Vegetation History and Archaeobotany (2023) 32:501–516
https://doi.org/10.1007/s00334-023-00938-w

ORIGINAL ARTICLE

Processing and storage of tree fruits, cereals and pulses at PPNA Sharara, southern Jordan

Jade Whitlam[1] · Bill Finlayson[1] · Amy Bogaard[1,2] · Michael Charles[1] · Cheryl A. Makarewicz[3]

Received: 14 March 2023 / Accepted: 7 June 2023 / Published online: 26 July 2023

Abstract

Recent excavations at the Pre-Pottery Neolithic A site of Sharara (ca. 9250 cal BC) in southern Jordan have yielded a rich assemblage of charred macrobotanical remains. The bulk of this assemblage was recovered from a single structure at the settlement that was destroyed by fire and which appears to have functioned as an area for processing and possibly also for storing plant foods. Among the charred plant remains recovered from this space were nearly 700 fig fruits. Based on detailed archaeobotanical and contextual analyses, we infer that these were laid out to dry on the roof of the structure when it burnt down. We also demonstrate that plant exploitation and processing strategies at Sharara focused on a range of wild cereals, pulses and tree fruits (fig and pistachio), including several taxa that are not part of the canonical 'Neolithic founder crop package'. We discuss our findings in relation to broader understandings of pre-agricultural plant management in southwest Asia and within the southern Levant specifically.

Keywords Southwest Asia · Early Holocene · *Ficus carica* (fig) · *Lathyrus inconspicuus* (inconspicuous pea) · Cereal processing

Introduction

The emergence of farming in southwest Asia was a protracted and multicentric process, underwritten by local innovations in plant and animal management that took place alongside widespread social, technological and ideological transformations in the Early Holocene. Crucially, it was the systematic cultivation of wild crop progenitors, termed 'pre-domestication cultivation' (PDC), and the annual cycle of soil tillage, sowing and harvesting that this entailed, which led to the eventual domestication of these species (Harlan et al. 1973; Harris 1989; Zeder 2015). To date, PDC has been identified at a number of sites across the Fertile Crescent, beginning in the Pre-Pottery Neolithic A (PPNA; 9700 – 8500 BC) (van Zeist and de Roller 1994; Kislev 1997; Colledge 1998; Hillman et al. 2001; Edwards et al. 2004; Weiss et al. 2006; Willcox et al. 2008; White and Makarewicz 2012; Riehl et al. 2013; Colledge et al. 2018). A key criterion used to support inferences of PDC, especially with respect to wild cereals, is the identification of associated arable weed species characteristic of cultivated (i.e. tilled) fields (Hillman et al. 2001; Willcox et al. 2008; White and Makarewicz 2012; Willcox 2012b; Riehl et al. 2013; Snir et al. 2015; Colledge et al. 2018). Recent studies, however, have questioned the validity of using the presence of potential arable weeds per se as a leading-edge marker of cultivation, demonstrating that many of these weed taxa co-occur with wild cereals in unmanaged stands and are indicative of untilled environments in terms of their functional ecology (Weide et al. 2021, 2022). In particular, previous claims of PDC at southern Levantine sites such as Netiv Hagdud and Gilgal I have been reassessed as instead reflecting intensive

Communicated by A. Weide.

Jade Whitlam
jade.whitlam@arch.ox.ac.uk

Bill Finlayson
bill.finlayson@arch.ox.ac.uk

Cheryl A. Makarewicz
c.makarewicz@ufg.uni-kiel.de

1 School of Archaeology, University of Oxford, 1 S Parks Rd, Oxford OX1 3TG, UK

2 Sante Fe Institute, Hyde Park Road, Sante Fe, NM 87501, USA

3 Institute for Prehistoric and Protohistoric Archaeology, University of Kiel, Johanna-Mestorf Straße 2-6, 24118 Kiel, Germany

gathering of wild stands (Weide et al. 2022). Similarly, the occurrence in early Pre-Pottery Neolithic assemblages of seeds of wild progenitor species that are similar in size to their domestic counterparts, the distribution of species outside their presumed biogeographic range, the presence of seeds in greater numbers than might be considered feasible by harvesting local wild stands, a decline in wild plant species abundances over time, and the storing and processing of plants for consumption and/or sowing, also present ambiguous lines of evidence for PDC (Colledge 2001; Weiss et al. 2006; Willcox 2012a).

With this in mind, it is necessary to step back and consider to what extent a focus on the progenitors of later domesticates and PDC, as currently conceptualised, imposes constraints on our understanding of early plant management in southwest Asia, especially in the PPNA. The danger in applying these terms uncritically is that we limit our understanding of the potential diversity of strategies practiced across the transition from foraging to farming. Recent excavations at the site of Sharara (ca. 9250 cal BC) in southern Jordan, have provided us with an opportunity to further reflect on these issues and contribute to understandings of pre-agricultural plant use and management in the southern Levant. Here, we report on the charred plant remains recovered from Sharara and interpret these in relation to available contextual, architectural, and artefactual data. We also present the results of metric and morphological analyses of cereal remains, which we use to assess their 'domestication' status at the site. However, we emphasise that grain size is plausibly a reflection of growing conditions rather than cultivation or domestication necessarily. Finally, we discuss our results in terms of plant use and potential management strategies employed at Sharara, drawing comparisons with other PPN datasets from the southern Levant and southwest Asia where relevant.

Sharara, an early PPNA site in the Wadi el-Hasa

Location, climate and vegetation

Sharara is located in the lower reaches of the Wadi el-Hasa, Jordan, approximately 10 km east of the southern end of the Dead Sea (31°0'40.72"N, 35°33'0.30"E, elevation 100 m a.s.l., Fig. 1a). Providing a pivotal access route between the rift valley and Jordanian Plateau, the Wadi el-Hasa served as a locus of intense human activity throughout the Early Holocene (Peterson 2004; Makarewicz et al. 2006; Makarewicz and Rose 2011). This topographically varied landscape is home to a number of other PPN sites, including el-Hemmeh, which has a PPNA phase dating between 9200 – 8600 cal BC (Makarewicz et al. 2006; White and Makarewicz 2012). El-Hemmeh lies approximately 20 km upstream of Sharara on an alluvial fan overlooking the wadi floodplain. In contrast, Sharara is situated on a rocky slope, high above a point

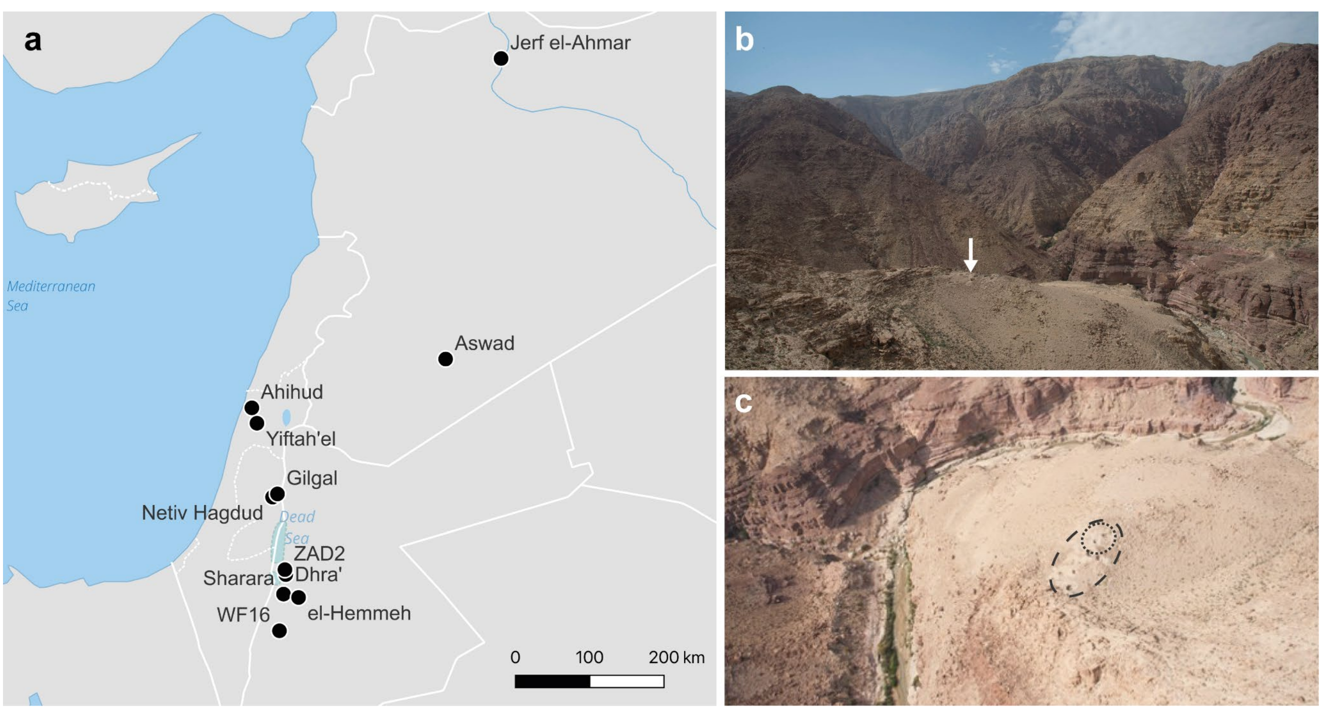

Fig. 1 **a** Map showing the location of Sharara and other sites mentioned in the text. **b** Position of Sharara (indicated by arrow) on a high rocky slope in the Wadi el-Hasa. **c** Aerial view of Sharara with the approximate extent of the PPNA settlement indicated by a dashed line and the approximate extent of excavations indicated by a dotted line

of marked constriction in the wadi where there would have been little opportunity for Holocene floodplain formation (Fig. 1b, c; Contreras, personal communication).

Today, the climate of the Wadi el-Hasa is characterised by hot, dry summers and cooler, wetter winters (Köppen-Geiger classification: Csa). Precipitation levels average 100–300 mm per year with the majority of rain falling in heavy downpours between the months of November and March. Lying at the southwestern edge of the Irano-Turanian phytogeographic zone, vegetation in the lower Wadi el-Hasa is generally sparse and dominated by dwarf shrubs, such as *Artemisia herba-alba* (white wormwood) (Zohary 1973). Trees and other hydrophyllic vegetation, including *Ficus carica* (fig), *Phragmites australis* (common reed) and *Nerium oleander* (oleander), are restricted to the wadi bottom or found growing in pockets around springs where they are protected from summer droughts and winter frosts (White 2013, p 47). During the Early Holocene warmer and wetter conditions prevailed across the arid zone of the southern Levant (Bar-Matthews et al. 1997; Robinson et al. 2006). Analysis of wood charcoal from el-Hemmeh indicates that woodland steppe would have covered much of the middle Wadi el-Hasa at this time, supporting *Pistacia* (pistachio)-dominated grasslands, with other vegetation communities including riparian woodland composed of Salicacae, *Fraxinus* (ash), *Tamarix* (tamarisk) and Chenopodiaceae shrubs (Asouti et al. 2015).

Excavations and archaeology

The Early PPNA settlement of Sharara consists of a loose scatter of structures spread over an area of ca. 0.5 ha. Three seasons of excavation between 2016 and 2019 focused on the western portion of the occupation where a series of stone structures corresponding to multiple phases of construction were uncovered, along with associated human burials (Fig. 1c). Among the structures identified was a sub-circular stone-built structure, probably semi-subterranean, that had been altered by numerous remodelling events and more recently damaged by illicit excavations (Space 5; Fig. 2a, b). The latest iteration of this structure was approximately 4 m in its internal diameter and featured a large cup-hole mortar set into a mud-plaster floor. The fill of the structure was outstandingly rich in charred plant remains and burnt structural material (e.g. supporting wood beams and reeds), indicating that it had collapsed as the result of a catastrophic fire. Other evidence to show Space 5 was heavily burnt included the red baked face of the wall plaster and blackening of the floor surface and cup-hole mortar.

Opposite Space 5 in the southern part of the excavation area a feature was uncovered that consisted of two channels running perpendicular to each other before joining up (the 'channel system' Fig. 2b). These channels appear to have been constructed sometime after Space 5, as part of a phase of extensive re-modelling at the site that also saw the area between these levelled out (the 'burial area'; Fig. 2b). This whole area was then covered over with a plaster floor that was subsequently burnt and covered with an accumulation

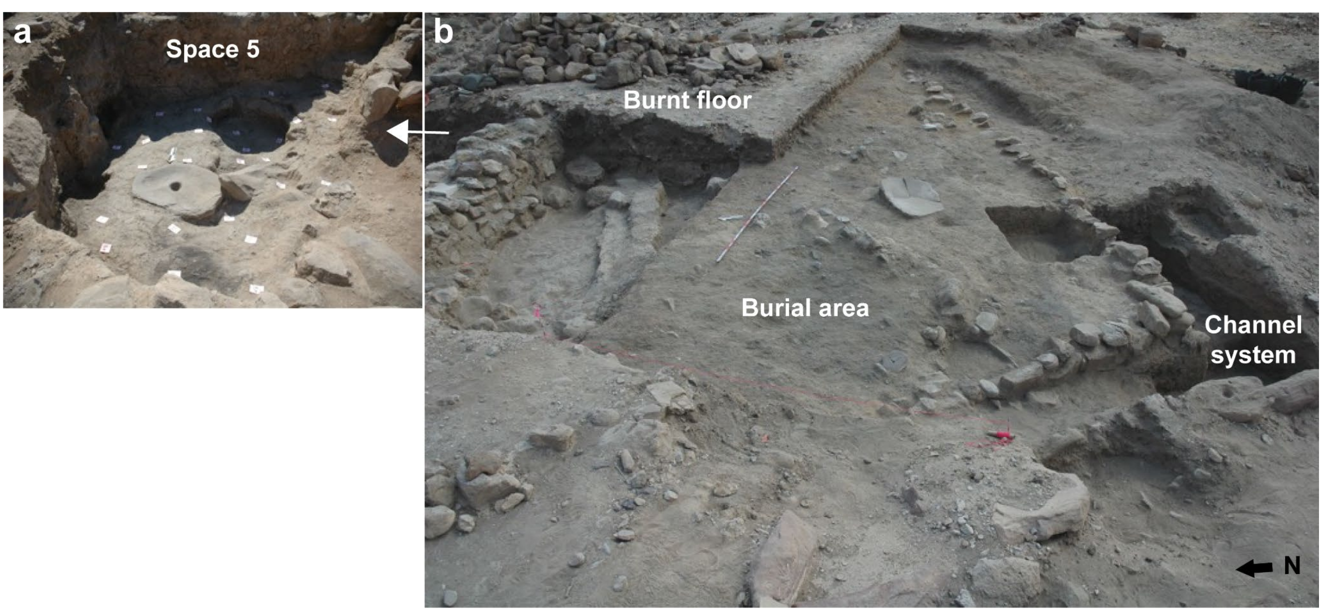

Fig. 2 **a** Space 5 at Sharara showing the cup-hole mortar set into a mud-plaster floor. The circular, sunken area to the upper right of the cup-hole mortar is where the floor has subsided in antiquity, indicating an area of soft deposits below. **b** Photo of the excavations at Sharara (taken in the 2017 season) with areas labelled as mentioned in the text

of silts and burnt material (unexcavated location labelled as 'burnt floor' Fig. 2b).

Materials and methods

Sampling and recovery

A total of 93 archaeobotanical samples representing 50 unique depositional events (contexts) were collected at Sharara between 2016 and 2019, as part of a systematic sampling programme. Twenty-one samples, including all nine samples collected in 2016, were hand-picked in the field, being visible as discrete deposits of charred plant remains during excavation. The remaining 72 samples were collected as bulk sediment samples (total 891 l) and processed by bucket flotation. A full description of samples is reported in ESM 1. Prior to flotation, sediment samples were dry-sieved through a 4 mm (2017 season) or 1 cm (2019 season) mesh to recover any larger plant macrofossils, such as fig fruits and wood charcoal. This additional step was taken to minimise potential damage and fragmentation of charred plant remains during flotation, which has been a significant recovery issue at other PPN sites in the Wadi el-Hasa (Peterson 2004; Shelton and White 2010). The sieved sediments were then processed by bucket flotation using a mesh with an aperture of ca. 250 µm to collect any floating plant material. Heavy residues were washed through a 1 mm sieve and any plant material that had failed to float was removed by hand.

Sorting and identification

All 72 floated and 21 hand-picked samples were exported to the School of Archaeology, University of Oxford for analysis. In the laboratory, samples were first rapidly scanned to evaluate their richness and botanical composition. Based on the results of scanning and in conjunction with spatial and contextual information, 39 samples estimated to contain 30 or more plant remains were chosen for detailed sorting and analysis. Before sorting, samples were separated into fractions by passing them through a stack of nested Endecott sieves with aperture sizes of 4 mm, 2 mm, 1 mm, and 0.3 mm. All coarse fractions (> 1 mm) were sorted in their entirety, along with 30 of the 39 fine fractions (< 1 mm > 0.3 mm). However, due to time constraints it was only possible to examine sub-samples of between 12.5 and 50% for nine of the more productive fine fractions. To allow for meaningful comparison between samples, counts from these fractions were multiplied up before data analysis to give an estimate of the total count that would be expected if 100% of the material for each sample had been sorted (i.e. if 50% of the fine fraction had been sorted then counts were doubled). Samples that originated from the same archaeological context and which were compositionally indistinguishable were also amalgamated to avoid unique depositional events being represented more than once in data analysis. After amalgamations, a total of 34 samples, representing 26 different contexts and 514 l of sediment remained.

Sorting and identification were undertaken using a Leica MZ75 stereomicroscope at magnifications of 6× to 50×. Scanning electron microscopy (SEM) using a Jeol JSM-5510 provided magnifications of up to 250,000× where necessary. Photographs and measurements of charred plant remains were obtained using either a PixeLINK camera attached to a Nikon SMZ25 stereomicroscope and coupled to a PC, assisted by PixeLINK Capture and NIS-Elements D software, or a Leica DFC495 camera attached to a Leica Z6 APO and coupled to a PC, assisted by LAS software. Identifications were made according to morphological characteristics, surface texture and size, and verified by comparison to modern reference material housed at the School of Archaeology, University of Oxford. Plant remains were quantified using the principle of recording the 'minimum number of individuals' (MNI) following Jones (1991). The volume (ml) of wood charcoal fragments > 2 mm in size was also recorded for each sample but no further analysis of this material was conducted. Nomenclature follows the *Flora Palaestina* (Zohary 1966, 1972; Feinbrun-Dothan 1978, 1986), except for family names where modern conventions have been applied. A seed catalogue providing detailed identification and quantification criteria along with photographs of representative specimens is provided in ESM 2.

Assigning 'wild'/'domestic' status of cereal remains

To assess the 'domestic' status of cereal remains at Sharara, both grain size and chaff morphology were examined. For *Hordeum spontaneum*/*vulgare* (barley), breadth and thickness measurements were obtained from all grains and grain fragments at their widest point. These data were then used to assign grains to 'wild', 'intermediate' and 'domestic' size categories, following criteria applied to specimens recovered from el-Hemmeh (White 2013, p 96). In this classification, barley grains were categorised as 'wild' if they had a breadth of 2.25 mm or less and a thickness of 1.5 mm or less, and 'domestic' if they had a breadth of 2.5 mm or more and a thickness of 1.5 mm or more. Grains falling between these two groups were categorised as 'intermediate'. For barley rachis internodes, specimens were grouped according to whether they exhibited a smooth (wild-type) or rough (domestic-type) abscission scar, following criteria described by Colledge (2001, p 65) and Tanno and Willcox (2012). Rachis remains that were missing their scar, normally along with part of their ventral surface, were recorded as 'ripped' following the description of similar morphological types identified at el-Hemmeh (White and Makarewicz 2012). If the abscission scar could not be confidently identified as belonging to one of these types, usually due to poor preservation of diagnostic morphology, then the scar was recorded as 'non-diagnostic'. The barley rachis was further classified according to whether any palea and lemma material remained attached to the top of the rachis internode. When present, this morphological feature gave specimens a characteristic spikey appearance (see ESM 2 and 3).

Glume bases of *Triticum dicoccoides/dicoccum* (emmer wheat) were categorised according to whether they possessed a flat (wild-type), lifted (domestic-type) or non-diagnostic abscission scar, following criteria laid out by Weide et al. (2015). 'Ripped' specimens, which displayed a morphology similar to that described above for barley, were also recorded. The small number of glume wheat grains recovered at Sharara and lack of species-level identifications ruled out metrical analyses.

Results

Summary of the assemblage

The 34 samples analysed in this study produced an estimated 19,400 charred macrobotanical remains, with densities ranging from < 1 to 391 items/l of sediment (see ESM 1). The vast majority of plant remains (*n* = 17,993) were produced by samples collected from Space 5, where the average sample density was 112 items/l. Samples collected from deposits outside of this space produced fewer charred plant remains, with an average density of four items/l. Preservation was generally good and, in some cases, exceptional. However, it was observed that many specimens lacked adhering sediment on broken surfaces, suggesting that some damage may have occurred during flotation. Taxa identified at Sharara included various cereals, pulses and tree fruits, as well as a range of wild grasses and other wild taxa. Uncharred plant remains, including Boraginaceae spp., *Aizoon* sp. and a single *Phoenix dactylifera* (date) stone were also recorded, representing potentially intrusive modern material, which has been excluded from the data analysis on this basis. Table 1 provides a summary of the charred macrobotanical assemblage with full data published in ESM 1.

Taxonomic composition of the assemblage

Cereals were ubiquitous at Sharara, present in 91% of the samples examined. Of the 640 cereal remains recorded, 85% were identified as belonging to barley, including 53 grains, 312 rachis internodes, 173 lateral florets and seven detached lemma bases (Table 1). The majority of barley grains (60%; *n* = 32) overlapped with wild barley in size, while 13% (*n* = 7) fell into the domestic size range. The remaining 27% (*n* = 14) of grains were intermediate in size between these two groups. More than half of the barley rachis internodes were classified as non-diagnostic in terms of their scar type (*n* = 172; Table 2a), with 54% of the remaining 140 diagnostic rachis exhibiting a smooth (wild-type) abscission scar, 21% a rough (domestic-type) abscission scar and 25% a ripped morphology, as described above. The majority of barley rachis internodes (65%), regardless of scar type, possessed palea and lemma attachments (Table 2a). Based on the size of barley grains and the proportions of different rachis morphologies present, we consider barley at the site to be morphologically wild, as discussed below.

Along with barley, glume wheats were also present at Sharara, although in significantly lower numbers, with a total of four grains and 47 glume bases recorded (Table 1). Twenty-nine glume bases were further identified as emmer wheat, more than half of which (*n* = 15) had abscission scars that were non-diagnostic to type (Table 2b), while the remaining 14 glume bases possessed either a flat (wild-type) abscission scar (29%), or a ripped morphology (71%). No lifted (domestic-type) scars were identified and we consider emmer to be morphologically wild on this basis. The rest of the cereal assemblage at Sharara was composed of indeterminate barley, wheat and cereal remains.

Pulses, while less ubiquitous than cereals, were present in nearly two-thirds of samples (65%; Table 1). However, in terms of abundance pulses were represented by fewer specimens and largely restricted to samples from Space 5, which produced 256 of the 273 pulses identified at the site. This included 102 of the 109 seeds of *Lens* sp. (lentil), the sole specimen of *Vicia ervilia* (bitter vetch) and all 56 seeds of *Lathyrus inconspicuus* (inconspicuous pea). The latter species, tentatively identified based on its morphological appearance and distinctive reticulate patterning of its testa (see ESM 2), has previously been documented from Early PPNB levels at Ahihud (Caracuta et al. 2017). Four fragments of pulse stalk were also recovered from Sharara. The remainder of the pulse assemblage was represented by seeds of *Vicia/Lathyrus* spp. and other indeterminate pulses.

Dominating the macrobotanical assemblage in terms of abundance were drupelets of fig, which accounted for nearly 90% of plant specimens identified in this study (*n* = 17,319; Table 1). Present in 82% of the samples examined, the vast majority of drupelets (*n* = 16,340) were produced by samples recovered from Space 5, accounting for the extremely high densities of charred plant remains recorded here. In addition to drupelets, 695 fig syconia (fruits) were also recovered. Many of these were preserved as whole fruits (Fig. 3), while others were represented by substantial fragments that

Table 1 Summary of the frequency of taxa and types identified in 34 PPNA samples from Sharara. Full data are published in the Tables of ESM 1

Taxa	Remain type	Sum	Presence	Ubiquity (%)
Cereals				
Hordeum spontaneum vel *vulgare*	Grain/rachis	53/312	19/25	56/74
Hordeum spontaneum vel *vulgare*	Lateral floret/lemma base	173/7	27/5	79/15
Hordeum sp. grain	Grain	9	8	24
Triticum dicoccoides/dicoccum	Glume base	29	9	26
Triticum sp. (glume wheat)	Grain/glume base	4/18	3/5	9/15
Triticum sp. (wheat indet.)	Internode frag.	6	3	9
Cereal indet.	Grain/embryo	17/12	14/7	41/21
Cereals total	All	640	31	91
Pulses				
Vicia ervilia	Seed	1	1	3
Lens sp.	Seed	109	15	44
Lathyrus inconspicuus	Seed	56	10	29
Vicia/Lathyrus spp.	Seed	24	9	26
Pulse indet.	Seed/stalk	79/4	17/3	50/9
Pulses total	All	273	22	65
Tree fruits				
Ficus carica	Fruit/stalk	695/11	10/6	29/18
Ficus carica	Drupelet	17,319	28	82
Pistacia sp.	Nutlet	82	31	91
Fruit vel nut indet.	Nut/flesh (pod)	3/1	2/1	6/3
Tree fruits total	All	18,111	34	100
Wild grasses				
cf. *Eremopyrum* sp.	Grain	1	1	3
Aegilops spp.	Spikelet base	4	4	12
Hordeum glaucum	Grain	20	8	24
Taeniatherum crinitum	Spikelet base	1	1	3
Bromus sp.	Grain	1	1	3
Avena sp.	Grain	1	1	3
Poa bulbosa	Bulbil	50	13	38
Poa sp.	Grain	2	2	6
Piptatherum holciforme/blancheanum	Grain	1	1	3
Stipa capensis	Grain	3	3	9
Stipa sp.	Grain/awn	7/24	6/22	18/65
Medium-seeded grass indet.	Grain	33	17	50
Wild grasses total	All	148	26	77
Wild (non-grass)				
Capparis sp.	Seed	7	4	12
Brassica/Sinapis	Seed	2	2	6
Brassicaceae spp.	Seed	5	2	6
Erodium sp.	Seed/beak	2/31	2/25	6/74
Small-seeded legumes	Seed	10	8	24
Malva sp./Malvaceae spp.	Seed	5/3	2/3	6/9
Ammi majus	Seed	1	1	3
Solanaceae sp.	Seed	1	1	3
Plantago sp.	Seed	12	4	12
Centaurea sp.	Seed	1	1	3
Asteraceae sp.	Seed	3	2	6
Indeterminate items	N/A	24	11	32
Wild (non-grass) total	All	107	30	88
Other				
cf. *Phragmites australis*	Node/nodal plate	87/12	14/5	41/15
cf. *Phragmites australis*	Rootlets, rhizome	19	3	9
Culm indet.	Node	3	1	3
Wood charcoal (> 2 mm)	Fragments (ml)	1,877	34	100
Rodent pellets	Pellets	63	6	18
Total no. items (not inc. rodent pellets or wood charcoal)		19,400		

Table 2 Morphological classification of chaff remains examined at Sharara as described in the text; **a**, scar type and presence of palea and lemma attachments on barley rachis, **b**, scar-type documented on emmer wheat glume bases

	Palea and lemma attachments	No palea and lemma attachments	Total
a			
Smooth (wild-type) scar	68	8	76
Rough (domestic-type) scar	11	19	30
Ripped scar	33	1	34
Non-diagnostic scar	90	82	172
Total	202	110	312
b			
Flat (wild-type) scar	4		
Lifted (domestic-type) scar	0		
Ripped scar	10		
Non-diagnostic scar	15		
Total	29		

have been converted to whole fruit counts based on volume (10 ml = 1 fig fruit; see ESM 2). Fig fruits were less ubiquitous than drupelets and present in only 10 samples (29%), nine of which originated from Space 5. The remaining sample was collected during excavation of the burnt floor deposits south of Space 5 and produced only a single syconium (Sample BOT 017/051, Context 1013). Fig fruits recovered at Sharara compare favourably to modern dried figs in terms of their gross morphology (see ESM 2), and SEM indicates crystalline structures on the outer surface of these archaeological specimens similar to those that form on the surface of the fruit skin during the drying process (Cartwright 2003). Other tree fruits represented at Sharara include *Pistacia* sp. (pistachio) nutlets, which were found in 91% of samples (Table 1). No whole pistachio nutlets have been found at the site however and MNIs were calculated based on the fragmented remains of nutshell (see ESM 2).

A range of wild grasses were also recovered from deposits at Sharara. These included *Poa bulbosa* (bulbous meadow-grass; $n=50$), *Hordeum glaucum* (syn. *H. murinum* ssp. *glaucum* (Steud.) Tzvelev; wall barley; $n=20$) and *Stipa* spp. (feathergrass; $n=34$), which together accounted for 70% of the grass specimens identified during this study (Table 1). *Hordeum glaucum* was represented exclusively by grains, while the majority of *Stipa* remains (71%) corresponded to the tightly spiralled awn of this grass rather than its seed. *Poa bulbosa* meanwhile was represented by its distinctive bulbils, which have previously been reported from PPNA levels at el-Hemmeh (White and Makarewicz 2012), as well as from Netiv Hagdud where they were interpreted as a potential food (Kislev 1997). Other wild grasses present at Sharara included *Aegilops* spp. (goatgrass) and *Taeniatherum crinitum* (syn. *T. caput-medusae* (L.) Nevski; medusa-head grass), both represented by their chaff, along with *Avena* sp. (oat), *Piptatherum holciforme/blancheanum* (ricegrass) and *Bromus* sp. (brome grass), which were each represented by a single grain (Table 1). A narrow spectrum of other wild (non-grass) taxa were identified at the site (Table 1). Of these, only *Erodium* sp. (storksbill), *Plantago* sp. (plantain) and small-seeded legumes were identified in more than 10% of samples, whilst also being represented by more than 10 items. *Erodium* sp. was the most ubiquitous (74%) and abundant ($n=33$) of the wild (non-grass) taxa,

Fig. 3 Selection of well-preserved whole fig fruits recovered from Space 5 at Sharara with stalk attachments (top row) and ostioles (bottom row) clearly visible. Photo by Ian Cartwright, University of Oxford; scale bar, 10 mm

with all but two *Erodium* specimens corresponding to the spiralled beak of the fruit rather than the seed.

Finally, a number of non-seed/fruit remains were present at Sharara. These included wood charcoal, which was identified in every sample examined (total volume = 1,877 ml) and reed culm, which was present in 41% of samples and represented by 118 items (Table 1). The majority of wood charcoal (1,220 ml) and reed culm remains (n = 95) were produced by samples collected from Space 5. Based on preliminary morphological analysis, reed culm remains have been identified as *Phragmites australis* (see ESM 2). However, some culm specimens may belong to *Arundo donax* (giant reed) and the presence of this species cannot be ruled out, especially given that morphologically diagnostic phytoliths representing both species have been identified from the same deposits at the site (Elliott, personal communication). Finally, non-botanical remains in the form of charred rodent pellets (n = 63) were recovered from six samples at Sharara (18%), the majority of which (n = 59) were found in three samples from Space 5.

Spatial distribution of charred plant remains at Sharara

Figure 4 illustrates the proportion of major plant categories recovered from different areas of Sharara, with fig drupelets removed to reveal underlying patterns in the data. Even after excluding fig drupelets, Space 5 stands out in terms of its richness, yielding more than 10 times as many charred plant remains as any other area. In part, this richness can be accounted for by the greater number of samples representing this space (14 samples). However, it also reflects the fact that individual samples from these deposits were more productive, with an average density of 37 items/l (excluding drupelets) compared to < 1 item/l for samples from the burnt floor and ca. 2 items/l for samples from the burial area and channel system. Compositionally, Space 5 is also an outlier, with fig fruits accounting for nearly half (45%; n = 694) of all the plant remains recovered here and pulses 17% (n = 256). In contrast, across the burnt floor, burial area and channel system, pulses were rare (Fig. 4), while only a single fig fruit was recorded, produced by a sample from the burnt floor deposits adjacent to Space 5 as previously stated. Beyond differences in the distribution of fig fruits and pulses, samples across the site were broadly comparable in their composition, with similar proportions of cereal grain, cereal chaff, pistachio, wild grasses and wild (non-grass) taxa. One explanation for this compositional consistency is that the charred plant remains recovered from areas outside of Space 5 represent material that has been redeposited from this space. Re-deposition might have occurred as a direct result of PPNA activities at the site or might simply reflect

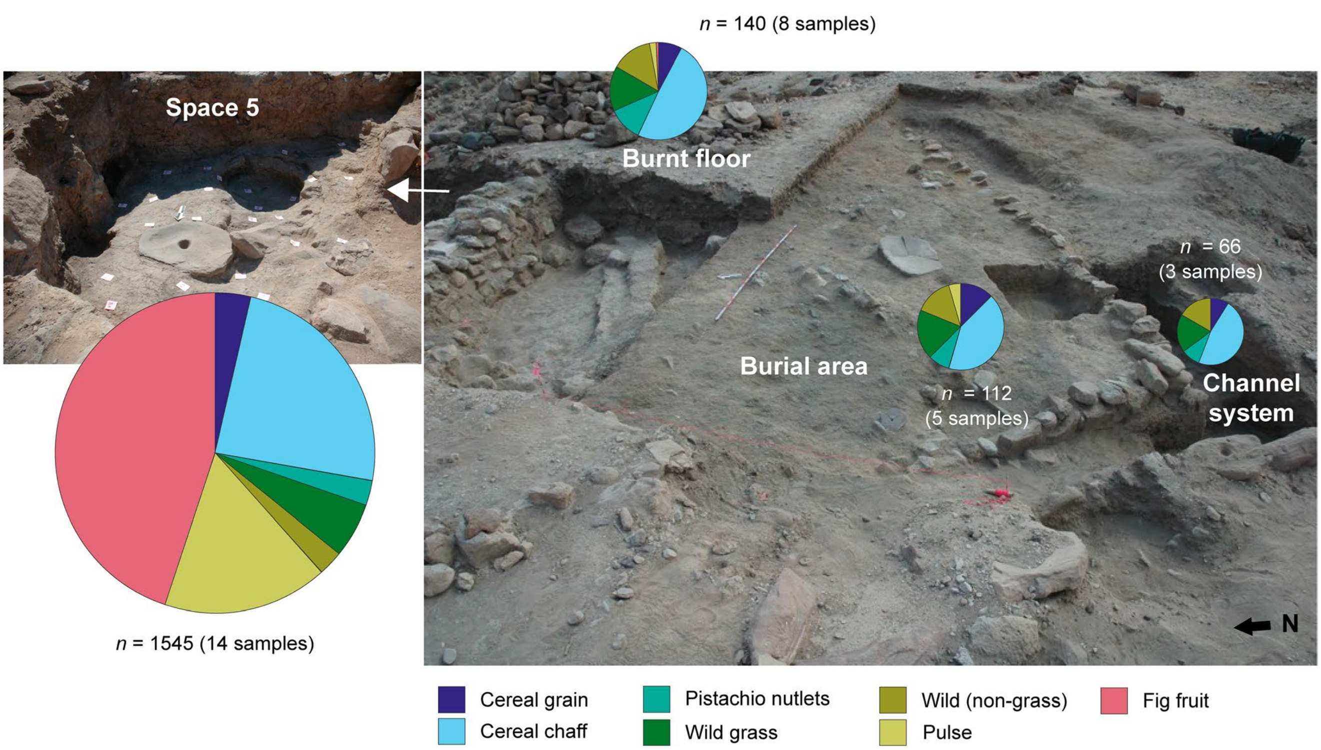

Fig. 4 Pie charts illustrating the proportions of major plant categories within different areas at PPNA Sharara as discussed in the text (see also Fig. 2). The relative size of the pie-charts reflects the size of each assemblage with exact number of items (n) and number of samples representing each area specified. Four samples that were collected from outside of these main excavation areas have not been included (see ESM 1 for raw data)

the erosion of charred plant remains into these deposits at a later date, for example as a result of being transported across the site by wind. This would correspond with the predominance of small and light remains (e.g. cereal chaff, *Stipa* awn, *Erodium* beak fragments) and lack of larger, heavier plant remains (e.g. fig fruits and pulses) in these samples.

There are also clear differences in the distribution of fig fruits and pulses within Space 5 itself. Figure 5a illustrates the composition of individual samples recovered from Space 5, arranged in stratigraphic order with the uppermost sample shown at the top. This demonstrates that the vast majority of fig fruits (98%; $n=680$) came from three samples collected from the upper part of Context 705, the fill of the structure (Fig. 5a, d). Hand-picked during the 2016 season, these three samples (Samples BOT086a, BOT086b and BOT086c) comprise 6.6 l, almost exclusively fig remains. In contrast, samples recovered from the lower part of Context 705, from the floor of the building (Context 1025) and from deposits beneath the floor (Context 1034), yielded few if any fig fruits. The majority of wood charcoal and reed culm remains from Space 5 were also recovered from samples collected from Context 705, although these were largely restricted to samples taken from immediately beneath the rich fig layer (Fig. 5b, c). Reed culm impressions identified on some charred fig fruits (Fig. 5e, f) further attest to a close stratigraphic association between these plant remains. Also standing out in terms of its composition within Space 5 is a single 0.5 l sample that was collected from the floor of the structure (Sample BOT025; Context 1025), and which was comprised almost entirely of pulses, including 27 lentils and 18 seeds of inconspicuous pea (Fig. 5a).

Discussion

Processing and storage of plants in space 5

The large quantity and in situ nature of the charred plant assemblage within Space 5 allows us to draw several inferences about how this space was used in its final iteration. We interpret the recovery of a concentration of 680 fig fruits from the upper part of Context 705, immediately above the lower part of Context 705 which was rich in wood charcoal and reed culm remains, as evidence that figs had been intentionally placed on top of the roof of this building before it burnt down. This roof would probably have been flat and constructed from mud supported by reeds and wooden beams, as has been inferred at other PPNA sites in southern Jordan, for example Wadi Faynan 16 (WF16) (Finlayson et al. 2012). The fig fruits were likely laid out on the roof of this structure for the purpose of drying them. Sun-drying is a traditional method of preservation that is still practiced across much of the Mediterranean, Middle East and North Africa today. After harvesting fully mature figs are laid out, normally on a flat surface such as a roof, in sunny and dry weather, ideally when temperatures are at ca. 25–30 °C (Tang and Yang 2004; Benkerroum 2013). Under these conditions, figs will dry within seven to ten days at which point they can be stored, either being pressed into loaves or threaded onto strings (Benkerroum 2013; Morales and Gil González 2014). As it is unlikely that the figs at Sharara would have been left on the roof after they had dried, we conclude that Space 5 burnt down while these were still drying and potentially when they were near the end of this process, based on their morphological similarity to modern dried figs. This constrains estimates of when this burning event took place, given that fruits would be laid out to dry immediately after harvesting. Fig trees produce two to three crops per year between the months of April and November (Morales and Gil González 2014, p 184). In future analyses it may be possible to detect what time of year the fig fruits at Sharara were collected and, therefore, the window of activity represented by the charred macrobotanical assemblage in Space 5.

The interior of Space 5 also appears to have functioned as an area for processing plant foods, indicated by a large cup-hole mortar set into the mud plaster floor of the building. Similar mortars are commonly found in PPNA settlements in the southern Levant and are widely associated with food processing (Rosenberg and Nadel 2017). Additional evidence for food processing comes from the morphology of cereal chaff remains, with notable proportions of barley and emmer wheat chaff bearing a ripped morphology. Based on experimental work, the presence of a similar ripped morphology on barley rachis internodes from el-Hemmeh has been interpreted as evidence that barley was harvested before it was fully ripe, with the ears manually torn apart in a downward motion while still green (White and Makarewicz 2012). However, based on preliminary experiments carried out for this study, a similar morphology is produced by pounding barley spikelets in a mortar and pestle, regardless of their ripeness when collected (see ESM 3). This suggests that the ripped morphology identified at Sharara reflects pounding to remove and dehusk grain, rather than a specific harvesting strategy. This is consistent with the interpretation of similar 'tear off' scars documented by Tanno and Willcox (2012) on einkorn and emmer wheat chaff following experimental pounding.

Our pounding experiment also produced rachis internodes that retained some palea and lemma material, which was the case for nearly two-thirds of the barley rachises at Sharara (see Table 2a). In contrast, ripping ears apart in a downwards motion, as described by White and Makarewicz (2012), failed to create these morphological types, removing

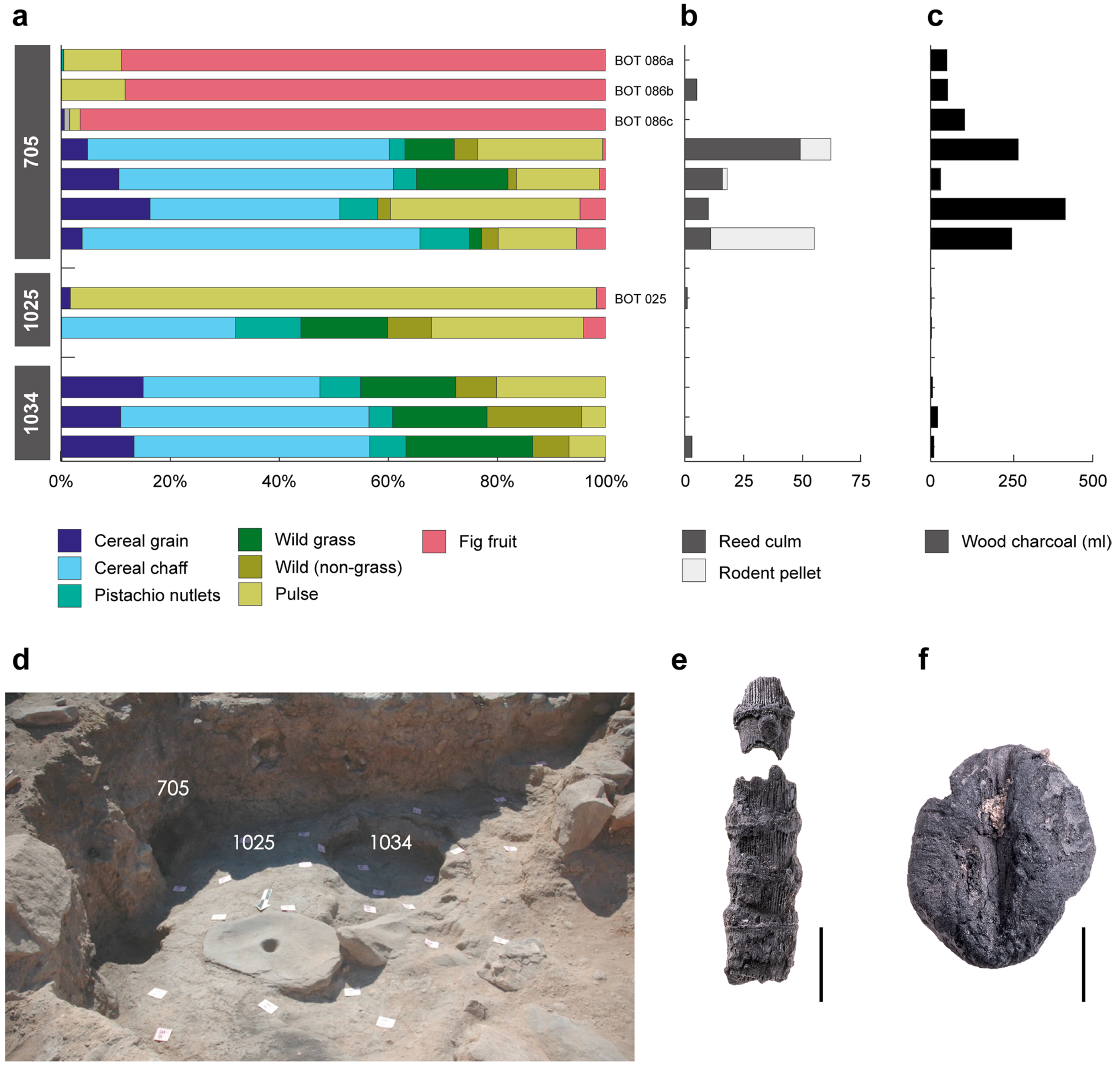

Fig. 5 **a** Relative percentage of major plant categories within 12 samples from Space 5 that contained 20 or more macrobotanical items. Samples are illustrated in stratigraphic order so that the uppermost sample is shown at the top. Archaeological contexts and samples labelled as mentioned in text. **b** Number of reed culm remains and rodent pellets within the 12 samples. **c** Volume (ml) of wood charcoal fragments > 2 mm in size within the 12 samples. **d** Photo of Space 5 with Context 705 (fill deposits, shown in section), Context 1025 (floor deposits) and Context 1034 (fill beneath floor, revealed in section of circular, sunken area). **e** Charred section of reed culm collected from Space 5. **f** Charred fig fruit with reed culm impression, collected from Space 5. Photos of charred reed culm and fig fruit by Ian Cartwright, University of Oxford; scale bars, 10 mm

grains along with their surrounding palea and lemma (see ESM 3). Finally, experimental pounding of barley also generated a large number of detached lateral florets and broken grains, both of which have been recorded at Sharara, the former in relatively high numbers (see Table 1). At Sharara, barley grains that were broken before charring (Fig. 6a) were identified based on the distinctive oozing of their endosperm and bulging-smooth appearance of the grain at the broken surfaces (Willcox 2002; Valamoti 2011).

Other plant parts recovered from Space 5 that were plausibly processed here include pistachio nutlets, which often require crushing as part of their preparation, for example to extract oil (Willcox 2016). Pistachio nutlets had likely been crushed before Space 5 burned down, explaining why no whole specimens and only a single fragment of nut kernel were recovered from the site. Wild grasses also appear to have been processed here, suggested by the presence of numerous chaff remains, including the fragmented awn of *Stipa* and the chaff of *Aegilops* and *T. crinitum*. Further evidence for grass processing is visible in the identification of *Stipa* grains that were broken prior to charring (Fig. 6b), indicating that these had been subject to the same mechanical processes as cereal grains at the site. While many of the wild grasses identified at Sharara have been interpreted as gathered foods at contemporaneous settlements in southwest Asia (Weide et al. 2018; Whitlam et al. 2018), it is also possible that these were unintentionally collected and processed alongside cereals and pulses. Finally, it is unclear whether cereals, wild grasses and/or pistachios were stored in Space 5 prior to being processed. However, based on the relatively high proportions of cereal chaff compared to grains in these samples, it is likely that by the time the building burnt down the majority of cereal grain had either been consumed, or moved to a different area of the settlement for storage.

More convincing evidence for plant storage in Space 5 is provided by the high density and purity of pulses (lentil and inconspicuous pea) found within a single sample here (Sample BOT025), which is consistent with this being a storage deposit (Jones 1991; Wallace et al. 2019). The recovery of charred rodent pellets may also indicate that plants or plant products were stored in this space. The identification of rodent pellets in structural fill deposits at other PPNA sites, for example at Dhra' in southern Jordan and Jerf el-Ahmar in northern Syria (Willcox and Stordeur 2012; Colledge et al. 2018), has been previously argued as indirect evidence for storage. However, no direct evidence for storage facilities has been found in Space 5, either in the form of durable storage containers (e.g. clay bins) or perishable containers, such as the type of baskets documented at Gilgal I (Noy 1989). Given the challenges of identifying storage based solely on the abundance and density of plant remains (Wallace et al. 2019), we therefore leave open the question as to whether or not plant storage was an important function of this space, while also noting the separation between storage and processing activities at other contemporaneous sites in southern Jordan (Finlayson et al. 2011). In this scenario, the concentrated deposit of pulses found on the floor of the Space 5 may simply represent seeds that were brought here and stored temporarily, in a bag or similar container, before being processed on the cup-hole mortar.

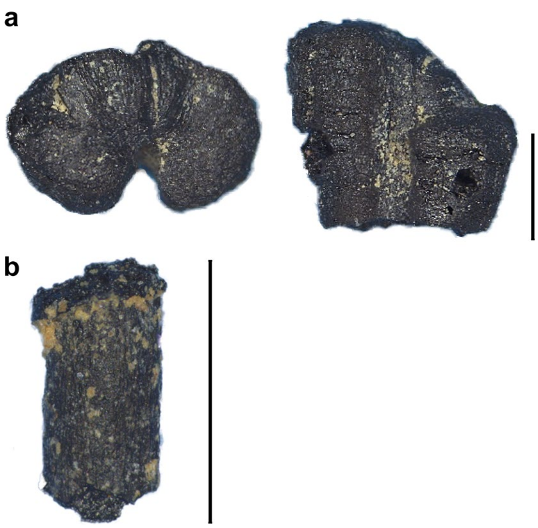

Fig. 6 **a** Barley grain broken before charring in cross section (left) and ventral (right) view. **b** *Stipa* grain broken before charring; scale bars, 1 mm

Evidence for plant-based subsistence and management

The charred macrobotanical assemblage from Sharara is largely comprised of cereals, pulses, figs and pistachio nutlets. We regard these as staple foods that were consumed at the site, based on their edibility, high proportions relative to other taxa represented in the assemblage, and evidence for their storage and processing.

Cereals

Cereals at Sharara are primarily represented by barley and, to a lesser extent, emmer wheat, a pattern mirrored at other contemporary settlements in southern Jordan, including at Zahrat adh-Dhra' 2 (ZAD2), el-Hemmeh and Dhra' (Edwards et al. 2004; White and Makarewicz 2012; Colledge et al. 2018). At all three of these sites barley is thought to have been under PDC, based principally on the high proportion of barley grains (36–40%) that fall within the size range of the domestic species and the presence of potential arable weed taxa. It remains unclear whether or not barley was cultivated at Sharara, but it is clear that the exploited barley was morphologically wild. Only a small proportion of barley grains recovered from the site overlap in size with the domestic species (13%), with a much higher proportion of 'wild'-sized grains present when compared to ZAD2, el-Hemmeh and Dhra'. However, it should be noted that slightly different metrical criteria were applied in assigning grains to 'wild', 'intermediate' and 'domestic' categories at these sites, limiting direct comparisons. At ZAD2 (Edwards et al. 2004, p 42) barley grains were classified as 'wild' if they had a breadth less than 2.2 mm and thickness less than 1.4 mm and 'domestic' if they had a breadth greater than 2.2 mm and thickness greater than 1.0 mm, following criteria laid out by Colledge (2001, p 64). At el-Hemmeh meanwhile, barley grains were classified as 'wild' if they had a breadth less than 2.25 mm and thickness less than 1.25 mm, while those with larger measurements were classified as 'cultivated'. Grains producing measurements that straddled the wild/cultivated division by ± 0.25 mm were categorised as 'intermediate' (White and Makarewicz 2012). These criteria are reported slightly differently in White (2013, p 96). At Dhra', grain measurements were superimposed on a scattergram plot showing barley breadth and thickness data compiled from 24 other southwest Asia sites. The number and proportion of grains falling within the size range of the domestic species were also reported in the text, but otherwise no specific metric criteria were given for distinguishing between 'wild' and 'domestic' barley (Colledge et al. 2018, p 21).

Despite differences in how grains were assigned to 'wild', 'intermediate' and 'domestic' categories at these sites, comparison of the mean breadth and thickness of barley grains from Sharara (1.91 × 1.25 mm) to those reported from ZAD2 (2.10 × 1.34 mm) and Dhra' (2.14 × 1.34 mm) indicates that the Sharara grains are somewhat smaller. The presence of a handful of larger, 'domestic'-sized, barley grains in the assemblage may simply reflect natural variation in grain size, with a range of developmental and environmental factors independent of cultivation and domestication known to influence this, for example the position of the grain on the ear and water availability (Cottrell and Dale 1984; Altenbach et al. 2003). Future analysis of cereal growing conditions at Sharara will incorporate stable isotope analysis of individual grains to assess the role of water availability in grain size variation.

The chaff assemblage recovered from Sharara is also dominated by wild-type barley rachis internodes (54%), with a moderate proportion of domestic-type rachis internodes (21%). This proportion of domestic-type internodes is higher than expected from a population of wild barley, where approximately 10% of the rachis internodes exhibit a rough (domestic-type) abscission scar (Kislev 1989), but is still lower than in a domestic population where this non-shattering trait would be fixed. However, as the majority of rachis internodes found at Sharara were non-diagnostic in terms of scar type or possessed a ripped morphology (see Table 2) this should not necessarily be taken as evidence for domestication, especially given the grain size data.

Finally, while several wild taxa present at Sharara could be considered potential weeds of cultivation, for example *Aegilops, Stipa, H. glaucum, Centaurea, Erodium*, *Plantago* and small-seeded legumes (see Willcox 2012b; White and Makarewicz 2012 for relevant lists of potential arable weeds), there are numerous pathways by which these species may have entered the assemblage, including as separately gathered foods or via their use in crafts and construction. Recent studies have also demonstrated that many of the wild and potential weed taxa identified at Sharara, including those mentioned above, grow alongside wild cereals in untilled stands (Weide et al. 2021, 2022). Thus, even if they arrived on site with harvested cereals this cannot, by itself, be taken as evidence for cereals being under cultivation. Future analysis of cereal growing conditions at Sharara will incorporate the functional ecology of potential weeds to assess whether or not they are indicative of tillage (Weide et al. 2022).

Pulses

Along with cereals, pulses are well-represented at Sharara with lentils the most abundant. Lentils are a common component of PPNA plant assemblages in southern Jordan and widely documented across southwest Asia where they appear to be closely associated with nascent barley and wheat cultivation (Zohary and Hopf 2000, p 98). After lentil, the most abundant pulse species recorded at the site is the inconspicuous pea. This species has not previously been identified in a PPNA assemblage, but its presence at Sharara is consistent with increasing evidence from Early Neolithic sites for the exploitation of a wider range of pulses than represented in the canonical 'Neolithic founder crop package' (wheat, barley lentil, chickpea, bitter vetch and flax). Within the southern Levant specifically, previous research has argued for PDC of *Vicia peregrina* (rambling vetch) at PPNA Netiv Hagdud in the Jordan Valley, based on their high abundance and their association with wild barley that is also considered to have been under PDC there (Melamed et al. 2008). Later, at Early PPNB Ahihud, in addition to inconspicuous pea, large numbers of *Lathyrus hirosolymitanus* (Jerusalem vetchling), *Vicia narbonesis* (narbon vetch) and *V. faba* (faba bean) were also found in storage pits at the site and interpreted as cultivars (Caracuta et al. 2017). Meanwhile, thousands of seeds of faba bean were discovered in a storage facility at the nearby Middle PPNB site of Yiftah'el (Kislev 1985).

The presence of a small number of pulse stalk fragments at Sharara provides tentative evidence that pulses were brought to the site in their pods before being processed. Given that the pods of wild pulses shatter upon ripening the recovery of stalk fragments could also be taken as evidence of indehiscence and hence domestication, although we consider it more likely that this reflects the harvesting of pulses before they were fully ripe, as attested ethnographically (Butler and D'Andrea 2000). It should also be noted that while *L. inconspicuus* was interpreted as a fodder crop at Early PPNB Ahihud (Caracuta et al. 2017), there is no evidence for animal management at this time in the southern Levant (Arbuckle 2018) and nor is this species toxic to humans (Mifsud 2020). Thus, its identification at Sharara alongside other edible pulses and within a building used to process and possibly store plant foods, suggests it was collected for human consumption.

Tree fruits

Tree fruits in the form of fig and pistachio were important elements of plant-based subsistence strategies at Sharara, and featured heavily in plant exploitation at numerous settlements in southern Jordan and across the Levant (Douché and Willcox 2018). Fig drupelets in particular are well attested at PPN sites with high numbers reported from Netiv Hagdud in the Jordan valley ($n = 4{,}913$; Kislev et al. 2006) and Aswad in the northern Euphrates ($n = 5{,}649$; Douché and Willcox 2018; Douché, personal communication). While the 17,319 drupelets recovered from Sharara far outnumber these assemblages, it is the recovery of nearly 700 fig fruits here that is particularly remarkable, given that these are rare or absent at other PPN sites. The nine carbonised fig fruits reported from Gilgal I represent a notable exception (Kislev et al. 2006). Previous research has argued for vegetative propagation and domestication of figs in the southern Levant in the PPNA, based on the identification of parthenocarpic (seedless) figs at Gilgal I and Netiv Hagdud (Kislev et al. 2006). However, the presence of parthenocarpic figs in itself is not necessarily indicative of the deliberate planting of shoots, and might more reasonably represent the preferential gathering of wild, persistent female figs (Lev-Yadun et al. 2006; Denham 2007). The large assemblage of well-preserved fig fruits recovered from Sharara, collected contemporaneously and likely from multiple trees, offers an unprecedented opportunity for future work to address these long running debates.

Pistachio nutlets, like fig drupelets, are a common component of PPNA plant assemblages in the Levant, with species such as *Pistacia atlantica* (Mt. Atlas mastic tree) tentatively identified at ZAD2 and el-Hemmeh in southern Jordan (Edwards et al. 2002; White and Makarewicz 2012), while both *P. atlantica* and *P. palaestina* (syn. *P. terebinthus;* terebinth) have been reported from Gilgal I in the Jordan Valley (Kislev et al. 2010). Crucially, both figs and pistachios would have helped to expand the nutritional profile of the PPNA diet, the former being an excellent source of fibre and magnesium and the latter providing an essential source of fat/oils, vitamin B6 and potassium (USDA 2018). When prepared correctly (e.g. dried), fig fruits and pistachio nutlets could also have been stored year-round to fill an important subsistence gap when other plant resources became seasonally unavailable.

Conclusions

This paper has laid out direct evidence that the inhabitants of PPNA Sharara engaged in diverse plant exploitation strategies that included harvesting a range of morphologically wild cereals, pulses and tree fruits, as well as processing and possibly storing these. Key amongst our findings is the discovery that nearly 700 fig fruits were drying on the roof of Space 5 at the time it burnt down. At present, in the absence of evidence for PDC at the site, we stop short of calling any of the plants recovered at Sharara 'crops', a term whose usage may need reconsidering more broadly, given recent debates regarding PDC in the PPNA (Weide et al. 2021, 2022) and whether, in fact, this can be considered to have been cultivation in a strict sense (i.e. involving annual cycles of tillage). Regardless, the wild cereals, legumes and tree fruits identified here clearly represent 'plants of particular interest', in the sense that they were extensively harvested, processed and stored as part of plant-based subsistence strategies at the site and were the focus of people's repeated attention and labour investment. This does not exclude the possibility that these plants were under other forms of management that may have enhanced yields or their accessibility (e.g. fencing and protection of stands, watering, weeding, pruning), even in the absence of cultivation. We recognise that there is a strong need to develop new approaches for elucidating such management practices, in order to arrive at a more accurate understanding of how local and regional plant management strategies shaped agricultural trajectories across southwest Asia.

Overall, the archaeobotanical evidence from Sharara corresponds with patterns of plant use documented at other sites in southern Jordan and the southern Levant more widely, where cereals and pulses, particularly barley and lentils, along with fig and pistachio formed the foundation of early Neolithic plant economies. The identification of figs and pistachios as 'plants of particular interest' at the site, along with inconspicuous pea, also agrees with a growing body of evidence that suggests a broader spectrum of plants were managed and potentially cultivated as part of Early Neolithic food production strategies than represented by the canonical 'Neolithic founder crop package' (Weiss et al. 2006; Fuller et al. 2012; Arranz-Otaegui and Roe 2023). Our findings are consistent with interpretations of the PPNA as a period in which widespread experimentation in plant management was taking place as part of newly emerging Neolithic lifeways. When contextualised with other datasets from the site, the archaeobotanical evidence presented here provides an opportunity to further explore these connections and their role in shaping pathways to farming in this region.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00334-

023-00938-w.

Acknowledgements This research has been supported by a British Academy Postdoctoral Fellowship (pf170053, J.W.), the National Geographic Council for Exploration and Research (HJ-043R-17, C.M.) and the Chair for Zooarchaeology and Stable Isotope Biogeochemistry at the Institute for Prehistoric and Protohistoric Archaeology, University of Kiel. The authors would like to thank the Department of Antiquities of Jordan for inviting Finlayson and Makarewicz to undertake these excavations and for authorising the export of archaeobotanical material (Jordanian Department of Antiquities Export Permit No. 12/5/4056 and 12/5/2180), as well as the Council for British Research in the Levant in Amman for their logistical support. We are especially grateful to all the members of the Sharara team who helped with the collection and transport of archaeobotanical samples between 2016 and 2019 and to Ian Cartwright (University of Oxford) for his assistance with photographing the charred fig fruits and reed culm. Finally, we would like to thank the two anonymous reviewers who offered comments on this manuscript.

Declarations

Competing interests The authors have no relevant financial or non-financial interest to disclose.

References

Altenbach SB, Dupont FM, Kothari KM et al (2003) Temperature, water and fertilizer influence the timing of key events during grain development in a US Spring wheat. J Cereal Sci 37:9–20

Arbuckle BS (2018) Early history of animal domestication in Southwest Asia. Oxford University Press, Oxford. https://doi.org/10.1093/acrefore/9780199389414.013.548

Arranz-Otaegui A, Roe J (2023) Revisiting the concept of the 'Neolithic founder crops' in southwest Asia. https://doi.org/10.1007/s00334-023-00917-1. Veget Hist Archaeobot online

Asouti E, Kabukcu C, White CE et al (2015) Early holocene woodland vegetation and human impacts in the arid zone of the southern Levant. Holocene 25:1565–1580. https://doi.org/10.1177/0959683615580199

Bar-Matthews M, Ayalon A, Kaufman A (1997) Late quaternary Paleoclimate in the Eastern Mediterranean Region from stable isotope analysis of Speleothems at Soreq Cave, Israel. Quat Res 47:155–168. https://doi.org/10.1006/qres.1997.1883

Benkerroum N (2013) Traditional Fermented Foods of North African Countries: Technology and Food Safety challenges with regard to microbiological risks. Compr Rev Food Sci Food Saf 12:54–89. https://doi.org/10.1111/j.1541-4337.2012.00215.x

Butler A, D'Andrea AC (2000) Farming and famine: subsistence strategies in highland Ethiopia. In: Barker G, Gilbertson D (eds) The archaeology of drylands: living at the margin. Routledge, London, pp 174–193

Caracuta V, Vardi J, Paz Y, Boaretto E (2017) Farming legumes in the pre-pottery neolithic: new discoveries from the site of Ahihud (Israel). PLoS ONE 12:e0177859. https://doi.org/10.1371/journal.pone.0177859

Cartwright CR (2003) Grapes or raisins? An early bronze age larder under the microscope. Antiquity 77:345–348

Colledge S (1998) Identifying pre-domestication cultivation using multivariate analysis. In: Damania AB, Valkoun J, Willcox G, Qualset CO (eds) The origins of agriculture and crop domestication. Proceedings of the Harlan Symposium, 10–14 May 1997, Aleppo, Syria. ICARDA, Aleppo, pp 121–131

Colledge S (2001) Plant exploitation on Epipalaeolithic and Early Neolithic sites in the Levant. BAR International Series S986. British Archaeological Reports, Oxford

Colledge S, Conolly J, Finlayson B, Kuijt I (2018) New insights on plant domestication, production intensification, and food storage: the archaeobotanical evidence from PPNA Dhra'. Levant 50:14–31. https://doi.org/10.1080/00758914.2018.1424746

Cottrell JE, Dale JE (1984) Variation in size and development of spikelets within the ear of barley. New Phytol 97:565–573

Denham T (2007) Early fig domestication, or gathering of wild parthenocarpic figs? Antiquity 81:457–461. https://doi.org/10.1017/S0003598X00095326

Douché C, Willcox G (2018) New archaeobotanical data from the early neolithic sites of dja'de el-Mughara and tell Aswad (Syria): a comparison between the Northern and the Southern Levant. Paléorient 44:45–58

Edwards PC, Meadows J, Sayej G, Metzger MC (2002) Zahrat Adh-Dhra' 2: a new Pre-Pottery Neolithic A site on the Dead Sea plain in Jordan. Bull Am Sch Orient Res 327:1–15

Edwards PC, Meadows J, Sayej G, Westaway M (2004) From the PPNA to the PPNB: new views from the Southern Levant after excavations at Zahrat adh-dhra' 2 in Jordan. Paléorient 30:21–60. https://doi.org/10.3406/paleo.2004.1010

Feinbrun-Dothan N (1978) Flora Palaestina, Part 3: Ericaeae to Compositae. Israel Academy of Sciences and Humanities, Jerusalem

Feinbrun-Dothan N (1986) Flora Palaestina, Part 4: Alismataceae to Orchidaceae. Israel Academy of Sciences and Humanities, Jerusalem

Finlayson B, Mithen SJ, Najjar M et al (2011) Architecture, sedentism, and social complexity at Pre-Pottery Neolithic A WF16, Southern Jordan. Proc Natl Acad Sci USA 108:8183–8188. https://doi.org/10.1073/pnas.1017642108

Finlayson B, Mithen S, Najjar M (2012) WF16. Architecture, Sedentism and Social Complexity Communal Building in Pre-Pottery Neolithic A Settlements: New evidence from WF16. Bull Counc Br Res Levant 7:18–23. https://doi.org/10.1179/1752726012Z.0000000002

Fuller DQ, Willcox G, Allaby RG (2012) Early agricultural pathways: moving outside the 'core area' hypothesis in Southwest Asia. J Exp Bot 63:617–633. https://doi.org/10.1093/jxb/err307

Harlan JR, de Wet JMJ, Price EG (1973) Comparative evolution of cereals. Evolution 27:311–325

Harris DR (1989) An evolutionary continuum of people-plant interaction. In: Harris DR, Hillman GC (eds) Foraging and farming: the evolution of plant exploitation. Unwin Hyman, London, pp 11–26

Hillman G, Hedges R, Moore A, Colledge S, Pettitt P (2001) New evidence of Lateglacial cereal cultivation at Abu Hureyra on the Euphrates. Holocene 11:383–393

Jones G (1991) Numerical analysis in archaeobotany. In: van Zeist W, Wasylikowa K, Behre K-E (eds) Progress in old world palaeoethnobotany. A.A. Balkema, Rotterdam, pp 63–80

Kislev ME (1985) Early neolithic horsebean from Yiftah'el. Isr Sci 228:319–320
Kislev ME (1989) Pre-domesticated cereals in the Pre-Pottery Neolithic A period. In: Hershkovitz I (ed) People and culture in change. BAR International Series, vol 1. British Archaeological Reports, Oxford, pp 147–152
Kislev ME (1997) Early agriculture and paleoecology of Netiv Hagdud. In: Bar-Yosef O, Gopher A (eds) An early neolithic village in the Jordan valley, part 1: the archaeology of Netiv Hagdud. Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, MA, pp 209–236
Kislev ME, Hartmann A, Bar-Yosef O (2006) Early domesticated fig in the Jordan Valley. Science 312:1372–1374
Kislev ME, Hartmann A, Noy T (2010) The vegetal subsistence of Gilgal I as reflected in the assemblage of locus 11. In: Bar-Yosef O, Goring-Morris N, Gopher A (eds) Gilgal: early neolithic occupations in the Lower Jordan Valley: the Excavations of Tamar Noy. Oxbow Books, Oxford, pp 251–257
Lev-Yadun S, Ne'eman G, Abbo S, Flaishman MA (2006) Comment on "Early domesticated fig in the Jordan Valley. Science 314:1683
Makarewicz CA, Rose K (2011) Early pre-pottery neolithic settlement at el-Hemmeh: a Survey of the Architecture. Neo-Lithics: Newsl Southwest Asian Res 1:23–29
Makarewicz CA, Goodale NB, Rassmann P et al (2006) El-Hemmeh: a multi-period Pre-Pottery Neolithic Site in the Wadi el-Hasa, Jordan. Eurasian Prehist 4:183–220
Melamed Y, Plitmann U, Kislev ME (2008) *Vicia peregrina*: an edible early neolithic legume. Veget Hist Archaeobotany 17(Suppl 1):S29–S34
Mifsud S (2020) *Lathyrus inconspicuus*. Datasheet created on December 2009
Morales J, Gil González J (2014) Fruit as staple food: the role of fig (*Ficus carica* L.) during the pre-hispanic period of the Canary Islands, Sain (from the 3rd-2nd centuries BCE to the 15th century CE). In: Chevalier A, Marinova E, Peña-Chocarro L (eds) Plants and people: choices and diversity through Time. Oxbow Books, Oxford and Philadelphia, pp 182–190
Noy T (1989) Gilgal I - a Pre-Pottery neolithic site, Israel - the 1985–1987 seasons. Paléorient 15:11–18
Peterson J (2004) Khirbet Hammam (WHS 149): a late pre-pottery neolithic B settlement in the Wadi el-Hasa, Jordan. Bull Am Sch Orient Res 334:1–17. https://doi.org/10.2307/4150103
Riehl S, Zeidi M, Conard NJ (2013) Emergence of Agriculture in the Foothills of the Zagros Mountains of Iran. Science 341:65–67. https://doi.org/10.1126/science.1236743
Robinson SA, Black S, Sellwood BW, Valdes PJ (2006) A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP: setting the environmental background for the evolution of human civilisation. Quat Sci Rev 25:1517–1541
Rosenberg D, Nadel D (2017) The significance of the morphometric and contextual variation in stone hewn mortars during the Natufian-PPNA transition in the southern Levant. Quat Int 439:83–93. https://doi.org/10.1016/j.quaint.2016.11.023
Shelton CP, White CE (2010) The Hand-Pump Flotation System: a New Method for Archaeobotanical Recovery. J Field Archaeol 35:316–326. https://doi.org/10.1179/009346910X12707321358838
Snir A, Nadel D, Groman-Yaroslavski I et al (2015) The origin of cultivation and Proto-Weeds, long before neolithic farming. PLoS ONE 10:e0131422. https://doi.org/10.1371/journal.pone.0131422
Tang J, Yang T (2004) Dehyrated vegetables: principles and Systems. In: Hui YH, Ghazala S, Graham DM, Murrell KD, Nip W-K (eds) Handbook of Vegetable Preservation and Processing. Marcel Dekker, Inc., New York, pp 335–370
Tanno K, Willcox G (2012) Distinguishing wild and domestic wheat and barley spikelets from early holocene sites in the Near East. Veget Hist Archaeobot 21:107–115
USDA (U.S. Department of Agriculture) (2018) FoodData Central. https://fdc.nal.usda.gov/index.html. Accessed 8 January 2023
Valamoti SM (2011) Ground cereal food preparations from Greece: the prehistory and modern survival of traditional Mediterranean 'fast foods'. Archaeol Anthropol Sci 3:19–39. https://doi.org/10.1007/s12520-011-0058-z
Van Zeist W, de Roller GJ (1994) The plant husbandry of Aceramic Çayönü. SE Turk Palaeohistoria 33/34(1991/1992):65–96
Wallace M, Jones G, Charles M et al (2019) Re-analysis of archaeobotanical remains from pre- and early agricultural sites provides no evidence for a narrowing of the wild plant food spectrum during the origins of agriculture in southwest Asia. Veget Hist Archaeobot 28:449–463. https://doi.org/10.1007/s00334-018-0702-y
Weide A, Riehl S, Zeidi M, Conard NJ (2015) Using new morphological criteria to identify domesticated emmer wheat at the aceramic neolithic site of Chogha Golan (Iran). J Archaeol Sci 57:109–118. https://doi.org/10.1016/j.jas.2015.01.013
Weide A, Riehl S, Zeidi M, Conard NJ (2018) A systematic review of wild grass exploitation in relation to emerging cereal cultivation throughout the epipalaeolithic and aceramic neolithic of the Fertile Crescent. PLoS ONE 13:e0189811. https://doi.org/10.1371/journal.pone.0189811
Weide A, Hodgson JG, Leschner H et al (2021) The association of arable weeds with modern wild cereal habitats: implications for reconstructing the Origins of Plant Cultivation in the Levant. Environ Archaeol online 1–16. https://doi.org/10.1080/14614103.2021.1882715
Weide A, Green L, Hodgson JG et al (2022) A new functional ecological model reveals the nature of early plant management in southwest Asia. Nat Plants 8:623–634. https://doi.org/10.1038/s41477-022-01161-7
Weiss E, Kislev ME, Hartmann A (2006) Autonomous cultivation before domestication. Science 312:1608–1610
White C (2013) The emergence and intensification of cultivation practices at the Pre-Pottery Neolithic site of el-Hemmeh, Jordan: an archaeobotanical study. PhD Thesis, Boston University, Boston
White CE, Makarewicz CA (2012) Harvesting practices and early neolithic barley cultivation at el-Hemmeh, Jordan. Veget Hist Archaeobot 21:85–94. https://doi.org/10.1007/s00334-011-0309-z
Whitlam J, Bogaard A, Matthews R et al (2018) Pre-agricultural plant management in the uplands of the central Zagros: the archaeobotanical evidence from Sheikh-e Abad. Veget Hist Archaeobot 27:817–831. https://doi.org/10.1007/s00334-018-0675-x
Willcox G (2002) Charred plant remains from a 10th millenium B.P. kitchen at Jerf el Ahmar (Syria). Veget Hist Archaeobot 11:55–60
Willcox G (2012a) The beginnings of cereal cultivation and domestication in Southwest Asia. In: Potts DT (ed) A companion to the archaeology of the ancient Near East. Wiley-Blackwell, Malden, pp 163–180
Willcox G (2012b) Searching for the origins of arable weeds in the Near East. Veget Hist Archaeobot 21:163–167. https://doi.org/10.1007/s00334-011-0307-1
Willcox G (2016) Les fruits au Proche-Orient avant la domestication des fruitiers. In: Ruas M-P (ed) Des fruits d'ici et d'ailleurs: regards sur l'histoire de quelques fruits consommés en Europe. Omniscience, Montreuil, pp 41–54
Willcox G, Stordeur D (2012) Large-scale cereal processing before domestication during the tenth millenium cal BC in northern Syria. Antiquity 86:99–114
Willcox G, Fornite S, Herveux L (2008) Early holocene cultivation before domestication in northern Syria. Veget Hist Archaeobot 17:313–325

Zeder MA (2015) Core questions in domestication research. Proc Natl Acad Sci USA 112:3,191–3,198. https://doi.org/10.1073/pnas.1501711112
Zohary M (1966) Flora Palaestina, Part 1: Equisetaceae to Moringaceae. Israel Academy of Sciences and Humanities, Jerusalem
Zohary M (1972) Flora Palaestina, Part 2: Platanaceae to Umbelliferae. Israel Academy of Sciences and Humanities, Jerusalem
Zohary M (1973) Geobotanical foundations of the Middle East. 2 vols. Fischer, Stuttgart
Zohary D, Hopf M (2000) Domestication of plants in the Old World: the origin and spread of cultivated plants in West Asia, Europe, and the Nile Valley, 3rd edn. Oxford University Press, Oxford