

Crop management and agricultural responses at Early Bronze IV Tell Abu en-Ni'aj, Jordan

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ABSTRACT

This study employs an array of quantitative methods to analyze village agricultural practices during a time of regional urban abandonment at the end of the Early Bronze Age in the Southern Levant. Coordinated cluster and canonical discriminant analyses of stratified archaeobotanical assemblages from the village of Tell Abu en-Ni'aj, Jordan support a detailed portrait of changing crop management at a sedentary agrarian community during Early Bronze IV, a period marked by widespread mobile pastoralism. Our quantified analyses of carbonized plant remains are augmented with stable isotope composition data for major cultigens to offer an innovative perspective on Early Bronze IV agrarian life in the northern Jordan Valley. Seeds from seven occupation phases spanning the time period from about 2500 to 2200 cal BC indicate increasing primary reliance on *Hordeum vulgare* (hulled barley), and only modest cultivation of wheat, mostly *Triticum dicoccum* (emmer) over this time span. Constrained incremental sum of squares (CONISS) cluster analysis and canonical discriminant analysis (CDA) illustrate significant shifts in crop cultivation, and possibly related animal management, including a major transition at about 2375 cal BC. Our analyses further highlight the most important plant taxa that contributed to these shifts. Cultivated crops, wild species and chaff are more ubiquitous in the earlier phases at Tell Abu en-Ni'aj, while percentages of *H. vulgare* and ubiquities of *Lens culinaris* (lentil) increase in the later phases. Lower seed densities, weed ubiquities and chaff to cereal ratios suggest more distant crop processing after about 2375 cal BC. Values of $\Delta^{13}\text{C}$ for the major cereals, which provide a proxy for water availability, indicate dry farming of barley and preferential watering of wheat. This study proposes that a suite of changes occurred between the earlier and later phases at Tell Abu en-Ni'aj, which portray generally diminished, more remote crop production, possibly amid greater drought stress, leading to village abandonment. We illustrate a multi-faceted analytical approach suitable for interpretation of comparable archaeobotanical evidence and inference of agrarian dynamics elsewhere in prehistory.

1. Introduction

Agriculture is an inherently human endeavor involving plant selection, maintenance, and modification that has transformed wild vegetation to feed sedentary populations. Understanding the prehistory of crop cultivation is critical for our comprehension of ancient agrarian economies and social dynamics. In particular, archaeobotanical analyses of excavated plant remains can not only portray the larger anthropogenic landscapes created by ancient agricultural communities, but may also illuminate human responses to environmental stress.

The third millennium BC witnessed the development of fortified towns atop southern Levantine tells during Early Bronze II and III (about 3000–2500 cal BC), and their abandonment during the Early Bronze IV Period (also known as the Intermediate Bronze Age) which began about 2500 cal BC (Regev et al., 2012) and featured deurbanization across Southwestern Asia between about 2200 and 1900 cal BC (Fall et al., 2020). Research highlights the importance of sedentary agrarian villages for investigating Early Bronze IV society (Prag, 2001; 2014; Cohen, 2009; Falconer and Fall 2009; 2019; Richard et al., 2010; D'Andrea, 2014). Recent ceramic chronology from Tell Abu en-Ni'aj and Tell

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el-Hayyat, Jordan are responsible for the higher chronology of the Early Bronze IV (Fall et al., 2020). Traditional archaeological interpretations of this period posit a shift from agriculturally-based town life to mobile pastoralism (Dever, 1980, 2014) as a consequence of political collapse during the Egyptian First Intermediate Period. Other literature attributes Early Bronze Age urban collapse to regional aridification about 2200 cal BC, as part of the century-scale 4.2 ka BP climate event (e.g., Weiss et al., 1993; deMenocal, 2001; Staubwasser and Weiss, 2006; Langgut et al., 2015; Weiss, 2017; Kaniewski et al., 2018; Bini et al., 2019).

A variety of proxy data sources across the Eastern Mediterranean characterize the third millennium BC as an arid climatic phase (Roberts et al., 2011). An Early Bronze Age emphasis on drought-adapted crop cultivation is reflected in site-specific archaeobotanical studies, for example at Bab edh-Dhra', Numeira, Tell Arad, and Jericho (e.g., Miller, 1991; McCreery, 2003a), and in a time series of settlements along the Jordan Rift (Fall et al., 1998, 2002). Potential vegetation modeling across the Southern Levant shows pronounced Early Bronze Age vegetation changes in the northern Jordan Valley culminating in particularly warm dry conditions in Early Bronze IV (Soto-Berelov et al., 2015; Fall et al., 2018). We combine analyses of stratified archaeobotanical evidence and stable isotope data based on carbonized seeds and relative proportions of chaff fragments excavated from Tell Abu en-Ni'aj, Jordan to offer a detailed perspective on agrarian responses to town abandonment and possible environmental stress toward the end of the Levantine Early Bronze Age.

2. Methods

2.1. Study area

Tell Abu en-Ni'aj incorporates the remains of a modestly-sized Bronze Age farming village in the northern Jordan Valley, Jordan (Fig. 1). This 2.5 ha mound is situated about 250 m below sea level just east of the Jordan River, overlooking the river's modern floodplain. The settlement at Tell Abu en-Ni'aj consisted of mudbrick houses, courtyards and sherd-paved streets that were built and rebuilt through seven stratified phases of habitation from basal Phase 7 to uppermost Phase 1. Bayesian modeling of 25 calibrated AMS seed ages from all seven phases estimates founding of the village about 2500 cal BC, occupation through seven architectural phases of about 30–45 years each, and abandonment by 2200 cal BC (Fall et al., 2020). This time range corresponds roughly to the earlier portions of Early Bronze IV as defined currently on the basis of regional radiocarbon modeling (Regev et al., 2012; Höflmayer et al., 2014; Falconer and Fall 2016). The modern northern Jordan

Valley has a Mediterranean climate with long, dry summers and short, wet winters. The modern vegetation of the Jordan Valley consists of drought-tolerant Saharo-Arabian species. Shrubs include *Zygophyllum dumosum*, *Retama raetam*, *Haloxylon articulatum*, *Anabasis articulata*, *Astragalus spinosus*, *Suaeda palaestina*, *Salsola tetrandra*, *Suaeda asphaltica*, and *Achillea fragrantissima*. The riparian taxa *Tamarix* sp., *Phragmites* sp., *Salix* sp., *Nerium oleander*, *Populus euphratica* and *Tamarix jordanensis* grow in wadis and along the Jordan River. The slopes adjacent to the Jordan Valley are populated by Irano-Turanian shrubs, including *Artemisia herba-alba*, *Noaea mucronata*, *Salsola vermiculata* and *Anabasis syriaca* (Danin, 1995; Davies and Fall 2001; Soto-Berelov et al., 2012, 2015).

2.2. Field methods

Tell Abu en-Ni'aj was excavated over three field seasons in 1985, 1996/97 and 2000 (Falconer and Fall 2019). Sediment samples ranging from 1 to 14 L (mean = 4.14 L) were collected for flotation of plant remains from locations with a high likelihood of burning and organic preservation, such as hearths, tabuns (ovens), storage pits and floors. Each sample was assigned a unique spatial identifier based on excavation area, locus (three-dimensional feature), and bag number. Seeds, wood fragments and chaff (glume bases and rachis fragments) were recovered during the 1985 excavations through non-mechanized water flotation, using metal baskets with screen mesh thicknesses of 3.2 mm and 1.6 mm overlaid by cheese cloth to ensure recovery of very small seeds. During the 1996/97 and 2000 excavation seasons, a Flote-Tech 2000 flotation machine was used to mechanically separate organic remains from non-organic sediment. Light and heavy fractions were then dried and examined for carbonized remains in Jordan. Samples were selected from a variety of contexts, with each phase containing several samples from the most common ones: occupational debris, pits, and earthen surfaces. As a means of reducing the potential effect of spatial variability between phases, our analysis concentrated on plant macrofossil evidence from a limited number of contexts that remained largely consistent through the occupation of Tell Abu en-Ni'aj (excavation areas AA, C, GG, and K). Areas AA and K represented interior spaces through all of their excavated phases, Area C was an alleyway through five of its seven phases and Area GG constituted exterior space through five of its six phases. All material larger than 500 µm was sorted under a binocular microscope to separate charred plant fragments, seeds and charcoal for identification and analysis at Arizona State University and the University of North Carolina at Charlotte. The basic data utilized in this study, including plant macrofossil counts and stable isotope values, are provided in Tables S1–S4 in the supplementary data. Plant macrofossil

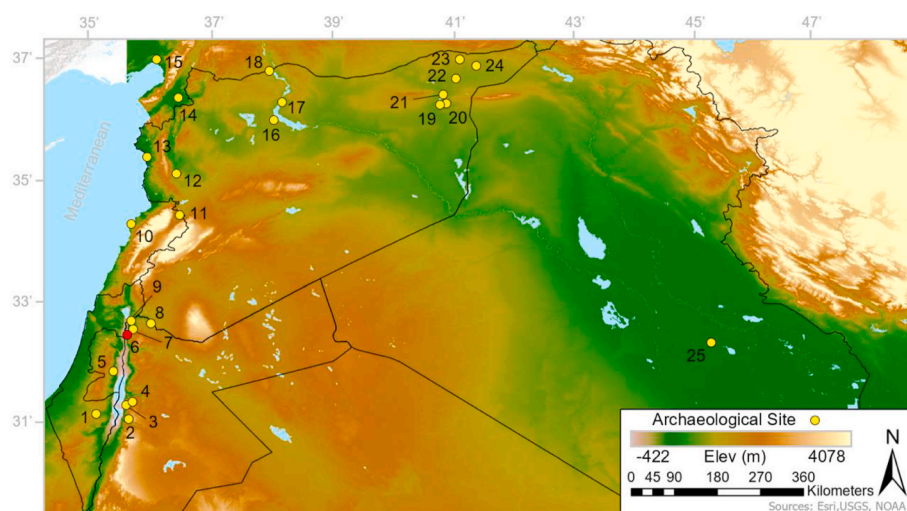


Fig. 1. Map based on elevation and water data from DIVA-GIS showing Bronze Age archaeological sites that provide archaeobotanical and/or carbon isotope data for the Levant and Mesopotamia (see Riehl et al., 2008; 2014; Wallace et al., 2015; Styring et al., 2017). (1) Tell Arad, (2) Numeira, (3) Bab edh-Dhra', (4) Zahrat adh-Dhra' 1, (5) Jericho, (6) Tell Abu en-Ni'aj, (7) Tell el-Hayyat, (8) Khirbat ez-Zeraqon, (9) Tell esh-Shuna [N], (10) Tell Fadous Kfarabida, (11) Tell Nebi Mend, (12) Qatna, (13) Tell Tweini, (14) Tell Atchana, (15) Kinet Hoyuk, (16) Emar, (17) Tell 'el Abd, (18) Tell Shioikh Faouqani, (19) Tell Atij, (20) Tell Raqa'i, (21) Tell Kerma, (22) Tell Brak, (23) Tell Mozan, (24) Tell Leilan, and (25) Abu Salabikh.

counts also are tabulated in [Falconer and Fall \(2019\): Appendix 3](#).

Food processing is one means by which seeds may be burned and incorporated in archaeological sediments (e.g., [Dennell, 1974](#); [Jones, 1987](#); [Chernoff and Paley, 1998](#); [Hastorf and Sissel, 1988](#); [Jones and Halstead, 1995](#); [Fuller and Harvey, 2006](#); [van der Veen, 2007](#); [Fuller and Stevens, 2009](#)). For communities that practice animal husbandry amid diminished local woodlands (and wood fuel), burning of dung fuel provides an important mechanism for carbonizing and preserving both cultivated crops and wild plants ([Bottema, 1984](#); [Miller, 1984](#); [Miller and Smart, 1984](#); [Anderson and Ertuğ-Yaras, 1998](#); [Charles, 1998](#); [Hastorf and Wright, 1998](#); [Reddy, 1998](#); [Klinge and Fall 2010](#); [Shahack-Gross, 2011](#)). Local deforestation, substantial sheep/goat husbandry, the recovery of abundant cultivated plant remains, the recovery of equally abundant wild weeds and chaff not intended for human consumption, and the much greater abundance of seeds than charcoal suggest that dung burning was a major source of carbonized plant remains from which we may infer crop cultivation practices at Tell Abu en-Ni'aj ([Klinge and Fall 2010](#); [Fall et al., 2015](#)). Burning of dung fuel is an excellent source of carbonized seeds, offering a pathway for burning a rich assemblage of both cultivated and wild plant taxa, incorporating a mixture of what livestock were fed, what they grazed on in local fields, as well as plant remains which might have been captured or intentionally mixed with dung (particularly chaff) during the creation of dung cakes ([Miller and Smart, 1984](#); [Charles, 1998](#)).

2.3. Taxonomic analysis of carbonized plant remains and numerical analyses

Carbonized plant remains were identified in 123 flotation samples representing all seven stratigraphic phases at Tell Abu en-Ni'aj. We categorize these plant macrofossils as cultivated cereals, pulses, fruits, and wild taxa (mostly arable weeds; [Willcox, 2012](#)). Seed identification was based on comparative literature for the Near East (e.g., [Delorit, 1970](#); [Helbaek, 1959](#); [Martin and Barkley, 1973](#); [Zohary and Hopf, 1973](#); [Zohary, 1966](#); [1972](#); [Zohary and Spiegel-Roy, 1975](#); [van Zeist, 1976](#); [Feinbrun-Dothan, 1978](#); [van Zeist and Bakker-Heeres, 1982](#); [Feinbrun-Dothan, 1986](#); [Hubbard, 1992](#); [Jacomet, 2006](#)). All seeds were identified to the lowest taxonomic level possible (species-to family-level identifications) and tabulated according to the number of identified specimens (NISP) for each taxon ([O'Connor, 2000](#): 54).

All seed counts were converted to percentages of the total seed assemblage for each habitation phase. Percentages of plant categories, as well as percentages for individual cultivated and wild taxa, were plotted according to stratigraphic phase using *TILIA* and *TGView* ([Grimm, 2004](#)). Percentages provide a standardized measure for comparisons between the relative abundances of plant categories or individual taxa in each phase ([Miller, 1988](#); [Kreuz et al., 2005](#); [van der Veen, 2007](#); [Šmilauer and Lepš, 2014](#)). To highlight the shifting contributions of chaff (glume bases and rachis fragments) through time, we also calculated ratios of chaff fragments to seeds for barley and wheat (*Hordeum* spp. and *Triticum* spp.), using both expected and observed values of total glume base and rachis counts. Hierarchical cluster analysis of the seven stratified assemblages uses the CONISS program (constrained incremental sum of squares) in *TILIA* ([Grimm, 1987](#)), based on seed counts from all 123 samples for all taxa. To assess the commonality of plant taxa, ubiquity values were calculated, representing the percentage of samples per phase in which a taxon was present ([Hubbard, 1980](#)). Ubiquity values provide a complementary standardized measure ([Popper, 1988](#): 60–64; [Pearsall, 2000](#): 212–216) that accommodates varying sample volumes, and taxa that differ in fragmentation rate or the number of seeds produced per plant ([Marston, 2014](#): 167).

We use canonical discriminant analysis (CDA) to quantify and visualize the compositional differences between the seven stratigraphic floral assemblages from Tell Abu en-Ni'aj and the relative contributions of each taxon to those differences ([Legendre and Legendre, 2012](#)). Canonical discriminant plots and their accompanying statistics were

produced with SPSS 26 ([IBM, 2019](#)). The data used for the first CDA include percentages of cultigens from 119 samples, which excludes four samples with no remains of cultivated taxa. These cultigens include the cereals *Hordeum vulgare* (hulled barley), *H. vulgare* var. *nudum* (naked barley), both two-row, *Triticum aestivum* (bread wheat), *T. dicoccum* (emmer wheat) and *T. monococcum* (einkorn wheat) ([Table 1](#)). The *Hordeum* remains are identified morphologically as representing two-row barley. Cultivated pulses are represented by *Lens culinaris* (lentil) and *Pisum sativum* (garden pea), while cultivated fruits include *Ficus carica* (fig), *Olea europaea* (olive) and *Vitis vinifera* (grape). *Triticum spelta* (spelt), *Vicia* sp. (bean) and *Pistacia atlantica* (pistachio) were excluded from this CDA based on their modest seed counts (<25 total seeds). A second CDA uses percentages of the ten cultivated taxa above, plus those for the most abundant wild taxa (*Amaranthus* sp., *Anagallis* sp., *Bellevia* sp., *Bupleurum* sp., *Chenopodium* sp., *Coriandrum* sp., *Galium* sp., *Malva* sp., *Medicago/Onobrychis* spp., *Melilotus* sp., *Phalaris* sp., *Plantago* sp., *Prosopis farcta*, *Rumex/Polygonum* spp.), as well as chaff fragments. Our second CDA includes data from 107 samples with at least 10 macrofossils each to minimize the effect of samples with extremely low counts.

2.4. Stable carbon isotope analysis

Stable isotope analysis was conducted on 37 samples of carbonized cereal grains and legumes from all seven phases of occupation at Tell Abu en-Ni'aj. Concentrations of stable carbon isotopes in plant macrofossils, derived from atmospheric CO₂, can be used as indicators of relative water availability. The lighter ¹²C isotope is preferentially incorporated over ¹³C during photosynthesis when water availability is higher ([Farquhar et al., 1982](#); [Ehleringer, 1991](#)). The ratio of ¹²C–¹³C, expressed using the value $\delta^{13}\text{C}$ ([Farquhar et al., 1982](#)), serves as a proxy indicator of water availability, such that lower values of $\delta^{13}\text{C}$ are typically associated with increased water ([Wallace et al., 2015](#)). Since the $\delta^{13}\text{C}$ of atmospheric CO₂ has changed over time, we use the measured $\delta^{13}\text{C}$ values for our seed samples ($\delta^{13}\text{C}_{\text{sample}}$) in conjunction with atmospheric $\delta^{13}\text{C}$ values ($\delta^{13}\text{C}_{\text{air}}$) approximated by the AIRCO2_LOESS system (see [Ferrio et al., 2012](#)) to calculate carbon discrimination

Table 1

Scientific and common names for the most common cultivated and wild plant taxa found at Tell Abu en-Ni'aj.

Scientific Name	Common Name
Cultivated Taxa	
<i>Hordeum vulgare</i>	Hulled barley
<i>Hordeum vulgare</i> var. <i>nudum</i>	Naked barley
<i>Triticum aestivum</i>	Bread wheat
<i>Triticum dicoccum</i>	Emmer wheat
<i>Triticum monococcum</i>	Einkorn wheat
<i>Lens culinaris</i>	Lentil
<i>Pisum sativum</i>	Garden pea
<i>Ficus carica</i>	Fig
<i>Olea europaea</i>	Olive
<i>Vitis vinifera</i>	Grape
Wild Taxa	
<i>Amaranthus</i>	Amaranth
<i>Anagallis</i>	Pimpernel
<i>Bellevia</i>	Bellevia
<i>Bupleurum</i>	Thorow wax
<i>Chenopodium</i>	Goosefoot
<i>Coriandrum</i>	Coriander
<i>Galium</i>	Bedstraw
<i>Malva</i>	Mallow
<i>Medicago/Onobrychis</i>	Burclover/Sainfoin
<i>Melilotus</i>	Sweet clover
<i>Phalaris</i>	Canary grass
<i>Plantago</i>	Fleawort
<i>Prosopis farcta</i>	Syrian Mesquite
<i>Rumex/Polygonum</i>	Dock or Sorrel/Knotweed
<i>Scirpus</i>	Sedge

($\Delta^{13}\text{C}$). We calculate $\Delta^{13}\text{C}$ in accordance with Ferrio's et al.'s (2005) modification of Farquhar et al.'s (1989) isotope calibration formula:

$$\Delta^{13}\text{C} = (\delta^{13}\text{C}_{\text{air}} - \delta^{13}\text{C}_{\text{sample}}) / (1 + [\delta^{13}\text{C}_{\text{sample}}/1000])$$

Carbon discrimination calculation provides a proxy measure whereby higher $\Delta^{13}\text{C}$ values indicate greater water availability. This proxy, which has seen particular success for the interpretation of archaeological cereal remains, constitutes an important tool for assessing crop watering practices (e.g., Wallace et al., 2013, 2015; Styring et al., 2016, 2017), paleoclimate (e.g., Riehl et al., 2008, 2014), and their effects on ancient agriculture.

Isotope analyses of carbonized seed from Tell Abu en-Ni'aj were performed at the University of Arizona Accelerator Mass Spectrometry Laboratory, the University of Groningen Centre for Isotope Research, the Vienna Environmental Research Accelerator, the Oxford Radiocarbon Accelerator Unit and the University of Georgia Quaternary Isotope Paleocology Lab (UGA). At the University of Georgia, concentrations of $\delta^{13}\text{C}$ (‰) were determined using a Delta-V elemental analyzer isotope ratio mass spectrometer (EA-IRMS). At Groningen (GrM), Oxford (OxA) and Arizona (AA), $\delta^{13}\text{C}$ was measured with an isotope ratio mass spectrometer, while values from Vienna (VERA) were measured directly by AMS.

To account for the potential effect of seed carbonization, we corrected our initial $\delta^{13}\text{C}$ values by subtracting 0.11‰ for the average difference between experimentally derived values for carbonized and uncarbonized seeds (Styring et al., 2017; following methods in Nitsch et al., 2015). Values of $\Delta^{13}\text{C}$ were plotted chronologically based on median calibrated age (for AMS samples) or median modeled phase age (for UGA samples, not in conjunction with ^{14}C age determinations). Results are plotted for three taxonomic categories: (i) *Hordeum* sp., (ii) *Triticum* sp., and (iii) mixed cereals and legumes (i.e., *Pisum* sp., *Prosopis farcta*). Multiple methods for distinguishing levels of water availability based on $\Delta^{13}\text{C}$ have been proposed (Riehl et al., 2008; Wallace et al., 2013, 2015; Styring et al., 2016, 2017; Flohr et al., 2019), incorporating precipitation, temperature, soil type, hydrology, and other variables likely to affect $\Delta^{13}\text{C}$ values. As a variety of studies indicate, wheat produces lower $\Delta^{13}\text{C}$ values than barley, when these crops are grown under comparable watering conditions (Araus et al., 1997; Ferrio et al., 2005; Wallace et al., 2013; Styring et al., 2017), yielding a difference quantified by Wallace et al. (2013) as 1–2‰. Lower wheat values reflect its longer grain filling period, which typically extends into early summer, during which decreasing water availability contributes to stomatal closure and correspondingly reduced $\Delta^{13}\text{C}$ (Araus et al., 1997; Ferrio et al., 2005; Riehl et al., 2008; Wallace et al., 2013). The shorter growing season for barley is a major factor in its greater tolerance of water stress, as compared to wheat. Based on these considerations, several influential studies propose similar categories of water availability (e.g., Riehl et al., 2014; Wallace et al., 2013, 2015; Styring et al., 2016, 2017), all of which use lower $\Delta^{13}\text{C}$ thresholds for wheat than for barley. We adopt categories of water availability for cereals derived from experimental crop cultivation trials conducted in arid settings in Syria, Jordan and Spain (Wallace et al., 2013). For wheat, we use values of $\Delta^{13}\text{C} > 17\text{‰}$ to denote “well-watered” conditions, in which water availability is not a major factor limiting crop growth. Values of $\Delta^{13}\text{C} < 16\text{‰}$ indicate “poorly watered” conditions for which water availability is a major limiting factor, while intermediary values constitute a “moderately watered” category. For barley, we use $\Delta^{13}\text{C}$ values $> 18.5\text{‰}$ to define well-watered conditions, while values $< 17\text{‰}$ denote poor watering conditions, and intermediary values indicate moderately watered conditions. These watering categories (which may be defined by different investigators according to different threshold values) are primarily informative in distinguishing differences in water availability between cultigens (e.g., wheat vs. barley).

3. Results

3.1. Percentages and ubiquities of plant taxa

The major crops cultivated by the farmers of Tell Abu en-Ni'aj may be categorized as cereals, pulses and fruits (Fig. 2). A wide variety of wild taxa also grew as arable weeds, most likely in both cultivated and fallowed fields. Water flotation recovered nearly 14,000 identified carbonized seeds and plant fragments from Tell Abu en-Ni'aj (Table 2), predominantly from cultivated cereals, chaff, and wild taxa, with lesser amounts of cultivated fruits and pulses (Fig. 3). Macrofossil densities show a continuous and pronounced decline from almost 83 fragments/liter in Phase 7 to less than 3 fragments/liter in Phase 1. We observe little change in the fragmentation rate of seeds, with the highest rates (~55% of cereals) in phases 6 and 5 (Table S4). Detailed profiles of the crops and weeds around Tell Abu en-Ni'aj are provided as seed percentages and ubiquities by phase for the most common cultivated and wild taxa (Figs. 4 and 5). CONISS cluster analysis, based on the seed counts for the cultivated and wild taxa shown in Figs. 4 and 5, reveals the most pronounced distinction between the assemblages of phases 7 to 4 compared to those of phases 3 to 1. At lower clustering levels, CONISS distinguishes phases 7 and 6 from phases 5 and 4 among the early strata, and phases 3 and 2 from Phase 1 in the later levels.

Taxonomic percentages and ubiquities reveal a variety of noteworthy changes through the seven occupation phases at Tell Abu en-Ni'aj. Taxonomic ubiquities seem to reinforce the contrasts noted in the percentages between the earlier and later phases. The transition from the earlier phases (7–4) to the later phases (3–1) includes increased percentages of barley and, to a lesser extent, pulses, while relative frequencies of chaff and fruits decline. *Hordeum vulgare* is the most frequent and ubiquitous taxon in all seven phases, with a clear increase in percentages from the earlier to later phases. This barley species peaks at nearly 60% of the seed total in Phase 3, and is one of the most ubiquitous taxa in all seven phases, with ubiquities of 80% or higher in phases 7 to 2. *Triticum dicoccum* is the most common wheat, appearing in more than 73% of samples from phases 7 to 4, but remains less than 5% through all phases. Among the other less prevalent cereals, *H. vulgare* var. *nudum* and *T. dicoccum* have higher relative frequencies, but show less of a trend between the earlier and later phases, while *T. monococcum* and *T. aestivum* percentages are lowest among cereals through all seven phases and decline in phases 3 to 1. All cereals except *T. aestivum* are more comparable in ubiquity in phases 7 to 4, and show similar declines in phases 3 to 1. Ratios of seeds for all species of *Hordeum* to all species of *Triticum* increase dramatically from 2.72:1 in phases 7 through 4 to 10.18:1 in phases 3 through 1, while ratios of chaff fragments to cereal seeds also show a clear temporal distinction between higher values in the earlier phases and lower values in the later phases (Fig. 6).

Lens culinaris and *Pisum sativum* are most abundant among pulses, while the most common fruits include *Ficus carica*, *Olea europaea*, and *Vitis vinifera*. *Lens* and *Pisum* have modest percentages and ubiquities throughout, with *Lens* percentages increasing slightly from the early to late phases. *Ficus* has the highest percentage and ubiquity of the fruits, reaching its greatest percentage (nearly 20%) in Phase 5, and occurring at relatively high, but variable, ubiquities through all seven phases. These fig percentages in part reflect the large number of pips produced by each *Ficus* fruit, as evidenced by a Phase 7 sample with 978 pips, which was excluded as an outlier in our percentage calculations. Percentages and ubiquities of *Olea* and *Vitis* are both consistently low, with values only slightly increased in Phase 1. Cultivation of fruits is inferred through the higher frequency of fruit remains and the morphology of olive fragments, possibly indicative of use in olive pressing.

Notable trends among wild plants, whose seeds are particularly well preserved in animal dung (Wallace and Charles, 2013), include greater percentages and/or ubiquities for several taxa in earlier phases (e.g., *Anagallis* sp., *Chenopodium* sp., *Coriandrum* sp., *Galium* sp., *Phalaris* sp., *Plantago* sp., *Rumex/Polygonum* spp.). The most abundant wild taxa

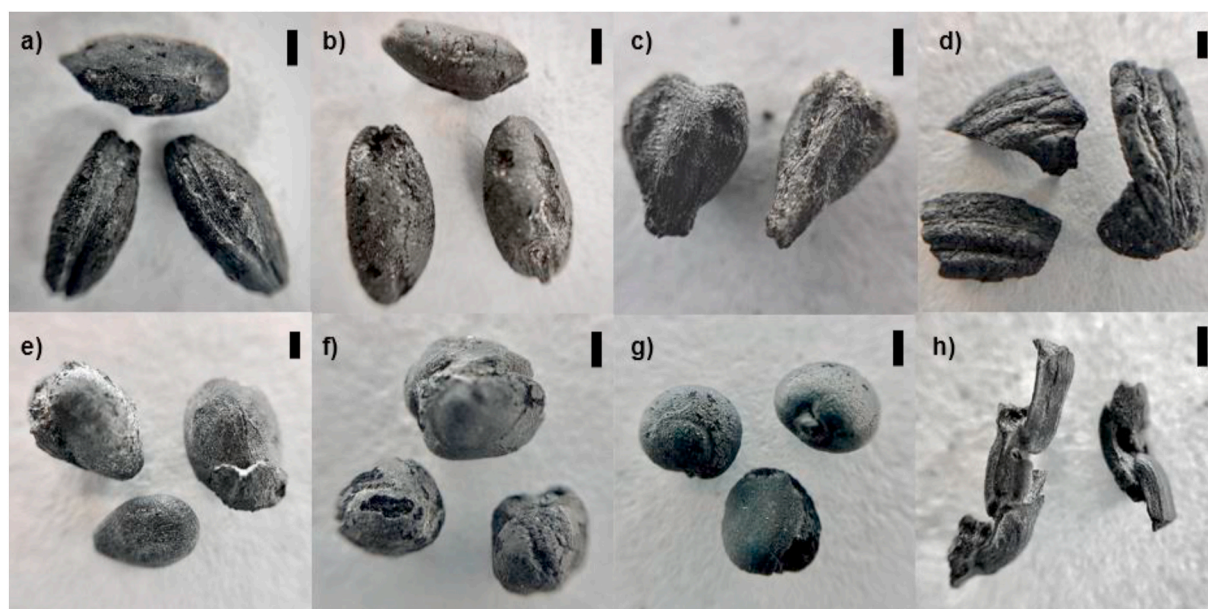


Fig. 2. Carbonized seeds from Tell Abu en-Ni'aj showing some of the most prominent taxa: a) hulled barley, *Hordeum vulgare*; b) emmer wheat, *Triticum dicoccum*; c) grape, *Vitis vinifera*; d) olive fragments, *Olea europaea*; e) *Prosopis farcta*; f) garden pea, *Pisum sativum*; g) lentil, *Lens culinaris*; h) rachis internodes. Black bar indicates approximately 1 mm.

Table 2

Summary of flotation samples and identified plant macrofossils by occupational phase at Tell Abu en-Ni'aj. Age ranges based on Bayesian modeling of 25 calibrated AMS ages (Fall et al., 2020).

Phase	Age Range (Cal BC)	Flotation Samples	Identified Macrofossils	Liters Floated	Macrofossils/ Liter
1	2294–2264	14	188	63.59	2.96
2	2331–2294	20	1249	103.06	12.12
3	2375–2331	17	1093	66.70	16.39
4	2418–2375	22	2651	99.34	26.69
5	2456–2418	15	2105	34.88	60.35
6	2487–2456	19	2941	52.61	55.90
7	2524–2487	16	3700	44.66	82.85
Total	123	13,927	509.04	mean = 36.75	

include uncultivated grasses (e.g., *Phalaris* sp.), uncultivated legumes (e.g., *Medicago/Onobrychis* spp.), and numerous wild and weedy species, all of which would have grown in the fields around Tell Abu en-Ni'aj. The uncultivated legume *Prosopis farcta* (Syrian mesquite), which grows in the Middle East as a small woody perennial, is the most abundant wild taxon.

3.2. Canonical discriminant analysis

Further comparisons based on CDA explore the variance between the samples in each phase based on the relative influence of each taxon. In our analysis of cultivated taxa, discriminant functions 1 and 2 jointly explain 78.0% of the variance in the data (Fig. 7). The sample points and centroids for each phase are distributed in general agreement with the CONISS dendrogram shown in Fig. 4, as reflected by an alignment of the phase 7 to 4 centroids on one side of the scatter plot and of the phase 3 to 1 centroids on the other side. Canonical discriminant function coefficients indicate the primary importance of *Hordeum*, *Triticum*, *Lens* and *Pisum* in generating the variance among cultigens on both axes 1 and 2 (Table S5). The highest coefficient for Axis 1 pertains to *Hordeum vulgare*, which is accompanied by values nearly as high for *Pisum* and *Lens*. The highest coefficients on Axis 2 are for *Triticum monococcum*, *Pisum* and *T. aestivum*.

Our second CDA, utilizing both cultivated and wild taxa, produced discriminant functions 1 and 2 which jointly explain 63.6% of the variance in the data (Fig. 8). The sample points and centroids for each phase are distributed in clear agreement with the CONISS dendrogram. Most notably, the phase centroids plot in proximate pairs for phases 7 and 6, 5 and 4, 3 and 2, with the Phase 1 centroid most distant from all others, in accordance with our CONISS clustering. The taxa contributing most substantially to variance on Axis 1 are indicated by large coefficients for the cultigens *Hordeum vulgare*, *Pisum*, and *Olea* (Table S6). Variance on Axis 1 also is driven by several wild taxa, as reflected by large coefficients for *Medicago/Onobrychis* spp., *Prosopis farcta*, and *Rumex/Polygonum* spp. The major contributions of cultivated taxa on Axis 2 are represented by large coefficients for *Hordeum vulgare*, *Lens*, and chaff (glume bases and rachis fragments), while the most substantial wild contributors are *Prosopis* and *Malva* sp.

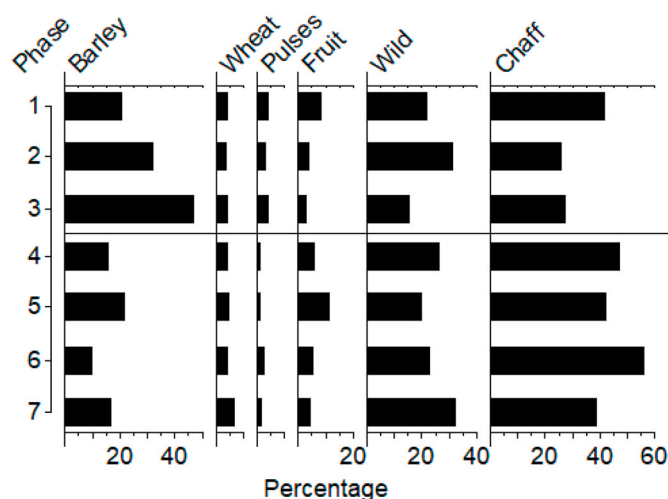


Fig. 3. Percentages of plant categories and chaff at Tell Abu en-Ni'aj plotted by phase (earliest Phase 7 on the bottom to latest Phase 1 on the top). Percentages are based on the total number of identified seeds and chaff fragments in each phase.

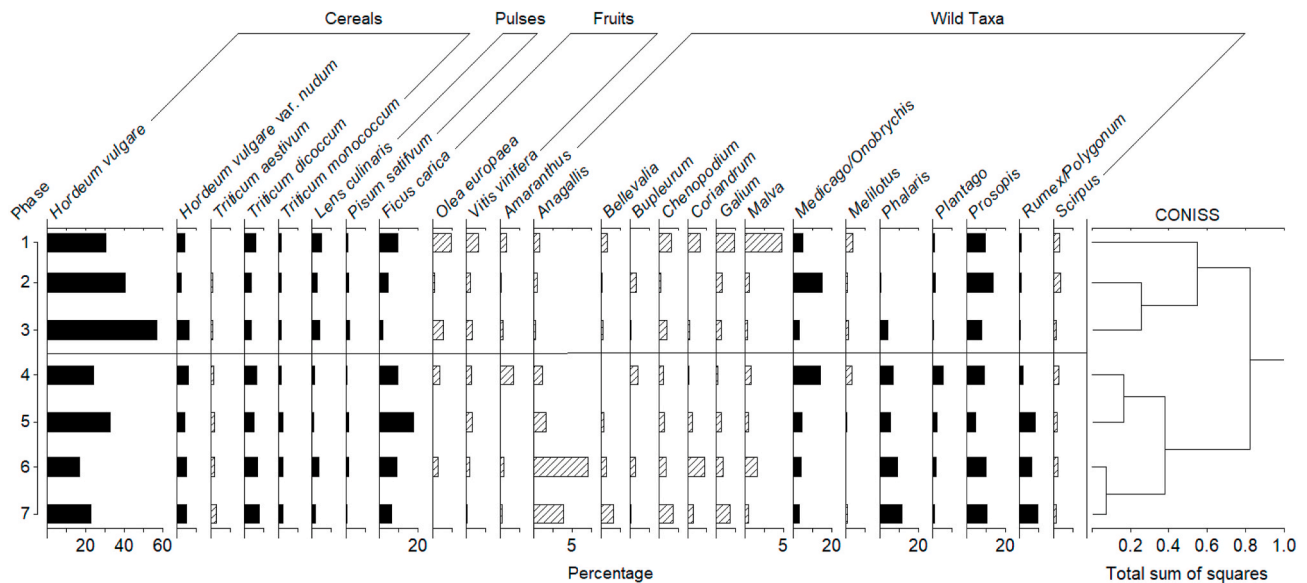


Fig. 4. Percentages of seeds from the most abundant cultivated and wild taxa at Tell Abu en-Ni'aj plotted by phase (earliest Phase 7 on the bottom to latest Phase 1 on the top). Percentages were calculated based on the total number of identified seeds in each phase. Taxonomic categories are indicated at the top. Taxa with lower percentages (those with stripped bars) are shown at 4 x scaling. Cluster analysis using CONISS (Grimm 1987) distinguishes primarily between the assemblages of Phases 7–4 vs. the assemblages of phases 3–1.

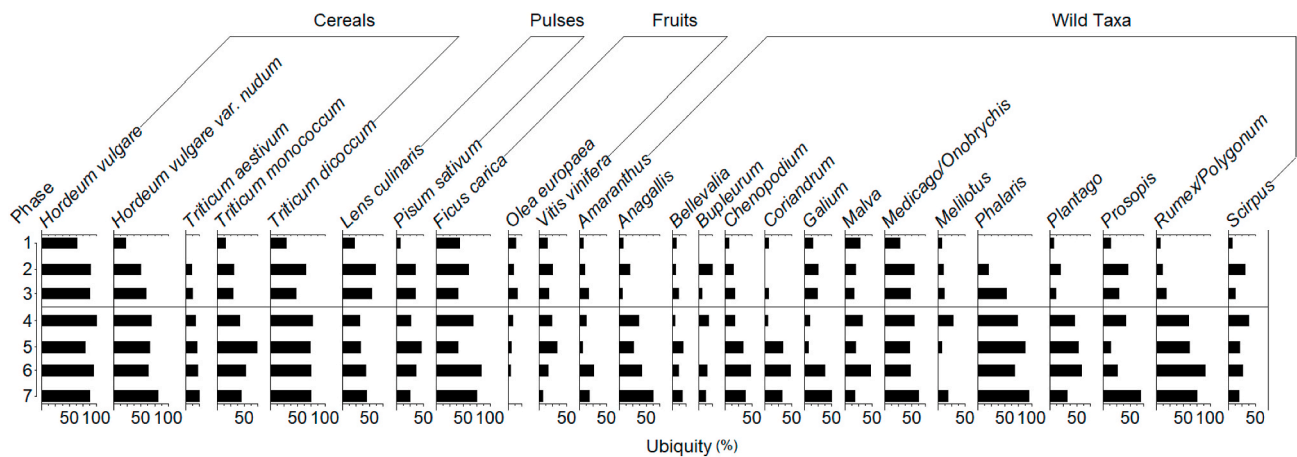


Fig. 5. Ubiquities of the most abundant cultivated and wild taxa plotted by phase at Tell Abu en-Ni'aj (earliest Phase 7 on the bottom to latest Phase 1 on the top). Ubiquities were calculated based on the number of flotation samples in which a taxon was represented in each phase. Taxa groups are indicated at the top. Taxa with lower percentages (those with stripped bars) are shown at 4 x scaling. Cluster analysis using CONISS (Grimm 1987) distinguishes primarily between the assemblages of Phases 7–4 vs. the assemblages of phases 3–1.

3.3. Stable carbon isotope analysis

We determined $\Delta^{13}\text{C}$ concentrations for 37 seed samples of *Hordeum* sp., *Triticum* sp., *Prosopis farcta* and mixed taxa from all seven phases at Tell Abu en-Ni'aj (Table 3). Values for $\Delta^{13}\text{C}$ range from 15.1 to 18.6‰ for wheat, 14.1–18.3‰ for barley, and 16.3–18.5‰ for samples with mixed taxa. These ranges are similar, especially at their upper ends, but carry different implications for inferring water availability (Fig. 9). The $\Delta^{13}\text{C}$ concentrations for wheat range from well-watered to poorly-watered, with most values falling in the well-watered category. In contrast, barley samples fall primarily in the moderately-watered range. No barley samples occur in the well-watered category, most samples lie in the moderately-watered range, and several sample values drop well into the poorly-watered range after 2375 cal BC. Samples of mixed cereals and legumes are spread across the moderately-watered ranges for barley and wheat.

4. Discussion

The major cereal and pulse taxa found at Tell Abu en-Ni'aj (*Hordeum*, *Triticum*, *Lens*, *Pisum*, *Vicia*) have been domesticated in southwestern Asia since the Neolithic (Zohary and Hopf, 2000; 1996; Zohary and Hopf, 2000; Caracuta et al., 2015). Domesticated taxa are typically distinguished from wild varieties by enlarged seeds sizes and, in the cases of *Hordeum* and *Triticum*, by a non-brittle rachis (Zohary and Spiegel-Roy, 1975; Liphshitz et al., 1991; Miller, 1992, 1999; Fuller and Harvey, 2006; Fuller, 2007). The major fruit taxa (*Olea*, *Vitis*, *Ficus*) were domesticated by the Levantine Chalcolithic Period and were rendered into storable and exchangeable commodities by the Bronze Age (Zohary and Spiegel-Roy, 1975). Domesticated olive and grape are indicated by larger seed sizes, with correspondingly enhanced oil content in domesticated olives (Zohary and Spiegel-Roy, 1975; Liphshitz et al., 1991; Miller, 1999; Stummer, 2011). Cultivation also is indicated indirectly by a variety of archaeological evidence from Tell Abu en-Ni'aj, including

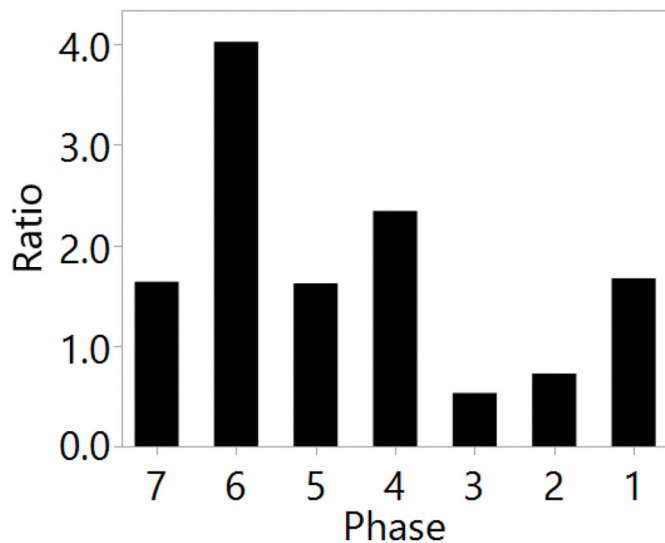


Fig. 6. Ratios of chaff fragments to cultivated cereal seeds (*Hordeum* sp. and *Triticum* sp.) at Tell Abu en-Ni'aj, showing more chaff to cereal in earlier phases (Phases 7–4) and a distinctive drop-off in phase 3, coinciding with a pronounced increase in hulled barley between Phases 4 and 3 (see Fig. 4).

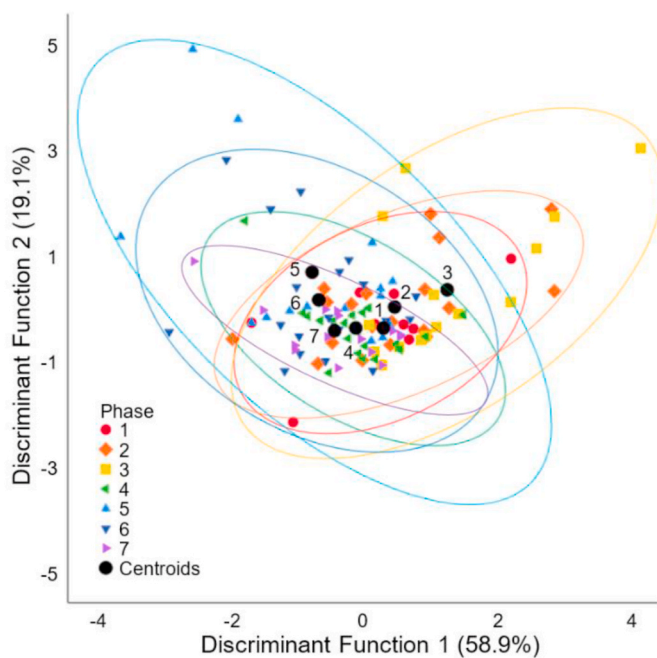


Fig. 7. Canonical discriminant analysis based on percentages of seeds from cultigens in 119 samples, excluding four samples with no remains of cultivated taxa. Phase centroids and ellipses aid comparison of phase-by-phase sample distributions. Functions 1 and 2 explain 78.0% of variance. Comparison of seed counts for Phases 7 to 4 vs. counts in Phases 3 to 1 produces Wilk's lambda: 0.832; and χ^2 : 21.125, $p = .020$, affirming a statistically significant distinction between the early and late phases. See canonical discriminant function coefficients in Table S5.

prismatic Canaanite chert blades with sickle sheen, clay-lined cooking ovens, grinding stones, narrow-necked storage jars and a large mudbrick feature in Phase 3 consisting of three descending settling basins, possibly for separating olive oil (Falconer and Fall 2019; see discussion of domestication implied by archaeological evidence in Miller, 1992). Some wild plant taxa may have represented food sources. Presence of *Prosopis farcta* does not correlate with times of maximum cereal and

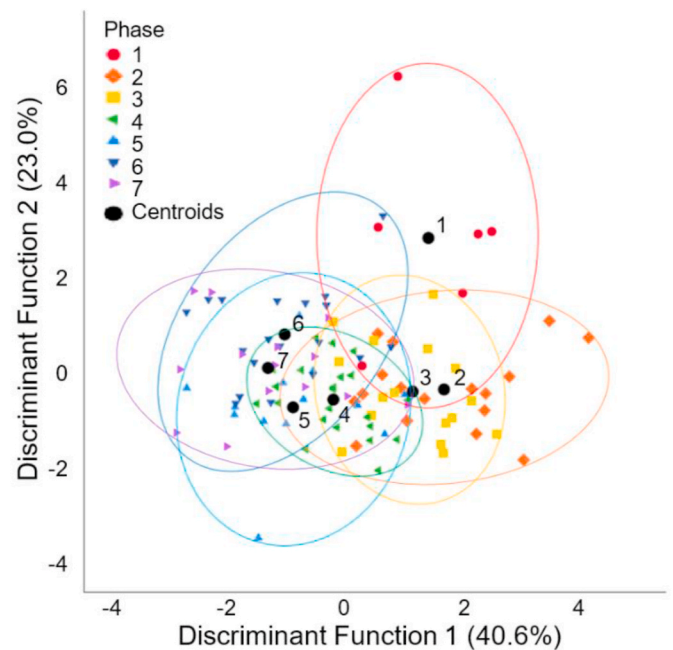


Fig. 8. Canonical discriminant analysis based on percentages of seeds and plant fragments from cultivated and wild taxa in all samples from Tell Abu en-Ni'aj with 10 or more seeds, totaling 107 samples. Phase centroids and ellipses aid comparison of phase-by-phase sample distributions. Functions 1 and 2 explain 63.6% of variance. Comparison of seed counts for Phases 7 to 4 compared to counts for Phases 3 to 1 produces Wilk's lambda: 0.577; and χ^2 : 49.971, $p = .007$, affirming a statistically significant distinction between the early and late phases. See canonical discriminant function coefficients in Table S6.

pulse cultivation, possibly indicating its use as an off-season food source for animals (Charles, 1998).

The cultigens represented in the plant macrofossil assemblages from phases 7 through 1 primarily include annual cereals, accompanied by lesser amounts of legumes and perennial fruit species. A hallmark feature of the evidence from Tell Abu en-Ni'aj is the predominance of *Hordeum vulgare* (hulled barley), which ranges between about 20% and 60% of the identified seed totals for each phase. Other cereals found in appreciable quantities are limited to *Hordeum vulgare* var. *nudum* (naked barley) and three wheat species (*Triticum monococcum*, *T. dicoccum*, and *T. aestivum*), none of which reach 10% in any phase (including only modest amounts of *T. aestivum* and fewer than 25 seeds of *T. spelta*). Likewise, cultivated pulses at Tell Abu en-Ni'aj include only low quantities of *Lens culinaris* (lentil) and *Pisum sativum* (grass pea), plus two seeds of *Vicia* sp.

This limited diversity of annual cultigens stands in contrast to several lines of evidence from two Middle Bronze Age settlements: nearby Tell el-Hayyat, in a nearly identical agricultural setting 1.5 km to the northeast, and Zahrat adh-Dhra' 1 (ZAD 1) on the hyperarid Dead Sea Plain (Fall et al., 2019). Plant macrofossils were recovered and analyzed using methods identical to those employed at Tell Abu en-Ni'aj, thereby providing readily comparable data. At these two Middle Bronze Age settlements, barley and wheat were supplemented by the cultivated cereals *Panicum miliaceum* (millet) and *Secale cereale* (rye), and at ZAD 1 cultivated legumes also included the beans *Vicia ervilia*/Lathyrus and *Vicia faba*. Cultivated cereals are relatively common, constituting about 30% of the identified seed totals at both Tell el-Hayyat and ZAD 1 (Fall et al., 2019). In stark contrast to Tell Abu en-Ni'aj, *Hordeum vulgare* contributes only about 8% of the total identified seeds at Tell el-Hayyat and about 2% at ZAD 1. The relative importance of barley cultivation is reflected in the overall barley:wheat ratio from Tell Abu en-Ni'aj (4.10:1), which approaches the ratio at Early Bronze IV Bab adh-Dhra' on the Dead Sea Plain (6.2:1; McCreery, 2003a, 2003b; Fall et al., 2002),

Table 3

Values of $\delta^{13}\text{C}$ and $\Delta^{13}\text{C}$ for seed samples from Tell Abu en-Ni'aj. Each sample is listed according to lab code, sample number, AMS age, and analyzed plant taxa. Original $\delta^{13}\text{C}$ values (presented here) were reduced by 0.11‰ prior to calculation of $\Delta^{13}\text{C}$ to offset experimentally determined differences between carbonized and uncarbonized seeds (Styring et al., 2017). AMS ages are median calibrated ages for individual samples or 6 median modeled calibrated ages for sample phase (see Table 1 for modeled phase ages).

Lab Code Number	Sample	AMS Age	$\delta^{13}\text{C}$	$\Delta^{13}\text{C}$	Sample Taxa
			(‰)	(‰)	
AA-113005	D.016.51	2242	-24.1	18.3	<i>Hordeum</i> sp.
VERA-2043	C.037.126	2251	-23.7	17.9	<i>Hordeum</i> sp.
VERA-2042	B.024.172	2264	-20.0	14.1	<i>Hordeum</i> sp.
AA-113003	C.015.50	2287	-23.9	18.1	<i>Hordeum</i> sp.
AA-113006	E.016.82	2290	-23.6	17.8	<i>Hordeum</i> sp.
AA-113004	D.009.41	2340	-22.6	16.8	<i>Hordeum</i> sp.
OxA-10991	B.024.172	2364	-22.4	16.6	<i>Hordeum</i> sp.
VERA-2041	K.018.030	2381	-22.9	17.1	<i>Hordeum</i> sp.
AA-90069	C.071.236	2381	-22.7	16.9	<i>Hordeum</i> sp.
AA-94178	GG.065.185	2397	-23.7	17.9	<i>Hordeum</i> sp.
AA-90073	C.089.386	2398	-23.5	17.7	<i>Hordeum</i> sp.
OxA-10990	K.018.030	2418	-23.3	17.5	<i>Hordeum vulgare</i>
AA-90071	C.075.278	2511	-23.4	17.6	<i>Hordeum</i> sp.
VERA-2044	B.010.063	2285	-21.8	15.9	<i>Triticum</i> sp.
30974 ^a	C.024.60	2313	-23.5	17.7	<i>Triticum dicoccum</i>
30975a ^a	AA.016.113	2353	-22.5	16.7	<i>Triticum dicoccum</i>
30975b ^a	AA.016.153	2353	-21.0	15.1	<i>Triticum dicoccum</i>
AA-90070	C.073.284	2353	-23.0	17.2	<i>Triticum</i> sp.
AA-90076	C.106.494	2388	-23.4	17.6	<i>Triticum</i> sp.
30976a ^a	C.071.256	2397	-23.7	17.9	<i>Triticum dicoccum</i>
30976b ^a	C.071.254	2397	-23.5	17.7	<i>Triticum dicoccum</i>
30977 ^a	GG.030.95	2397	-24.3	18.6	<i>Triticum dicoccum</i>
30978 ^a	C.075.279	2437	-23.4	17.6	<i>Triticum dicoccum</i>
30979 ^a	GG.039.123	2437	-22.8	17.0	<i>Triticum dicoccum</i>
30980 ^a	AA.064.390	2472	-23.0	17.2	<i>Triticum dicoccum</i>
30981 ^a	C.111.548	2472	-23.3	17.5	<i>Triticum dicoccum</i>
30982 ^a	GG.089.269	2506	-21.2	15.3	<i>Triticum dicoccum</i>
30983 ^a	AA.069.413	2506	-23.6	17.8	<i>Triticum dicoccum</i>
AA-90072	C.091.406	2518	-23.2	17.4	<i>Triticum</i> sp.
AA-94179	GG.015.49	2281	-24.3	18.5	<i>Prosopis farcta</i>
OxA-10992	B.010.063	2374	-22.8	17.0	Undifferentiated cereal
AA-94180	GG.100.289	2400	-23.4	17.6	<i>Prosopis farcta</i>
AA-107228	C.111.548	2413	-23.3	17.5	<i>Hordeum</i> sp., <i>Triticum</i> sp. & <i>Pisum</i> sp.
AA-107227	GG.098.295	2439	-23.8	18.0	<i>Hordeum</i> sp., <i>Triticum</i> sp. & <i>Pisum</i> sp.
AA-90067	C.035.239	2513	-23.1	17.3	<i>Hordeum</i> sp. & undifferentiated cereal
AA-90075	C.086.387	2546	-22.2	16.3	Undifferentiated cereal
AA-94177	GG.105.331	2572	-22.8	17.0	Undifferentiated cereal

^a Samples processed at the University of Georgia (UGA).

and clearly exceeds the ratios from Tell el-Hayyat (1.44:1) and ZAD 1 (2.89:1). All four settlements cultivated the fruits *Ficus carica* (fig) and *Vitis vinifera* (grape), whereas *Olea europaea* (olive) is absent at ZAD 1, but found at the others. Although the evidence for arboriculture is relatively modest, fruit seed frequencies at Tell el-Hayyat (16% of seed total) and even ZAD 1 (12% of seed total) exceed the percentage of identified fruit seeds at Tell Abu en-Ni'aj (6% of seed total). In further contrast, the plant spectra at Tell Abu en-Ni'aj include approximately 100 wild taxa, many in very small amounts, as compared to less than half

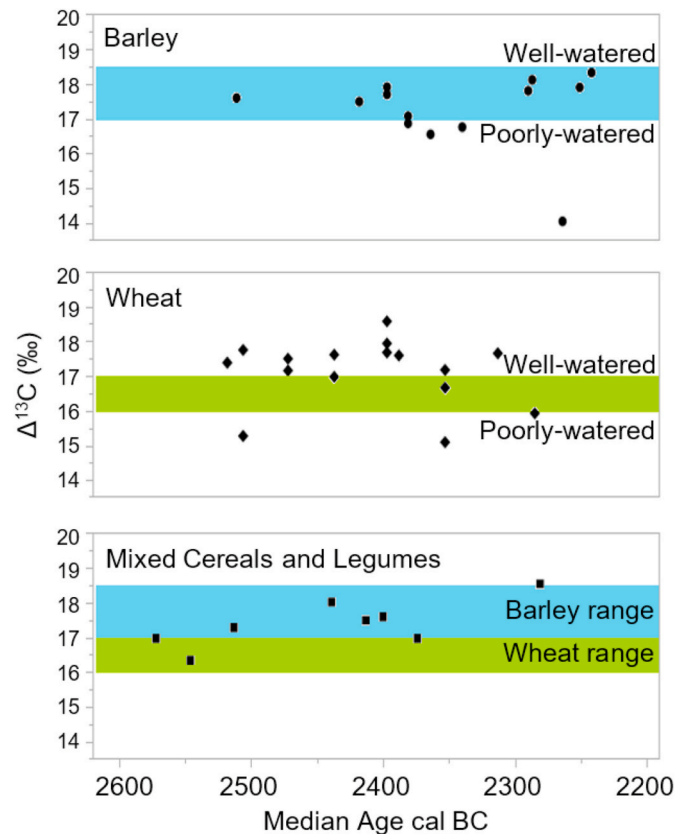


Fig. 9. $\Delta^{13}\text{C}$ values for cereals and legumes from Tell Abu-en Ni'aj plotted by sample age (see Table 2); higher $\Delta^{13}\text{C}$ values indicate greater water availability. Shading indicates moderately-watered conditions as differentiated from well-watered or poorly conditions for barley (blue) and wheat (green) based on Wallace et al. (2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

that number of taxa at Zahrat adh-Dhra' 1, and about 20 wild taxa at Tell el-Hayyat (Fall et al., 2019). In general, even if conditions may have been less agriculturally favorable during Early Bronze IV, the agriculture practiced at Tell Abu en-Ni'aj is striking for its pronounced emphasis on hulled barley cultivation, its apparently narrow array of other cultivated cereals, legumes and fruits, and an accompanying proliferation of wild and weedy taxa in the fields around this village.

The emphasis on annual crop cultivation at Tell Abu en-Ni'aj suggests the greater importance of local subsistence agriculture rather than arboriculture for marketable products. Rendered fruit products (e.g., olive oil, wine, dried figs) provided commodities better suited for storage or exchange than bulkier annual grains or legumes. Olive orchards, in particular, take several years to become productive, entail relatively long-term investment in larger landholdings, and traditionally make use of rockier topography less suited to annual croplands (Hopkins, 1985; Stager, 1985; Neef, 1997). Archaeological evidence from Bronze Age communities along the Jordan Rift suggests that olive horticulture coupled with wheat cultivation denotes a market-adapted agrarian strategy, especially in times of greater water availability (Fall et al., 2002; Dighten et al., 2017). Thus, the minimal occurrence of fruits and modest amounts of wheat (including the near absence of *Triticum aestivum*) suggest a lack of favorable environmental or economic conditions for the farmers of Tell Abu en-Ni'aj. Conversely, the emphasis on barley cultivation carries several different implications. In contrast to wheat, barley requires less water, tolerates saline soils better, and has a shorter growing season with correspondingly less susceptibility to insects (Zohary, 1982; Hopf, 1983; Zohary and Hopf, 1988; McCreery, 2003a, 2003b). Among barley varieties, *H. vulgare* can produce greater yields,

whereas *H. vulgare* var. *nudum* is richer in protein and does not require processing to remove a protective hull that is indigestible for humans (Dickin et al., 2011; Styring et al., 2019). Thus, in traditional agricultural systems, greater barley cultivation suggests a response to more arid conditions.

A consideration of $\Delta^{13}\text{C}$ concentrations for barley and wheat samples from Tell Abu en-Ni'aj expands these environmental and economic inferences. Most wheat values denote well-watered conditions possibly indicative of localized irrigation (Wallace et al., 2015; Styring et al., 2017), perhaps from springs or seasonal wadis draining into the Jordan Valley from the hills to the east. The barley values, however, fall entirely in the moderately-to poorly-watered ranges; no sample denotes well-watered conditions. These patterns may suggest rainfed farming of barley with ancillary preferential watering of some wheat fields, though they do not rule out the potential impact of manuring on stable isotope signals (Maxwell et al., 2014).

This result aligns with the general practice of growing wheat under wetter conditions at many Bronze Age settlements in Syria and the Northern Levant (Riehl et al., 2014; Wallace et al., 2015). More specifically, wheat was cultivated at Tell Abu en-Ni'aj with water availability similar to Tell Brak (Wallace et al., 2015), a rain-fed settlement in the foothills of upper Mesopotamia. Comparison of $\Delta^{13}\text{C}$ values suggests barley cultivation at Tell Abu en-Ni'aj in dry farming conditions similar to those found in Bronze Age Syria at Tell Brak, Tell Nebi Mend, Tell Mozan and Qatna (Riehl et al., 2008; Riehl, 2010; Wallace et al., 2015; Styring, 2017). Cereals were grown under more extreme dry farming conditions at Khirbet ez-Zeraqon (Riehl et al., 2008), located inland on the Transjordanian Plateau with correspondingly fewer water sources and less rainfall, and possibly Tell Nebi Mend in northeastern Syria, despite its proximity to a larger river (Wallace et al., 2015). The watering profile at Tell Abu en-Ni'aj also contrasts sharply with higher cereal $\Delta^{13}\text{C}$ values, for example at Abu Salabikh, Iraq from floodplain irrigation along the Euphrates (Wallace et al., 2015) and Tell Leilan, Syria (Styring et al., 2017). Thus, the watering practices for barley and wheat cultivation at Tell Abu en-Ni'aj generally accord with those of other Bronze Age settlements not located on perennial rivers, where rainfed barley cultivation appears to have been combined with some preferential watering of wheat.

Several facets of crop management at Tell Abu en-Ni'aj shift about 2375 cal BC, between phases 7 through 4 and phases 3 through 1, and again *Hordeum vulgare* drives many of these changes. *Hordeum vulgare* increases in relative frequency between the earlier and later phases, coupled with decreased ubiquities for all other cereals and most of the wild taxa in phases 3 through 1. Likewise, the ratios of chaff fragments to cultivated cereal seeds drop markedly over this transition. The nearly four-fold rise in barley:wheat ratios between the early and late phases accords with increasingly arid-adapted crop cultivation, though we do not see similar declines in all drought intolerant cultigens (e.g., grape or garden pea) (Riehl, 2009). The broad decline in cultivated and wild taxa ubiquities, as well as the precipitous and continuous decline in seed densities, indicate generally less abundant crop remains. This could be indicative of agricultural changes such as less production in fields adjacent to the village or the burning of less seed-rich animal dung, associated with animal management changes.

The decline in chaff:cereal ratios similarly reflects less abundant crop processing remains, either in fields close to the village or ingested by grazing animals. Both inferences suggest a decline in seed cleaning activities, which may be associated with the type of grain harvested (e.g., hulled barley vs. glume wheat), crop processing farther away from the village, or burning of less chaff-rich dung. These patterns fuel multiple inter-related inferences of agricultural behavior at Tell Abu en-Ni'aj: decreased plant cover in the vicinity of the village with increasingly distant crop processing as an agrarian response to potentially rising aridity and changing patterns of animal husbandry during this community's lifetime. These shifts about 2375 cal BC may have been a prelude to the abandonment of Tell Abu en-Ni'aj two centuries later in

keeping with the near absence of sedentary villages in the Southern Levant about 2200–1900 cal BC (Fall et al., 2020).

Analyses of animal bones and pottery from Tell Abu en-Ni'aj reveal temporal trends that dovetail with these inferences. Similar to the plant remains, temporal trends in the ceramic assemblages from Tell Abu en-Ni'aj segregate most distinctly between phases 7 to 4 and phases 3 to 1, based on vessel morphology, style, and parallels with other sites (Falconer and Fall 2019). Preliminary analysis of the faunal remains from phases 5 to 1 show that while the majority of bones represent *Ovis aries* (sheep) and *Capra hircus* (goat), the percentages of sheep/goat bones decrease, while *Sus scrofa* (pig) bone frequencies increase (Falconer et al., 2004; Falconer and Fall 2019: 29–33). Unlike sheep and goats, the mainstays of Middle Eastern mobile pastoralism, pigs have high water needs and are poorly suited for herding (Wapnish and Hesse 1988; Horwitz 1989; Horwitz and Tchernov 1989; Hesse 1990, 1995). Swine, however, reproduce prolifically, can scavenge domestic food scraps, and are therefore well-suited to localized household management (Grigson 1982; Zeder 1991: 30; Hesse 1995). Differences in diet and grazing patterns may also contribute to shifts in macrobotanical evidence, including decreases in wheats, weeds, and chaff. Functional and morphological analysis of the Tell Abu en-Ni'aj pottery assemblages also suggest a social expression of these stresses, based on evidence for increasingly concentrated meal preparation to serve households growing in size amid apparently reduced village agrarian production (Falconer and Fall 2019: 103–106).

This suite of results contributes to a portrait of the Early Bronze IV agrarian landscape around Tell Abu en-Ni'aj in keeping with larger scale reconstructions of vegetation and environmental change through the Bronze Age. On a regional scale, modeling of potential vegetation in the Southern Levant between about 3500 and 1000 BCE reveals decreased Mediterranean vegetation, consistent with declining precipitation through the Early Bronze Age, culminating in a rainfall nadir at the time of Tell Abu en-Ni'aj's abandonment (Soto-Berelov et al., 2015). Meanwhile, comparative studies of Bronze Age settlements in Jordan, Syria and Cyprus include high seed:charcoal ratios at Tell Abu en-Ni'aj that indicate a reliance on dung burning, coupled with charcoal indicative of limited burning of shrubs, orchard prunings and riparian trees (probably from along the Jordan River) (Klinge and Fall 2010; Fall et al., 2015). In other words, Tell Abu en-Ni'aj occupied a vegetation- and fuel-depleted landscape at a juncture of potential environmental stress. The shift in cultivation about 2375 cal BC incorporates archaeological signals of declining sheep/goat consumption and decreased local crop processing. The farmer/pastoralists of this village thus shifted to a more drought-adapted crop regime involving a relatively narrow array of cultigens that greatly emphasized hulled barley cultivation, consistent with dry farming and more limited ruminant grazing.

5. Conclusions

Coordinated quantitative analyses of carbonized plant remains from Tell Abu en-Ni'aj, Jordan, featuring a combination of cluster, CDA and stable isotope analyses of seeds and chaff from both crops and wild taxa, constitute an innovative approach for inferring ancient agricultural landscapes and possible human responses to environmental stress. Tell Abu en-Ni'aj provides a detailed case study of sedentary agrarian behavior from about 2500 to 2200 cal BC during Early Bronze IV, a period characterized traditionally in terms of mobile pastoralism. Plant macrofossil evidence from seven stratified habitation phases highlights an emphasis on hulled barley farming accompanied by more limited cultivation of a relatively modest array of other cereals, pulses and fruits. The primacy of barley may reflect its use as a foodstuff for both ancient humans and animals. Stable isotope analysis suggests watering practices generally similar to those implemented at other Bronze Age communities in Syria, the Southern Levant and Northern Levant, involving apparent dry farming of barley and preferential watering of wheat. Temporal trends, especially over an apparent transition at about

2375 cal BC, suggest increasingly distant crop processing on a depleted, potentially drought-stressed natural and social landscape, leading ultimately to the abandonment of Tell Abu en-Ni'aj before the end of Early Bronze IV. This study employs an innovative combination of analytical methods suitable for the inference of agrarian behaviors, including responses to environmental stress, in other ancient agro-pastoral settlements with comparable archaeobotanical evidence.

Author contribution

Steven Porson: Formal analysis, Investigation, Methodology, Writing – original draft. **Steven Falconer:** Conceptualization, Funding acquisition, Investigation, Writing – review & editing. **Suzanne Pilaar Birch:** Investigation, Writing – review & editing. **Elizabeth Ridder:** Data curation, Investigation, Writing – review and editing. **Patricia Fall:** Conceptualization, Funding acquisition, Investigation, Supervision, Project administration, Writing – review & editing.

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Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jas.2021.105435>.

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