seed	L (mm)	B (mm)	T (mm)	L/B	L/T
1	4.3	2.3	3.6	1.87	1.19
2	4.6	2.4	3.9	1.92	1.18
3	4.2	2.2	3.05	1.91	1.38
4	3.6	2.75	2.9	1.31	1.24
5	3.3	2.5	3.5	1.32	0.94
mean	4.00	2.43	3.39	1.66	1.19
s.d.	0.48	0.19	0.37	0.29	0.14



SI Figure 5. *Lathyrus clymenum* L.
seed from Shivta, midden K.
Length ca. 3.5 mm.

849

850 *White lupine (Lupinus albus L.)*

851 Three species of lupine (*Lupinus*) which grow today in the southern Levant are distinct for
852 their large (ca. 1 cm), compressed quadrangular seeds: *L. palaestinus*, *L. pilosus*, and the
853 cultivated *L. albus*. Viewed laterally, the seeds of these species have a near-circular, or D-
854 shaped outline and, frequently, a visible depression or dimple. The triangular radicle forms
855 the perimeter's straightest side, while the hilum leads from the radicle tip toward the lens at
856 an angle such that the lens and radicle are on perpendicular sides with the hilum cutting
857 across between the two. The lens is nearly as large as the hilum and both are elliptic. The
858 seed coat surrounds the hilum by a characteristic elliptical protrusion. Throughout, the seed
859 coat consists of at least two layers visibly distinct in cross-section, with the outer layer having
860 a smooth surface and the inner layer having a grainy surface. As is common among
861 domesticated legumes in general, the seed coat of cultivated *L. albus* is much thinner than its
862 local wild relatives. An additional feature distinguishing *L. albus* seeds from *L.*
863 *palaestinus/pilosus* is the presence of a clear transverse ridge separating the radicle
864 depression and the hilum on the seed surface. In *L. palaestinus/pilosus*, by contrast, the
865 radicle depression and hilum are essentially contiguous, running smoothly one into the other.

866 Three candidates for lupine seeds were identified among course-sifted archaeobotanical
867 remains from Nessana (Area A, Locus 101, Baskets 1008/1 and 1040/2). The single seed
868 from Basket 1040 (SI Figure 6) is compressed with a lateral depression and a near-circular
869 quadrangle in outline measuring 70 x 75 mm. Remains of a triangular radicle on the seed's

870 straight side are clearly visible. These features narrowed its identification to one of the three
871 aforementioned *Lupinus* species. Both lens and hilum are visible; their shape and orientation
872 match those of *Lupinus* seeds. A slight but clear protrusion separating the hilum from the
873 radicle depression warrant identification as *Lupinus albus*. Remnants of a thin and grainy
874 seed coat are visible in the center of the cotyleda's surface, in the middle of the lateral
875 depression.

876 Two additional seeds from Basket 1008/1 show characteristic lupine (*Lupinus* sp.) hila and
877 radicle. The seeds measure 65 x 70 mm and 75 x 80 mm which, together with their D-shaped
878 outlines, corresponds with that typical to the large lenticular lupine species mentioned above.
879 The two seeds from basket 1008/1 are broader than the *L. albus* seed from Basket 1040/2, and
880 the characteristic lateral depression is not visible. This is apparently due to lateral swelling
881 and partial disfiguration during charring as is common in charred legume seeds. In the larger
882 of the two seeds, a thin, grainy seed coat is visible surrounding the triangular radicle and
883 covering one of the cotyleda. In that same seed, a topographic separation between the radicle
884 depression and hilum justifies identification as *L. albus*.



890 SI Figure 6. *Lupinus albus* L.

891 seed faces A and B from Nessana (A 101-1040/2)

892

893 *Radiocarbon dating*

894 Periodization of the studied assemblages followed those used by Fuks et al. (2020), based on
895 ceramic typologies and previous radiocarbon dates (Bar-Oz et al. 2019). In this study we
896 dated the loci-baskets containing unprecedented finds for southern Levantine archaeobotany,
897 as well as the locus containing well-preserved aubergine seeds in Shivta. The aubergine,
898 lupin and jujuba seeds were too rare to sacrifice for direct radiocarbon so barley grains were
899 selected from the very same sediment sample within each locus-basket. Radiocarbon dating

900 was performed by the Poznan Radiocarbon Laboratory, and calibration was made with the
901 OxCal v4.4.2 (Bronk Ramsey 2020), using atmospheric data from Reimer et al (2020). All
902 dates reflect assemblages from the Early Islamic period (Table 4).

903 Although the calibrated ranges vary, the sample containing aubergine (*S. melongena*) falls
904 within the Abbasid period at the 95% confidence level; samples containing white lupin (*L.*
905 *albus*) and jujuba (*Z. jujuba*) are either Umayyad or from the early Abbasid period (mid-7th –
906 late 8th c. cal. CE).

907

908 *Micro-CT scanning*

909 Micro-CT scans on the *Z. jujuba* endocarp were conducted by Senthil Ram Prabhu
910 Thangadurai at the Laboratory of Bone Biomechanics, Hebrew University of Jerusalem.
911 Optical resolution (pixel size): 9.6 µm; exposure: 4500 ms; rotation step: 0.400 degrees; 180
912 degree rotation option was used; 0.25 mm thick aluminium filter. The scans confirmed
913 identification as an endocarp by revealing its hollow inner structure and partition. For full
914 identification criteria see above. The following scanning files are attached to this article:

915 *SI Video 1* – Micro-CT longitudinal scans of *Z. jujuba* endocarp.

916 *SI Video 2* – Micro-CT lateral scans of *Z. jujuba* endocarp.

917

918 *References to Supplementary Information*

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