



# From Early Bronze Age domestic plant production to Middle Bronze Age regional exchange economy: the archaeobotanical assemblages from Tel Kabri

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## Abstract

Recent excavations at the site of Tel Kabri have brought some extraordinary findings, including the earliest wine cellar in the ancient Near East discovered in 2013. During these excavations, archaeobotanical samples were collected continuously and then processed in 2019. The archaeobotanical studies focus on the Middle Bronze Age palace in Area DW and the Early Bronze Age domestic deposits in Area L. The results confirm the different nature of the two contexts. Legumes form a large portion of the crop remains in the Early Bronze Age Area L: *Lathyrus sativus* (grass pea), *Vicia faba* var. minor (faba bean), and *Lens culinaris* (lentil), all showing no drought stress and similar growing conditions in terms of moisture availability, as indicated by stable carbon isotope measurements. For Area L, several wild seeds have been identified to represent weeds of cereal crops, whereas Area DW is strongly affected by small wild seeds that entered the sediments as modern contaminants. Fruit crops are present in both assemblages with *Olea europaea* (olive), representing the most ubiquitous taxon, and *Vitis vinifera* (grape), with most of its pips found mineralized. The identified remains also include cereal crops, primarily *Triticum dicoccum* (emmer), which appears cultivated under exceptionally dry conditions. The stable nitrogen values for emmer also raised some questions regarding the growing location and cultivation strategy. Correspondence analysis has been applied, comparing the archaeobotanical assemblages of Tel Kabri within the wider geographical and chronological Levantine context and determining their placement in sub-regional patterns.

**Keywords** Levant · Olive production · Correspondence analysis · Stable isotopes · Bronze Age

## Introduction

Tel Kabri is an archaeological tell in the Western Galilee region of northwest Israel, located approximately 5 km from the Mediterranean Sea (Fig. 1). It is a multi-period site that reached the height of its power during the Middle Bronze Age, when one of the largest palaces in the Levant was built on the mound (Lazar et al. 2020). Since its discovery in the 1950s (Stekelis 1958), when Late Neolithic stone implements were found, the site has been the subject of different archaeological studies starting with a salvage excavation in 1957 and 1958 (Prausnitz 1959, 1969) in Area A. Salvage excavations continued after 1961 when a 500-m trench was cut to include two of the springs present around the tell into the national water system (Prausnitz and Kempinski 1977), which led to the discovery of Bronze Age settlement structures on the tell.

In 1969, another excavation carried out by the Department of Antiquities and Museums took place when Middle

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**Fig. 1** The position of Tel Kabri in the Southern Levant



Bronze Age vessels were discovered in the surroundings of Area B (Prausnitz and Kempinski 1977). One more short rescue excavation was conducted in Area B by the Israel Department of Antiquities and Tel Aviv University in 1975, to investigate and date the rampart present in the Area (Prausnitz and Kempinski 1977).

Starting in 1986, a large excavation by the Tel Aviv University and directed by Aharon Kempinski (Kempinski 2002) investigated four main areas around the site: Area B, Area C, Area D (where the first remains of the Middle Bronze Age palace were found), and Area E (in which the Iron Age settlement was discovered). This excavation, which ended in 1993, aimed to expose architecture in the different areas and included different types of analyses on the various finds, including the first study of botanical remains (Liphshitz 2002). After this major campaign, two minor salvage excavations took place prior to the current excavations: the

first one in 1999 focused on Area D (Shalem 2009) and the second in 2004 involved work in Area E (Smithline 2007).

The second major set of excavations started in 2005, with the current Tel Kabri Archaeological Project, and is still ongoing. The project, co-directed by Professor Assaf Yasur-Landau of the University of Haifa and Professor Eric H. Cline of the George Washington University, is providing more information regarding the development and extension of the palace in Area D (Figs. 2 and 3), where the oldest and largest wine cellar in the ancient Near East to date was found, as well as additional evidence for settlements outside the palace area (Yasur-Landau et al. 2018). Originally, trenches were opened in Area L to find residential Middle Bronze Age architecture west of the palace; instead, Early Bronze Age deposits were found.

Archaeobotanical research during the 2019 excavation season of the Tel Kabri Archaeological Project



**Fig. 2** Tel Kabri plan of Area DW (Yasur-Landau and Cline 2020)

systematically sampled and investigated plant resources for the first time, including studying contexts. Furthermore, stable isotope measurements on archaeobotanical seeds were analyzed, which add to our understanding of agricultural management and environmental parameters. Through correspondence analysis, the botanical assemblages from Tel Kabri have been defined and compared within the coeval regional framework in order to find any association with other sites and so as to help define chrono-geographical patterns regarding the regional agricultural resources.

### Environmental background

The modern Galilee region is characterized by a Mediterranean climate with an average annual precipitation of more than 500 mm and Mediterranean macchia vegetation (Danin and Plitmann 1987; Danin 1992; Zohary 1962). The climate of the Galilee, and in the southern Levant broader region in general, has not always been the same. In addition, the vegetation has also been heavily affected by human activities.

Paleoclimatic indicators show that the first phases of the Early Bronze Age (hereafter EBA) were the most humid during the Bronze and Iron Ages (IA); pollen records indicate

that olive trees, and in general all the Mediterranean vegetation, reached their peak at this time (Schiebel and Litt 2017; Langgut et al. 2015). At the end of the EBA, drier episodes are recorded in the pollen diagrams and have been associated with a declining level of the Dead Sea (Kagan et al. 2015; Migowski et al. 2006) and decreasing precipitation (Bar-Matthews and Ayalon 2011).

During the Intermediate Bronze Age period, no major changes in vegetation were recorded for the Galilee region; it is characterized by pollen from well-represented olive trees (Langgut et al. 2013). Throughout the Middle Bronze Age (MBA), when the palaces in Tel Kabri were built and its political influence in the region increased, the climate underwent variations, ranging from drier conditions in the earliest phases to more humid conditions afterwards (Langgut et al. 2015).

For the Late Bronze Age (LBA), rich arboreal vegetation is registered regarding Mediterranean macchia (Langgut et al. 2015) but with drier events occurring especially toward the end of the period (Schilman et al. 2002; Litt et al. 2012; Bar-Matthews and Ayalon 2004). Thanks to the availability of natural resources around the tell, which includes streams and perennial springs (Tsuk 2002), the



**Fig. 3** Aerial view of the northwestern part of the palace area at the end of the 2019 season (photo by Griffin Aerial Imaging). Blue: orthostat; red and yellow: L.3264 and L.3269 as part of the Northern Storage Complex. Below these two loci, the Southern Storage Complex (wine cellar)

oscillation in the regional climate conditions likely had little effect on the people living around Tel Kabri, which was almost continuously inhabited since the Neolithic period (Horowitz 2002).

Stability in vegetation patterns is also suggested by past anthracological studies in Tel Kabri, which record mostly the same arboreal species, *Quercus calliprinos*, *Olea europaea*, and *Pistacia palaestina*, throughout all the periods analyzed (Late Neolithic, EBA, MBA, IA) and they can still be found in the present-day environment (Liphschitz 2002).

**Fig. 4** Built on site flotation machine with water recycling system used at Tel Kabri



## Material and methods

Tel Kabri samples were collected during three different excavation seasons: 2015, 2017, and 2019. Sediment volumes range between 100 and 5 L, depending on the archaeological context. The majority of the 2015 samples measured 10 L, whereas the 2017 and 2019 samples had an average volume of 30 L.

There was a total volume of about 3961 L of sediment collected during these seasons that belong to two different areas:

- Area DW: 185 samples (MBA), in all 3840 L
- Area L: 6 samples (EBA), in all 121 L

All the samples collected during the three seasons were processed with a flotation machine using a water recycling system, built on-site in 2019 (Fig. 4). The heavy residues, gathered using a 1-mm mesh, were dried and sorted on-site, separating small archaeological finds, like fauna (Marom et al. 2015) and plant remains. A 0.2-mm sieve was used to collect the light fractions which were dried in small cloths.

The plant remains retrieved from the heavy residues and the light fractions were subsequently shipped to the archaeobotanical laboratory at the University of Tübingen. Using a Euromex binocular with up to 30× magnification, the plant remains collected were identified. For identification purposes, the Senckenberg seed reference collection (SeSam), with more than 15,000 specimens of primarily Mediterranean and Near Eastern floras, located in the archaeobotanical lab of Tübingen University was used. Seed catalogues and floras, together with already published archaeobotanical research, were also used (e.g., Jacomet 2006; Nesbitt 2008; Kislev et al. 2006, 2009; Neef et al. 2012; Post 1980; Danin and Fragman 2016). In all, a total of 29 taxa have been identified in Tel Kabri.

The majority of the botanical finds from Tel Kabri are carbonized, except for some seeds that are mineralized. It was difficult to determine if the latter are contemporary with the context analyzed (Area DW storage complexes) or if they are modern contaminants.

Some of the small-seeded wild taxa in the assemblage lack distinguishing features, which made it impossible to identify them to the species level. In addition, many cereal grains were highly fragmented, while others were heavily corroded, maybe through high charring temperatures. In general, however, most of the other crop remains were found in a good state of preservation.

To quantify the olive pit fragments recovered, they were weighed and converted into complete pits, using a whole preserved individual weight as the conversion factor. It should be noted that all seeds may present quantifying problem counts, such as grape (usually having 2 pips in a single fruit) listed in Table 1 as each individual specimen and therefore ubiquity is used. The ubiquity values in Tables 1 and 2 indicate the percentage of samples in which each taxon is present.

Two halves and four quarters of cereal grains were considered one seed; if only one fragment was found in a sample, it was counted as one seed. In the same way, each two glume bases were counted as a single spikelet fork.

To define the assemblages from Tel Kabri within the regional framework, a correspondence analysis (CA) approach was chosen to examine the large data sets of botanical remains collected from archaeological sites in the Levant (Table 3). CA is an ordination technique which permits the analysis of large data and arranges sites along axes based, in this case, on plant species. It has been used successfully in previous research to examine large data and define patterns (e.g., Riehl 1999a, b; Jones et al. 2000; Smith and Munro 2009; Vermeersch et al. 2021). Data selection and cleaning was conducted following Jones (1991) prior to analysis. Due to the lack of representativeness of small samples, sites with less than four crop taxa and only presence/absence data were excluded from the analysis. Furthermore, taxa that occur from less than four sites have not been included to avoid any “noise” in the graph that could conceal real patterns.

CANOCO 5 software was used to carry out the CA and design the graphs (Leps and Smilauer 2014). Although this method can experience some problems when the so-called arch effect appears (a distortion that may lead to wrong interpretation of the first and second axes (Jongman et al. 1995)), the results that we obtained for the data set could be safely interpreted, as the arch effect distortion is not present in the graph. The data were acquired from published reports

**Table 1** Cultivated plants identified from Tel Kabri

| Area                                     | Area DW       |          | Area L          |          |
|------------------------------------------|---------------|----------|-----------------|----------|
| Period                                   | Middle Bronze |          | Early Bronze II |          |
| Numbers of samples                       | 185           |          | 6               |          |
| Volume of sediment (L)                   | ~ 3840        |          | ~ 121           |          |
| Total no. of specimens                   | 255           |          | 240             |          |
|                                          | Items         | Ubiquity | Items           | Ubiquity |
| <b>Cereals</b>                           |               |          |                 |          |
| Cerealia (frag.)                         | 24            | 10%      | 22              | 50%      |
| <i>Hordeum vulgare</i>                   | 2             | 1%       | 3               | 33%      |
| <i>Triticum aestivum/durum</i>           | 1             | 1%       | —               | —        |
| <i>Triticum dicoccum</i>                 | 6             | 3%       | 21              | 67%      |
| <i>Triticum dicoccum</i> glume base      | —             | —        | 3               | 33%      |
| <i>Triticum monococcum/dicoccum</i>      | 1             | 1%       | —               | —        |
| <i>Triticum</i> sp. (frag.)              | 8             | 2%       | 26              | 67%      |
| <b>Legumes</b>                           |               |          |                 |          |
| Fabaceae (frag.)                         | 6             | 3%       | 57              | 67%      |
| <i>Lathyrus sativus</i>                  | 5             | 3%       | 22              | 50%      |
| <i>Lens culinaris</i>                    | 10            | 5%       | 11              | 50%      |
| <i>Vicia ervilia</i>                     | 9             | 4%       | —               | —        |
| <i>Vicia faba</i> var. <i>minor</i>      | —             | —        | 16              | 33%      |
| <b>Fruits</b>                            |               |          |                 |          |
| <i>Olea europaea</i>                     | 103           | 45%      | 48              | 83%      |
| <i>Punica granatum</i>                   | 1             | 1%       | —               | —        |
| <i>Vitis vinifera</i>                    | 79            | 16%      | 7               | 50%      |
| <i>Ziziphus</i> cf. <i>spina-christi</i> | —             | —        | 4               | 17%      |

**Table 2** Wild plants identified from Tel Kabri

| Area                                   | Area DW       |          | Area L          |          |
|----------------------------------------|---------------|----------|-----------------|----------|
| Period                                 | Middle Bronze |          | Early Bronze II |          |
| Numbers of samples                     | 185           |          | 6               |          |
| Volume of sediment (L)                 | ~ 3840        |          | ~ 121           |          |
| Total no. of specimens                 | 265           |          | 29              |          |
|                                        | Items         | Ubiquity | Items           | Ubiquity |
| <i>Avena</i> sp.                       | –             | –        | 1               | 17%      |
| <i>Chenopodium</i> sp.                 | 73            | 16%      | –               | –        |
| <i>Euphorbia</i> sp.                   | 1             | 1%       | –               | –        |
| <i>Galium</i> cf. <i>aparine</i>       | 1             | 1%       | 3               | 33%      |
| <i>Lolium</i> cf. <i>rigidum</i>       | –             | –        | 17              | 67%      |
| <i>Lolium</i> sp.                      | 9             | 5%       | –               | –        |
| <i>Phalaris</i> sp.                    | 2             | 1%       | 5               | 17%      |
| <i>Pistacia</i> sp.                    | 1             | 1%       | 1               | 17%      |
| Polygonaceae                           | 71            | 9%       | –               | –        |
| <i>Reseda</i> sp.                      | 104           | 17%      | 2               | 17%      |
| <i>Scorpiurus</i> cf. <i>muricatus</i> | 1             | 1%       | –               | –        |
| <i>Trifolium</i> sp.                   | 1             | 1%       | –               | –        |
| Undetermined                           | 46            | –        | 4               | –        |

and articles extracted from the ADEMNES database (<https://www.ademnes.de/>). Even though the contexts from these sites might be various (e.g., not being exclusively palatial contexts for MBA sites), we think this type of analysis might be beneficial in comparing and understanding the development of plant resources in the Levant. The methodology for collecting botanical samples may also differ (machine or manual flotation) but no sites with stated exclusive hand-picking collecting methods are present in the analysis, avoiding biased results. To simplify the process of using large data, chronological phases (e.g., EBA II, EBA IV, LBA II, etc.) were organized into broad EBA, MBA, and LBA groups.

Stable carbon and nitrogen analyses on 37 well-preserved crop seeds from Early and Middle Bronze Age levels at Tel Kabri were conducted at the Institute of Geosciences of the University of Tübingen, Germany, on a FinniganMAT252 gas source mass spectrometer with a ThermoFinnigan Gas-Bench II/CTC Combi-Pal autosampler (Tables 4).

Possible alteration of  $\delta^{15}\text{N}$  in plant remains through charring has been investigated experimentally by a number of authors (Bogaard et al. 2007; Aguilera et al. 2008; Fraser et al. 2013). They all found no or only insignificant change in  $\delta^{15}\text{N}$  values after charring at different temperatures, thus preserving the original environmental signal during the lifetime of the plants. Archaeological sediments, however, carry carbonate precipitates and humic/fulvic acids that may accumulate in archaeobiological material and distort stable carbon and nitrogen isotope measurements. Therefore, pretreatment of the material is required. The standard pretreatment method for removing carbonate crusts and humic/

fulvic acids is described by DeNiro and Hastorf (1985) and, since that, systematically refined (Fraser et al. 2013; Styring et al. 2013; Vaiglova et al. 2014). For this reason, prior to mass-spectrometric measurements, the carbonized seeds were reacted with 5% HCl to eliminate sedimentary carbonate. Changes in atmospheric  $\text{CO}_2$  concentration ( $\delta^{13}\text{C}_{\text{air}}$ ) over time were transferred into  $\Delta^{13}\text{C}$  values by using the approximation AIRCO2\_LOESS (Ferrio et al. 2012). In-depth discussion of methodological aspects of stable isotope measurements on archaeobotanical remains can be found in Fiorentino et al. (2014), Ferrio et al. (2020), and Riehl (2020).

Some of the seeds, e.g., *Lathyrus sativus*, *Lolium* sp., and *Lens culinaris*, contained insufficient amounts of measurable nitrogen. Despite an uneven representation of measurable seeds from the different chronological units, comparison with existing stable isotope measurements from other Levant sites was conducted (e.g., with the data published in Riehl et al. 2014) to increase the possibility of interpreting the values so far achieved from Tel Kabri.

## Results

Sixteen of the 29 taxa identified at Tel Kabri belong to cultivated plants, totaling 495 remains (Table 1). The rest are wild plant taxa, accounting for 294 seeds (Table 2).

Plant remains pictured in Fig. 5 were taken using a Zeiss digital microscope Stereo Discovery V8, keeping a 1-mm scale bar for each picture.

**Table 3** Levantine sites analyzed by CA. Number of plant remains based on the CA plant taxa

| Site                   | Reference                                                        | Modern reg./site elev. (m)  | Chron./no. of remains          |
|------------------------|------------------------------------------------------------------|-----------------------------|--------------------------------|
| Aphek                  | Kislev and Mahler-Slasky (2009)                                  | S. Levant, Israel/58        | LBA/23926                      |
| Arad                   | Hopf (1978)                                                      | S. Levant, Israel/500       | EBA/168                        |
| Bab'edh Dhra           | McCreery (1979, 2003, 2011)                                      | S. Levant, Jordan/ – 351    | EBA/867                        |
| Beth-Shean             | Kislev et al. (2009), Simchoni et al. (2007), Liph-schitz (1989) | S. Levant, Israel/ – 114    | EBA/7248-MBA/260<br>LBA/175510 |
| Ebla                   | Wachter-Sarkady (2013)                                           | N. Levant, Syria/389        | EBA/628                        |
| Emar                   | Riehl (1999, 2001)                                               | N. Levant, Syria/343        | EBA/850-MBA/176<br>LBA/170     |
| Hirbet ez-Zeraqon      | Riehl (2004)                                                     | S. Levant, Jordan/489       | EBA/3397                       |
| Jericho                | Hopf (1983), Bar-Yosef (1986)                                    | S. Levant, Palestine/ – 277 | EBA/110029–MBA/77987           |
| Lachish                | Helbaek (1958), Nicoli' et al. (2022)                            | S. Levant, Israel/252       | MBA/103-LBA/7714               |
| Manahat                | Kislev (1998)                                                    | S. Levant, Israel/762       | MBA/272                        |
| Megiddo                | Borojevic (2006)                                                 | S. Levant, Israel/80        | EBA/48-MBA/126                 |
| Pella                  | Wilcox (1992)                                                    | S. Levant, Jordan/-80       | EBA/370                        |
| Qatna                  | Riehl (2007)                                                     | N. Levant, Syria/492        | EBA/8215– MBA/4192-LBA/305     |
| Qubur el-Walaydah      | Riehl (2010), Orendi (unpublished data)                          | S. Levant, Israel/66        | LBA/76                         |
| Ras en-Numayra         | White et al. (2014)                                              | S. Levant, Jordan/ – 385    | EBA/600                        |
| Shiloh                 | Kislev (1993), Liphschitz (1993)                                 | S. Levant, Israel/690       | MBA/298                        |
| Sidon                  | De Moulins (2015)                                                | S. Levant, S. Lebanon/85    | MBA/791-LBA/133                |
| Tel Burna              | Orendi et al. (2017), and unpublished data                       | S. Levant, Israel/203       | LBA/45                         |
| Tel Yarmouth           | Salavert (2008)                                                  | S. Levant, Israel/291       | EBA/1382                       |
| Tell Abu el-Kharaz     | Holden (1994)                                                    | S. Levant, Jordan/275       | EBA/10635– LBA/23287           |
| Tell Abu en-Ni'aj      | Falconer and Fall (2019)                                         | S. Levant, Jordan/ – 257    | EBA/3151                       |
| Tell Afis              | Wachter-Sarkady (1998)                                           | N. Levant, Syria/330        | EBA/158-LBA 199                |
| Tell al-Rawda          | Herveux (2004)                                                   | N. Levant, Syria/710        | EBA/2958                       |
| Tell Atij              | McCorriston (1995)                                               | N. Levant, Syria/296        | EBA/414                        |
| Tell Bderi             | van Zeist (1999/2000)                                            | N. Levant, Syria/291        | EBA/5719-LBA/77                |
| Tell Brak              | Charles and Bogaard (2001), Colledge (2003)                      | N. Levant, Syria/346        | EBA/26193– MBA/11443           |
| Tell Deir'Alla         | van Zeist and Heeres (1973)                                      | S. Levant, Jordan/ – 256    | LBA/193561                     |
| Tell el-Burak          | Orendi (2020), Orendi and Deckers (2018)                         | S. Levant, S. Lebanon/ ~ 15 | MBA/223-LBA/57                 |
| Tell el-Hayyat         | Metzger (1984)                                                   | S. Levant, Jordan/ – 249    | EBA/43-MBA 3214                |
| Tell el-Raqa'I         | van Zeist (1999/2000)                                            | N. Levant, Syria/296        | EBA/1169                       |
| Tell el-Umeri          | Ramsay and Mueller (2016)                                        | S. Levant, Jordan/861       | LBA/743                        |
| Tell esh-Shuneh        | Holden (1999)                                                    | S. Levant, Jordan/212       | EBA/500                        |
| Tell es-Safi/Gath      | Mahler-Slasky and Kislev (2012)                                  | S. Levant, Israel/169       | LBA/196                        |
| Tell es-Sweyhat        | van Zeist and Bakker-Heeres (1985), Miller (1997)                | N. Levant, Syria/338        | EBA/9125                       |
| Tell Fadous-Kfarabida  | Riehl and Deckers (2009), Genz et al. (2009)                     | N. Levant, N. Lebanon/~ 5   | EBA/1085-MBA 79                |
| Tell Hammam et-Turkman | van Zeist et al. (1988)                                          | N. Levant, Syria/320        | EBA/96                         |
| Tell Kerma             | McCorriston (1995)                                               | N. Levant, Syria/315        | EBA/1060                       |
| Tell Mozan             | Riehl (2000)                                                     | N. Levant, Syria/452        | EBA/2536-MBA 669               |
| Tell Munbāqa           | Küster (1989)                                                    | N. Levant, Syria/311        | LBA/8848                       |
| Tell Nebi Mend         | Moffett (1989)                                                   | N. Levant, Syria/503        | EBA/2601-MBA 594<br>LBA/184    |
| Tell Qara Quzaq        | Matilla Séiquer and Rivera Núñez (1994)                          | N. Levant, Syria/332        | EBA/348-MBA 1019               |
| Tell Qarqur            | Smith (2005)                                                     | N. Levant, Syria/169        | EBA/250                        |
| Tell Selenkahiye       | van Zeist and Bakker-Heeres (1985)                               | N. Levant, Syria/371        | EBA/20023                      |
| Tell Shiukh Fawqani    | Pessin (2004)                                                    | N. Levant, Syria/328        | EBA/1226                       |
| Tell Tweini            | Linseele et al. (2019)                                           | N. Levant, Syria/~ 21       | EBA/92–MBA/1369<br>LBA/1667    |
| Timnah (Tel Batash)    | Kislev et al. (2006)                                             | S. Levant, Israel/158       | LBA/192002                     |

**Table 3** (continued)

| Site             | Reference            | Modern reg./site elev. (m) | Chron./no. of remains |
|------------------|----------------------|----------------------------|-----------------------|
| Umm el-Marra     | Miller et al. (2000) | N. Levant, Syria/339       | EBA/54-MBA/71-LBA/41  |
| Zahrat adh-Dhra' | Fall et al. (2019)   | S. Levant, Jordan/ – 169   | MBA/1947              |

The number of remains for Area DW is low compared to the number of samples and liters of sediment floated. Area L samples, despite the limited number, turned out to be denser in seed remains, with more than two plant remains per liter sediment.

### Cereal crops

Twenty-four percent of the cultivated plant assemblage in Tel Kabri is composed of cereal remains (117). *Triticum dicoccum* (emmer) is the best represented taxon, especially

**Table 4** Raw data of stable isotope measurements on crop seeds from different archaeological strata at Tel Kabri

| Taxon                 | Locus/description                                 | Period/Phase | $\Delta^{13}\text{C}$ | $\delta^{15}\text{N}$ |
|-----------------------|---------------------------------------------------|--------------|-----------------------|-----------------------|
| Hordeum vulgare       | L8010/organic sediment around stone installations | EB II        | 17.8058166            | 2.9198678             |
| Hordeum vulgare       | "                                                 | EB II        | 15.9951142            | 0.4087795             |
| Lathyrus sativus      | "                                                 | EB II        | 18.1062113            | –                     |
| Lathyrus sativus      | "                                                 | EB II        | 18.4542053            | –                     |
| Lathyrus sativus      | "                                                 | EB II        | 17.4904921            | –                     |
| Lathyrus sativus      | "                                                 | EB II        | 17.6828873            | –0.6349926            |
| Lathyrus sativus      | "                                                 | EB II        | 17.8350418            | 0.3669825             |
| Lathyrus sativus      | "                                                 | EB II        | 16.8463471            | 0.1697967             |
| Lolium sp.            | "                                                 | EB II        | 18.8367686            | –0.9896014            |
| Lolium sp.            | "                                                 | EB II        | 17.2901159            | 1.113893              |
| Lolium sp.            | "                                                 | EB II        | 18.2030205            | –                     |
| Lolium sp.            | "                                                 | EB II        | 16.00616              | –                     |
| Lolium sp.            | "                                                 | EB II        | 16.078466             | –                     |
| Lolium sp.            | "                                                 | EB II        | 17.750394             | –                     |
| Triticum dicoccum     | "                                                 | EB II        | 14.8927439            | 6.7563221             |
| Triticum dicoccum     | "                                                 | EB II        | 15.2696277            | 6.3810122             |
| Triticum dicoccum     | "                                                 | EB II        | 14.5822257            | 7.2272394             |
| Triticum dicoccum     | "                                                 | EB II        | 15.2977047            | 4.8573964             |
| Triticum dicoccum     | "                                                 | EB II        | 14.0777885            | 4.1505119             |
| Triticum dicoccum     | "                                                 | EB II        | 15.1322733            | 3.820492              |
| Vicia faba var. minor | "                                                 | EB II        | 19.6482687            | 1.8281247             |
| Vicia faba var. minor | "                                                 | EB II        | 18.0316001            | 0.65554               |
| Vicia faba var. minor | "                                                 | EB II        | 16.802092             | 0.9608016             |
| Lens culinaris        | L8006/organic soil, part of a colluvial fill      | MB           | 16.5375121            | –3.0825902            |
| Lens culinaris        | "                                                 | MB           | 18.7368351            | –0.676                |
| Lens culinaris        | "                                                 | MB           | 18.7964083            | –                     |
| Olea europaea         | "                                                 | MB           | 15.954771             | 3.6524787             |
| Olea europaea         | "                                                 | MB           | 16.8774179            | 1.5624698             |
| Olea europaea         | "                                                 | MB           | 15.1270221            | 2.4851111             |
| Olea europaea         | "                                                 | MB           | 16.5797365            | 1.5916066             |
| Olea europaea         | "                                                 | MB           | 17.0766399            | –0.6204543            |
| Olea europaea         | "                                                 | MB           | 16.9055859            | 4.6431698             |
| Vitis vinifera        | "                                                 | MB           | 19.4471189            | –0.0658583            |
| Vitis vinifera        | L8010/organic sediment around stone installations | MB           | 20.4936338            | –0.2264285            |
| Olea europaea         | DW3253/raised pottery layer                       | MBI-MBII     | 17.2417112            | 5.0740387             |
| Olea europaea         | "                                                 | MBI-MBII     | 16.6360412            | 3.429388              |
| Olea europaea         | "                                                 | MBI-MBII     | 17.4148923            | 12.8416314            |

**Fig. 5** **a** Emmer wheat, *Triticum dicoccum* (Area L, L.8010); **b** emmer wheat, *Triticum dicoccum* (Area DW, L.2765); **c** emmer wheat glume base, *Triticum dicoccum* (Area L, L.8006); **d** emmer wheat, *Triticum dicoccum* (Area L, L.8010); **e** emmer wheat lateral view, *Triticum dicoccum* (Area L, L.8010); **f** emmer wheat dorsal view, *Triticum dicoccum* (Area L, L.8010); **g** faba bean lateral view, *Vicia faba* var. *minor* (Area L, L.8010); **h** faba bean frontal view, *Vicia faba* var. *minor* (Area L, L.8010); **i** lentil, *Lens culinaris* (Area DW, L.2875); **j** bitter vetch, *Vicia ervilia* (Area DW, L.3311) **k** olive, *Olea europaea* (Area DW, L. 2533); **l** grape, *Vitis vinifera* (Area DW, L.2533); **m** mineralized grape, *Vitis vinifera* (Area L, L.8006); **n** mineralized grape (Area DW, L.3269); **o** jujube dorsal view, *Ziziphus cf. spina-christi* (Area L, L.8006); **p** jujube frontal view, *Ziziphus cf. spina-christi* (Area L, L.8006); **q** mineralized pomegranate (Area DW, L.3269); **r** ryegrass, *Lolium* (Area L, L.8010); **s** canarygrass, *Phalaris* (Area DW, L.2765); **t** weld, *Reseda* (Area DW, L.3264). Scale bars = 1 mm



in the EBA samples of Area L, where *Triticum dicoccum* glume remains have also been found. In general, the MBA samples of Area DW have yielded very few cereal grain remains apart from tiny fragments, i.e., a single *Triticum aestivum/durum* (free-threshing wheat) seed and two *Hordeum vulgare* (barley grain).

## Legumes

Legumes represent 27% of the cultivated plants (136 remains). The presence of *Lathyrus sativus* (grass pea) and *Lens culinaris* (lentil) is attested in both areas, the former being the

predominant legume in the EBA samples while the latter being the most represented in the MBA assemblage. We also have *Vicia ervilia* (bitter vetch), which starts appearing in the MBA samples of Area DW, and *Vicia faba* var. *minor* (faba bean) seeds that have been found solely in EBA samples of Area L.

## Fruits

Nearly half (49%) of the whole cultivated plants assemblage is composed of fruit remains (242).

*Olea europaea* (olive) is the most frequent taxon in Tel Kabri and the best represented in both areas. After olive,

the presence of *Vitis vinifera* (grape) is remarkable in the MBA samples of Area DW, where most of the grape pips have been found in a mineralized state but is also present in minor quantities in Area L. Noteworthy is the finding of a single mineralized seed of *Punica granatum* (pomegranate) in Area DW and four *Ziziphus* cf. *spina-christi* (jujube) seeds in Area L.

## Wild plant taxa

In total, 12 wild plant taxa have been identified at Tel Kabri. For Area DW, most of the wild plant seeds belong to *Cheponodium* sp., Polygonaceae, and *Reseda* sp. For most of these seeds, morphological differentiation into modern or ancient is impossible without destruction, but some considerations regarding their contextual relationship within the site may surely help. The orthostat trench, for example, due to the proximity of the topsoil, yielded wild plant seeds which are exclusively modern and that inevitably contaminated the samples (outlined in blue in Fig. 3).

A few more wild taxa, contributing only singular seeds, have been identified, including *Pistacia* sp., *Scorpiurus* cf. *muricatus*, *Galium* cf. *aparine*, *Phalaris* sp., and *Lolium* sp. which are part of the wild botanical assemblage. Regarding Area L, *Lolium* cf. *rigidum* is the main wild taxon.

## Correspondence analysis of Bronze Age sites

Correspondence analysis of crops data extracted from the ademnes.de database was applied to examine agricultural patterns at Tel Kabri within the wider regional framework.

The biplot (Fig. 6) is based on a total of 12 plant taxa and 72 Bronze Age botanical assemblages (34 EBA, 19 MBA, 19 LBA) coming from 47 Levant sites (Table 3).

The biplot graph that we produced (Fig. 6) provides patterns of how the different sites and their assemblages are interrelated on the basis of the counts of the plant taxa (variables), being more similar to each other the closer they are to the origin of the axes. The horizontal axis (first axis) delineates the highest variance within the data. The cumulative variation expressed in the graph legend informs about how much variation is explained by the two axes.

The CANOCO plot has been graphically modified to provide a better view of the assemblages and therefore of patterns: labels' size changes and spacing but also using different symbols, to improve the readability of the chronological differentiation, and different colors to highlight the geographical division.

The distance between the sites in Fig. 6 approximates the dissimilarities in their botanical assemblage with regard to the crop taxa considered. If some sites have a high similar

frequency of a certain taxon, they generally cluster together in proximity of that taxon. For interpreting the patterns, it is important to also consider the raw data and the context of the sites as provided in the original articles (Table 3). To assist the interpretation of the CA plot, three distribution maps (Figs. 7, 8, and 9) have been created, showing the sites location and their assemblages expressed as percentage data in pie charts.

Cereal crops are separated from fruit trees along the first axis and at the same time separate sites which are dominated by either cereal or fruit tree remains (Fig. 6). A chrono-geographic trend seems also to be associated to this. Most of the sites on the left side of the first axis are located in the northern Levant (modern Syria and N-Lebanon), with assemblages dominated by cereal crops, especially barley. On the right side of the first axis, a majority of sites of the southern Levant (modern S-Lebanon and Israel) are accumulating, in this case instead commonly associated by intense olive and grape cultivation (Riehl 2009; Langgut et al. 2016). The EBA assemblages of the northern Levant appear to be mostly associated with the cereals (notably barley), while those of the southern Levant are in closer association with the fruit trees (mostly olive and grape). This pattern is also supported with the percentage proportions plotted to the geographical maps (Fig. 7). The MBA assemblages of the sites of the southern Levant are located mostly in the first quadrant in association with the fruit trees which is also visualized in Fig. 8, while those of the northern Levant find their place in the second, third, and fourth quadrants, i.e., being strongly associated to high grape and wheat abundance in the crop assemblages. The LBA assemblages appear to accumulate mostly in quadrants 1 and 4, probably associated with decreased emmer cultivation during this period. This can be further specified in Fig. 9 showing comparatively higher proportions of the other cereals than before.

The Jordanian sites appear more diverse in their association with the crop species, while a distinction between the EBA and MBA samples may be linked to comparatively higher amounts of emmer during the EBA (Fig. 6).

## Stable isotope measurements

The  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  measurements on 37 crop seeds are provided in Table 4.  $\Delta^{13}\text{C}$  values are converted and corrected for changes in atmospheric  $\text{CO}_2$  concentrations throughout time. Barley and emmer wheat show the lowest  $\Delta^{13}\text{C}$  values (Fig. 10), indicating a considerable drought signal, whereas all other crop taxa indicate sufficient water availability. Most of the  $\delta^{15}\text{N}$  values fall into a range of no to medium manuring on a scale adapted to mean annual precipitation provided in Styring et al. (2017), with emmer wheat as the most likely candidate for manuring (Fig. 10).

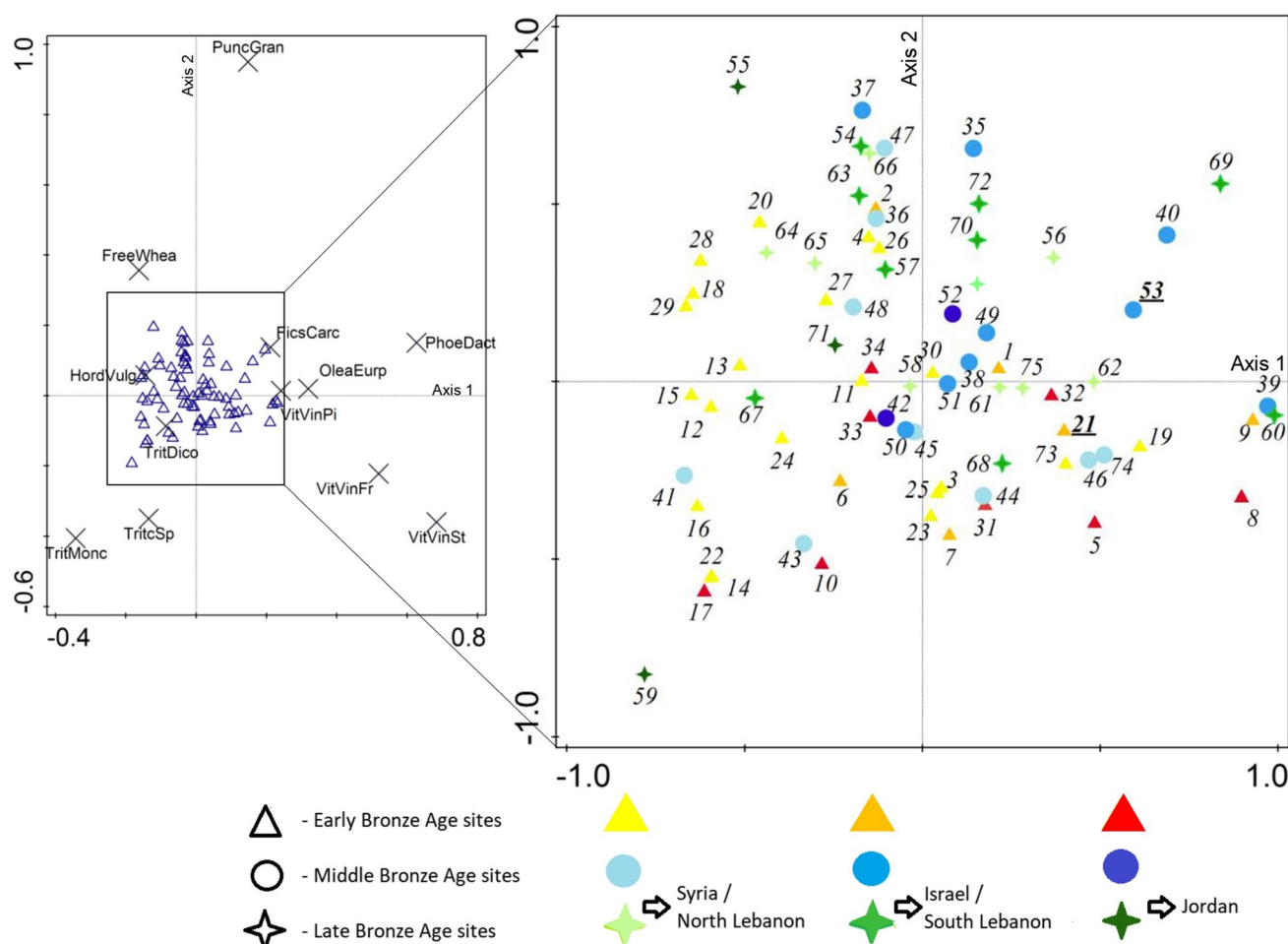


**Fig. 6** CA biplot of Levant Bronze Age sites patterns for cereal and fruit crops. Cumulative variance axis 1=23.70, axis 2=40.10; eigenvalues axis 1=0.2012, axis 2=0.1392. Legend: (1) Arad\_EBA; (2) Beit-Shean\_EBA; (3) Ebla\_EBA; (4) Emar\_EBA; (5) Hirbet ez-Zeraqon\_EBA; (6) Jericho\_EBA; (7) Megiddo\_EBA; (8) Ras en-Numayra\_EBA; (9) Tel Yarmouth\_EBA; (10) Tell Abu el-Kharaz\_EBA; (11) Tell Afis\_EBA; (12) Tell el-Raqai\_EBA; (13) Tell al-Rawda\_EBA; (14) Tell Atij\_EBA; (15) Tell Bderi\_EBA; (16) Tell Brak\_EBA; (17) Tell el-Hayyat\_EBA; (18) Tell es-Sweyhat\_EBA; (19) Tell Fadous-Kfarabida\_EBA; (20) Tell Hammam et-Turkman\_EBA; (21) **Tel Kabri\_EBA**; (22) Tell Kerma\_EBA; (23) Qatna\_EBA; (24) Tell Mozan\_EBA; (25) Tell Nebi Mend\_EBA; (26) Tell Qara Quzaq\_EBA; (27) Tell Qarqur\_EBA; (28) Tell Selenkahiye\_EBA; (29) Tell Shiukh Fawqani\_EBA; (30) Umm el-Marra\_EBA; (31) Tell esh-Shuneh\_EBA; (32) Bab'edh Dhra\_EBA; (33) Tell Abu en-Ni'aj\_EBA; (34) Pella\_EBA; (35) Beth Shean\_MBA; (36)

Emar\_MBA; (37) Jericho\_MBA; (38) Megiddo\_MBA; (39) Manahat\_MBA; (40) Shiloh\_MBA; (41) Tell Brak\_MBA; (42) Tell el-Hayyat\_MBA; (43) Qatna\_MBA; (44) Tell Fadous-Kfarabida\_MBA; (45) Tell Mozan\_MBA; (46) Tell Nebi Mend\_MBA; (47) Tell Qara Quzaq\_MBA; (48) Umm el-Marra\_MBA; (49) Tel Lachish\_MBA; (50) Sidon\_MBA; (51) Tell el-Burak\_MBA; (52) Zahrat adh-Dhra'\_MBA; (53) **Tel Kabri\_MBA**; (54) Beth Shean\_LBA; (55) Tell Deir'Alla\_LBA; (56) Emar\_LBA; (57) Tell es-Safi/Gath\_LBA; (58) Tell Afis\_LBA; (59) Tell Abu el-Kharaz\_LBA; (60) Aphek\_LBA; (61) Tell Bderi\_LBA; (62) Qatna\_LBA; (63) Timnah (Tel Batash) III\_LBA; (64) Tell Munbāqa\_LBA; (65) Tell Nebi Mend\_LBA; (66) Umm el-Marra\_LBA; (67) Qubur el-Walaydah\_LBA; (68) Sidon\_LBA; (69) Tel Burna\_LBA; (70) Tell el-Burak\_LBA; (71) Tell el-Umeri\_LBA; (72) Tel Lachish\_LBA; (73) Tel Tweini\_EBA; (74) Tell Tweini\_MBA; (75) Tell Tweini\_LBA

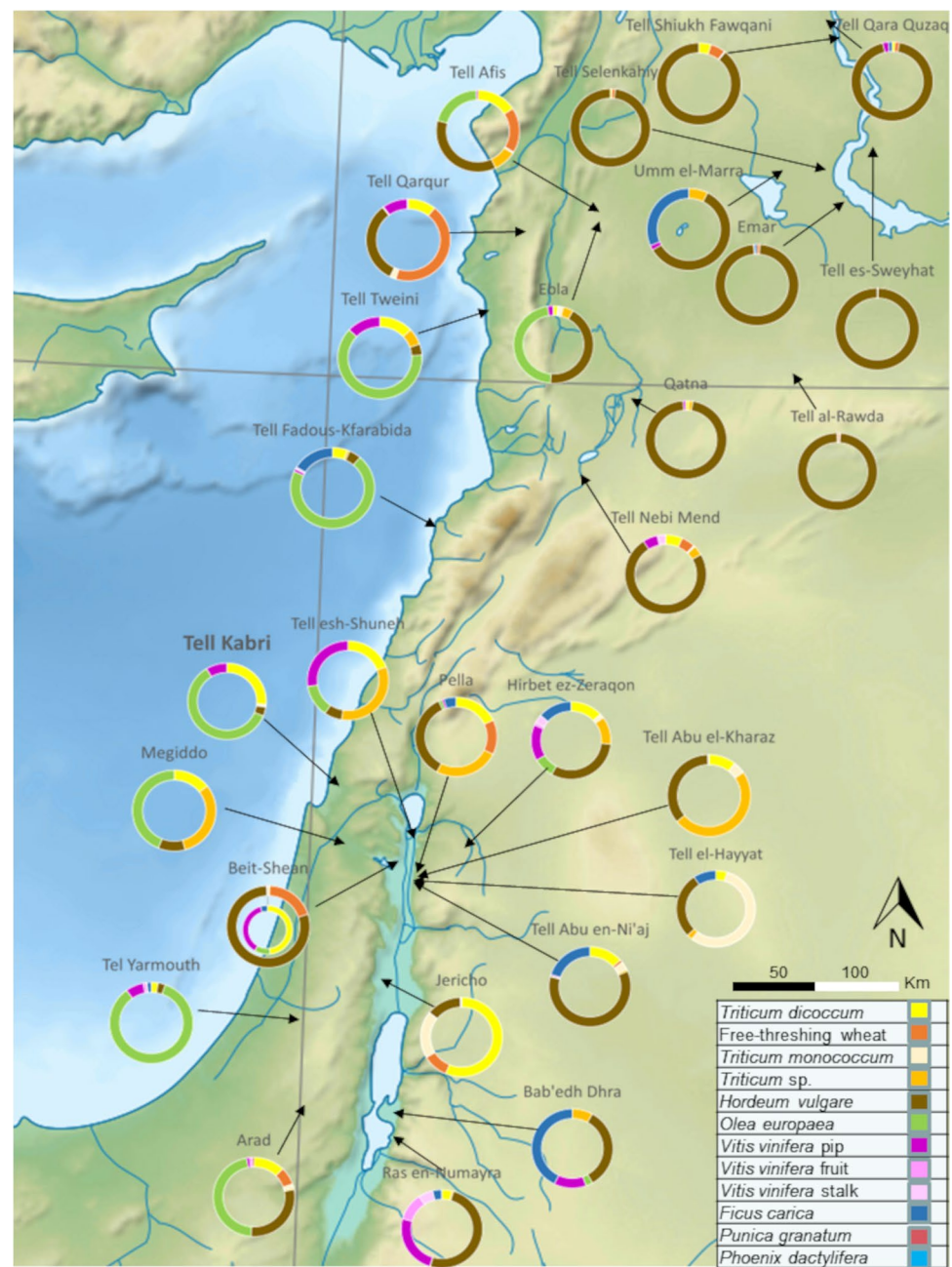
## Discussion

### Spatial and contextual patterns in crop distribution at Tel Kabri

Area DW includes the wine cellar (southern storage complex, Yasur-Landau et al. 2018; Koh et al. 2014) and was investigated to better understand the extension of the west part of the palace and its storerooms.

Within Area DW, only few cereal grains were found including a single free-threshing wheat grain. The few cereal seeds of emmer wheat (Fig. 5), barley, and some cereal crop weeds like *Phalaris* (Fig. 5s) and *Lolium* (Fig. 5r) have been found in connection with a good number of charcoal fragments. Weed species, such as *Lolium* spp., have rarely been analyzed for their stable isotope data, but in doing so, we may be able to identify the crop species with which they were associated. Although the

**Fig. 7** EBA crop proportions in Levantine sites



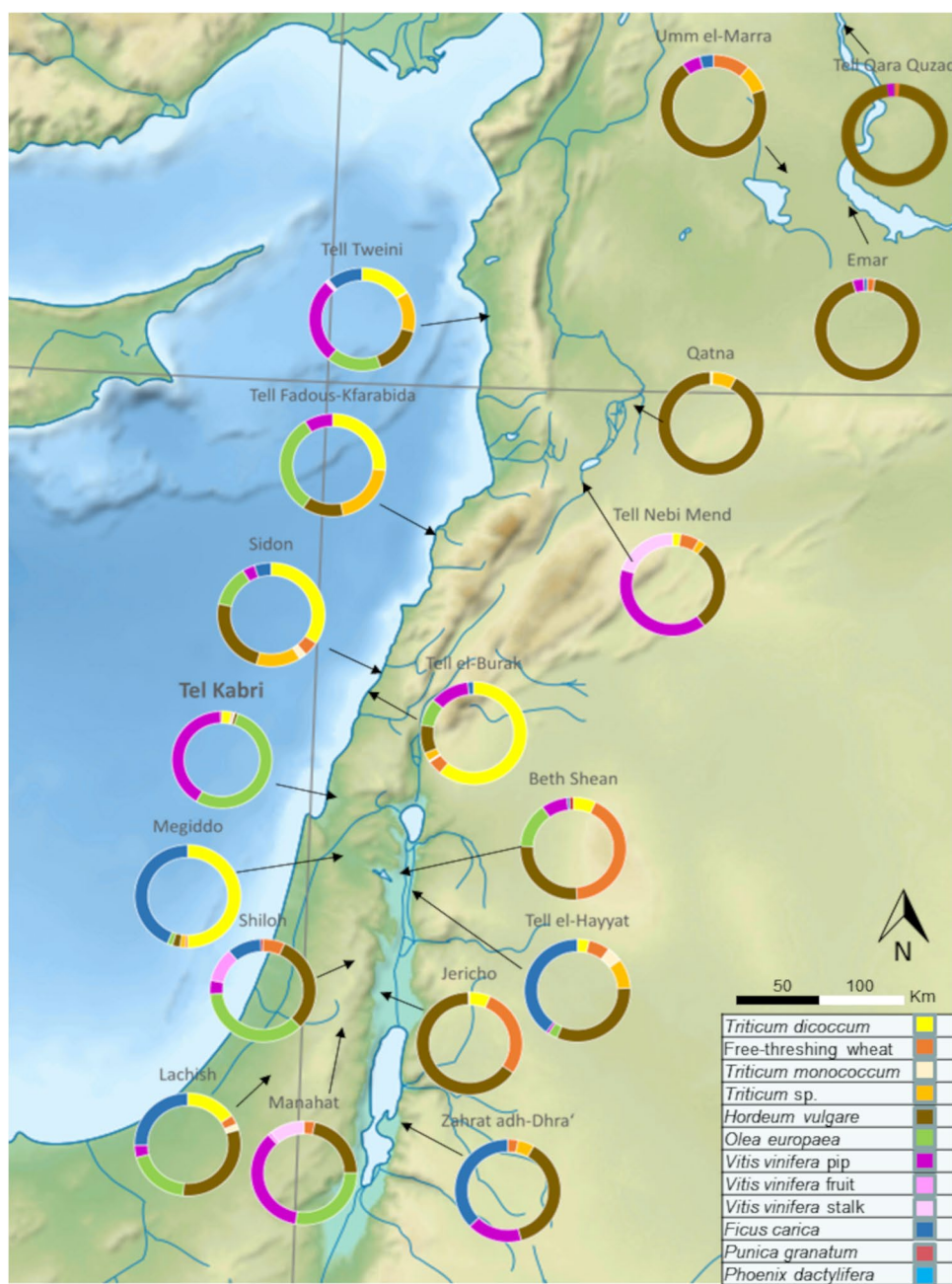
individual range of  $\Delta^{13}\text{C}$  values is so far unknown for *Lolium* sp., the similarity of the values measured to those of barley at Tel Kabri is striking, and since it is more likely that this grass was harvested together with a cereal species, rather than with legumes, it may be interpreted as a weed of barley cultivation.

Most of the legumes in Area DW were found within a single locus, L.3264, with ca. 22 vessels discovered in situ (outlined in red in Fig. 3). Olive and grape are the main findings of the Northern Storage Complex in terms of counts and ubiquities. Most of the grape pips identified in this area (ca. 70%) are mineralized (Fig. 5n), the majority of which come

from two loci which are part of the same floor where the previously mentioned vessels were located (Fig. 11).

This mineralization is an indication that the botanical remains went through a transformation process, which allowed them to be preserved, by exchanging organic molecules with inorganic ones (Green 1979; McCobb and Briggs 2001) and testifying to the causes depending on the nature of the context. Many mineralized seeds in Area DW were found in a layer that was probably the result of dumping due to the high quantities of bone remains and pottery sherds (L.3269 which location is outlined in yellow in Fig. 3). This is confirmed also by the botanical remains

**Fig. 8** MBA botanical assemblages of Levant sites used in the CA



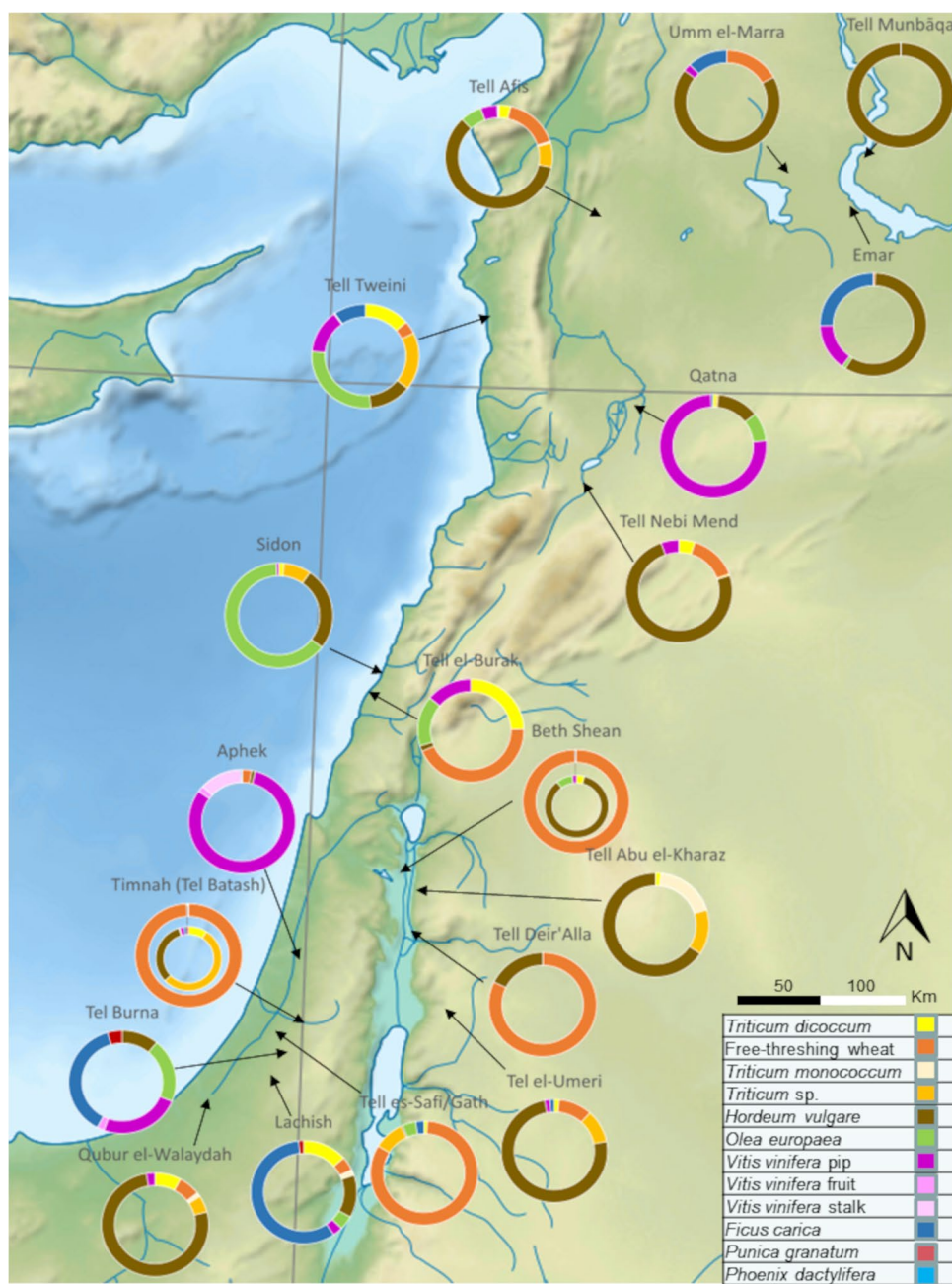
within the locus: there are many fruit remains, including charred olive (Fig. 5k), grape (all mineralized), and a mineralized pomegranate seed (Fig. 5q), charred legumes, and very few cereal, charcoal, and wild plants seeds, all indicating domestic waste. The presence of whole mineralized grape pips in the dumping context may usually indicate that the domestic waste also included part of latrine waste (Baeten et al. 2012; Matthews 2010) but no latrine installations or contexts have been found in Tel Kabri so far.

The nature of the sampled areas, their original functionality, preservation conditions, and modern intrusions all affected the outcome of the botanical assemblage.

Considering the elite setting in which the palace is located, it is not surprising that no results of cereal cleaning or cereal storage have been found in Area DW.

The plant remains suggest that the whole area was primarily used to store wine. The high presence of mineralized grape seeds might be evidence of unfiltered stored wine. Thanks to the tannin present in the grape seed, they could have acted as preservatives during the transportation and storage of wine vessels (White and Miller 2018). After the filtration, the residues would have probably been discarded in domestic wastes, hence the high presence of mineralized seeds in the archaeobotanical record.

**Fig. 9** LBA botanical assemblages of Levant sites used in the CA



The presence of mineralized grape seeds concentrated in locus 3269 where vessels and evidence of mudbrick collapse have been found could be the result of a different type of preservation. The plant material in the sediment, after the shattering of the vessels during the time of the palace collapse, could have been soaked with syringic acid present in the stored wine (Koh et al. 2014). That leaking could have enabled the survival of uncharred seeds, considering that syringic acid intervenes in the plant-soil microorganism interaction (Cheemanapalli et al. 2018).

Similar remarks may be made for the few wild seed taxa that have been found, apart those related to modern intrusions

(Fig. 5t), but the finding of *Pistacia* seed in the same locus (L.3269) is significant. Different studies have demonstrated that *Pistacia* fruit, leaves, or mastic could have been used to preserve or add flavor to wine contained in vessels (Hansson and Foley 2008; Stern et al. 2008). There is no guarantee that single findings of *Pistacia* seeds could validate the use of this plant as an additive to stored wine but can support the residue analysis already completed for the site, in which terebinth resin traces, among others, have been found within the jars retrieved in the MBA palace (Koh et al. 2014).

Only few olive pits have been found whole while the vast majority were fragmentary. We can speculate that olives

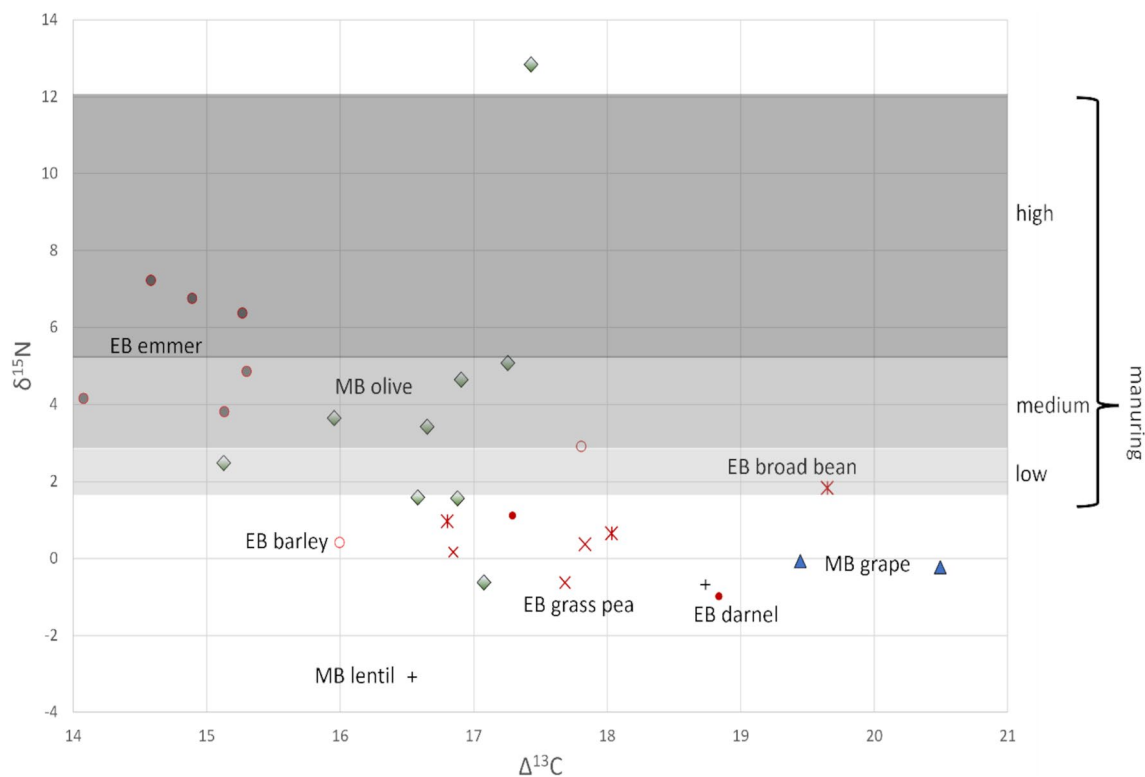


**Fig. 10**  $\Delta^{13}\text{C}/\delta^{15}\text{N}$  plot of the different taxa analyzed from Tel Kabri contexts. Manuring levels from Styring et al. (2017) applied to an assumed mean annual precipitation of 500 mm



**Fig. 11** In situ jars in L.3264 (Area DW)

were used for oil extraction, if we also consider the great amount of remains retrieved, but without a direct evidence of an oil press we cannot be certain. Nevertheless, it is very likely that these olive pit fragments were used as fuel sources and then discarded together with the other domestic waste found in the area. A great amount of olive charcoal has been identified in Tel Kabri, one of the most abundant taxa in the charcoal assemblage, probably used as fuel sources and partly as building timber (Lorentzen 2023).

Regarding Area L, together with a relatively high quantity of emmer wheat, emmer glume bases were also retrieved, representing the only cereal chaff found in Tel Kabri. Significant in this area is the finding of several legume remains, lentil, grass pea, and faba bean, which could be determined by the different type of context, but it also emphasizes the difference of the EBA botanical assemblage compared to the MBA which will be discussed below. Nevertheless, identical to the other two areas, the most frequent taxon of Area L is olive, although it proportionally plays a limited role compared with the Middle Bronze Age assemblage. Grape pips were also found in this area. The densest soil sample among all the areas in terms of plant remains was recovered in Area L, in a locus composed of dark organic sediment that intercepted a stone installation identified as a storage container or an apsidal house. The plant remains retrieved from this

locus might be associated with kitchen waste, confirming the identification of the context. These include large quantities of charred legumes (faba bean, lentils, grass pea), charred cereal seeds (emmer wheat and some barley), and very few fruit remains and wild plant seeds. It is interesting to note the discovery of whole faba bean seeds (Fig. 5g, h), a legume that has been intensively cultivated in the Galilee region since the Neolithic (Caracuta et al. 2015) and that, thanks to the easy access to the springs (it is required a constant amount of water) around the tell, could have been farmed in Tel Kabri during the EBA.

Noteworthy is also the presence of chaff remains in Area L, in comparison to their total absence in the palace area. Area L, a domestic context, has provided the finding of three emmer wheat glume base (Fig. 5c). They have been mostly found in a locus which is part of a colluvial deposit, together with a great number of olive stones and four seeds of jujube (Fig. 5o, p).

The Christ's Thorn Jujube grows nowadays in all valleys and lowlands of Israel, to an elevation of below a.s.l. 500 m. It is still very common in the coastal regions including Galilee and inland Lower Galilee (Danin and Fragman 2016). The tree is still particularly valued by the local population as the fruits are edible and can be dried or used as fodder; furthermore, the trunk is considered for its high-quality charcoal (Dafni et al. 2005). The utilization of jujube has been testified in the region since Palaeolithic as the finding of this plant remains in the archaeological sites of Ohalo II at the Sea of Galilee demonstrates (Weiss 2017).

## A diachronic consideration of crop plant distribution and proportions

### EBA

Pattern searching using correspondence analysis shows that the botanical assemblages of Tel Kabri, during both the EBA and MBA, are closely associated with the cultivation of olive and grape, but with a stronger association to olive in the MBA contexts (Fig. 6) which is well reflected in the ubiquities of the different crop taxa (Table 1). In these contexts, in addition to olive charcoal mentioned before, grape vine has also been identified (Lorentzen 2023), proving the importance of these crops for Tel Kabri.

Fruit tree proportions are generally more prominent in the EBA sites of the southern Levant, whereas in the North barley proportions are remarkably higher in the inland sites, in particular (Fig. 7). Olive is typical of the Mediterranean climate, characterized by dry summers and cool, but frost-free, winters, corresponding to the Mediterranean Sea coasts up to ca. 200 m. It can also tolerate arid conditions (Sofa et al. 2008). However, for increasing fruit production, mean annual precipitation of at least 600 mm or irrigation is required (Riehl 2009).

The presence of grape is also remarkable, a manifestation of the intensive horticulture that is prominent in this period. Both vineyards and olive orchards testify long-term agricultural planning as they require 3–8 years before bearing fruits and they would need 10–20 years for being fully productive (Fall et al. 2002). Regarding vineyards, a certain degree of soil moisture is recommended for a good harvest, and, unlike olive, it does not tolerate drought conditions for prolonged periods. In the EBA, it was cultivated mainly in areas with modern mean annual precipitation of above 400 mm (Riehl 2008).

In both the northern and the southern Levantine assemblages, barley is often dominating the EBA cereal assemblages, in the south particularly in those along the Jordan valley. Emmer is also present in most assemblages, but with higher proportions concentrating in the coastal region. The proportions of emmer wheat in the Levant assemblages start decreasing in later periods in favor of free threshing wheat. It is still present in MBA and LBA sites especially in the Southern Levant, in some cases even in high proportions (e.g., Tel Lachish, Nicoli et al. 2022). This crop preference has been associated with the influence of the Egyptian political power on these sites, since in Egypt emmer remained the main cereal crop species until the Graeco-Roman period and was used in bread and beer production together with barley (Nesbitt and Samuel 1996).

In the CA biplot, the EBA botanical assemblage from Tel Kabri seems to be closely associated with other EBA sites. The first one is Bab'edh Dhra. The site is located near the Dead Sea in modern-day Jordan. The assemblage of Bab'edh Dhra is heavily dominated by fruit taxa, fig, and grape as well as a few olive remains (Figs. 6 and 7; McCreery 1979, 2003). Even though the arid environmental background of the area around the Dead Sea with a low average of rainfall per year, Bab'edh Dhra had easy access to springs that allowed continuous irrigation of crops permitting a whole year yield. Moreover, thanks to its location in a low valley, it was made a virtual greenhouse which offered mild winter periods (McCreery 2011).

The ecological setting of this area, offering mitigated winters similar to the coastal regions and with the presence of many springs, similarly to Tel Kabri, differs from territories east and west of Bab'edh Dhra, making it a unique agricultural landscape.

Tell Tweini located in modern Syria is another site closely associated with Tel Kabri in the CA graph (Fig. 6). It presents similar botanical assemblages and environmental characteristics as Tel Kabri. The settlement is in fact situated at a short distance from the Mediterranean Sea (1.5 km) with different freshwater sources around the mound and a mean annual precipitation that can reach 600–1000 mm (Linseele et al. 2019). Olive is the main crop at the site during the EBA (Fig. 7) followed by emmer, which is constantly present in

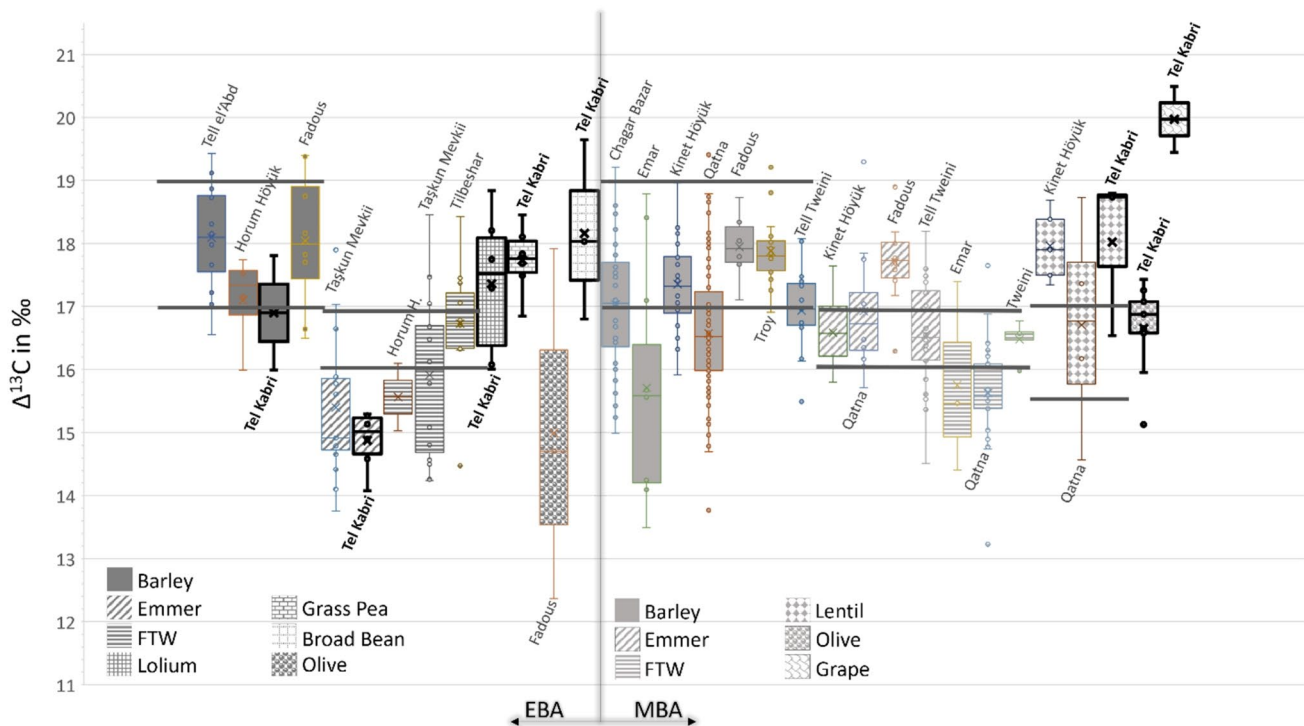


**Fig. 12**  $\Delta^{13}\text{C}$  values of different crop species from a number of Near Eastern archaeological sites of the Early and Middle Bronze Ages. The gray lines indicate the species individual ranges between no stress signal (values above the upper lines), moderate stress (values

between both lines), and increased drought stress (values below lower lines). Note that these ranges are only available for the cereals and lentil

later periods. Grape remains are also present but in smaller quantities.

Another site closely associated with EBA Tel Kabri in the CA plot is Tell Fadous-Kfarabida. The site, located on the coast in modern day Lebanon, is approximately 143 km north of Tel Kabri. Similar to the EBA assemblage in Tel Kabri, the seed records of Tell Fadous-Kfarabida are dominated by olive remains with an ubiquity in the samples close to 100% (Figs. 6 and 7, Riehl and Deckers 2009). Emmer is also very abundant in the botanical assemblage, which also include other crops in small numbers: barley, lentil, fig, free-threshing wheat, and grape. No moisture indicators were found in the wild plant assemblage, demonstrating that irrigation in Tell Fadous-Kfarabida was probably not practiced, nor were crops cultivated near freshwater sources. Comparing the available stable isotope data for barley from Tel Kabri and Tell Fadous-Kfarabida (Figs. 12 and 13), the barley from Tel Kabri seems to have experienced some drought stress, whereas at Tell Fadous-Kfarabida no stress is indicated. The nitrogen levels for barley are, in contrast to the  $\Delta^{13}\text{C}$  values, similarly low at both sites.

In terms of water availability at Tel Kabri and the role of the nearby springs for agricultural production,  $\Delta^{13}\text{C}$  values suggest that water availability for crop species was variable, indicating particular drought stress for emmer

wheat, which was probably also unirrigated (Fig. 12). Inter-site comparison of the  $\Delta^{13}\text{C}$  values in various crop species indicates considerably higher drought stress for barley and emmer wheat at Tel Kabri than can be noted for other sites. Drought stress signals are even stronger at Tel Kabri than at Tell el'Abd, today flooded in Lake Assad, and where barley despite low precipitation (ca. 200 mm) did not suffer any drought stress probably due to irrigation or cultivation near the fluvial catchment area (Riehl 2019). The legume remains at Tel Kabri, in contrast, do not show any stress signals. Even though there are only few comparative data for legumes (e.g., Styring et al. 2017), grass pea, broad bean, and lentil show similar ranges in  $\Delta^{13}\text{C}$ .

Interestingly, emmer appears to have been a manured crop at Tel Kabri, given its relatively high  $\delta^{15}\text{N}$  compared to the other crops retrieved from the site (Figs. 10 and 13).

The interpretation of  $\delta^{15}\text{N}$  values as indicators for manuring requires a deeper consideration, taking into account the fact that foliar  $\delta^{15}\text{N}$  increases with decreasing mean annual precipitation (Craine et al. 2009; Wang et al. 2014). A possible interpretation of the high  $\delta^{15}\text{N}$  values for emmer in Tel Kabri might be drought-released, which may be supported by the  $\Delta^{13}\text{C}$  values. These indeed indicate drought-stress, but since the ancient precipitation ranges are unknown, it is difficult to assess to which degree nitrogen levels in emmer

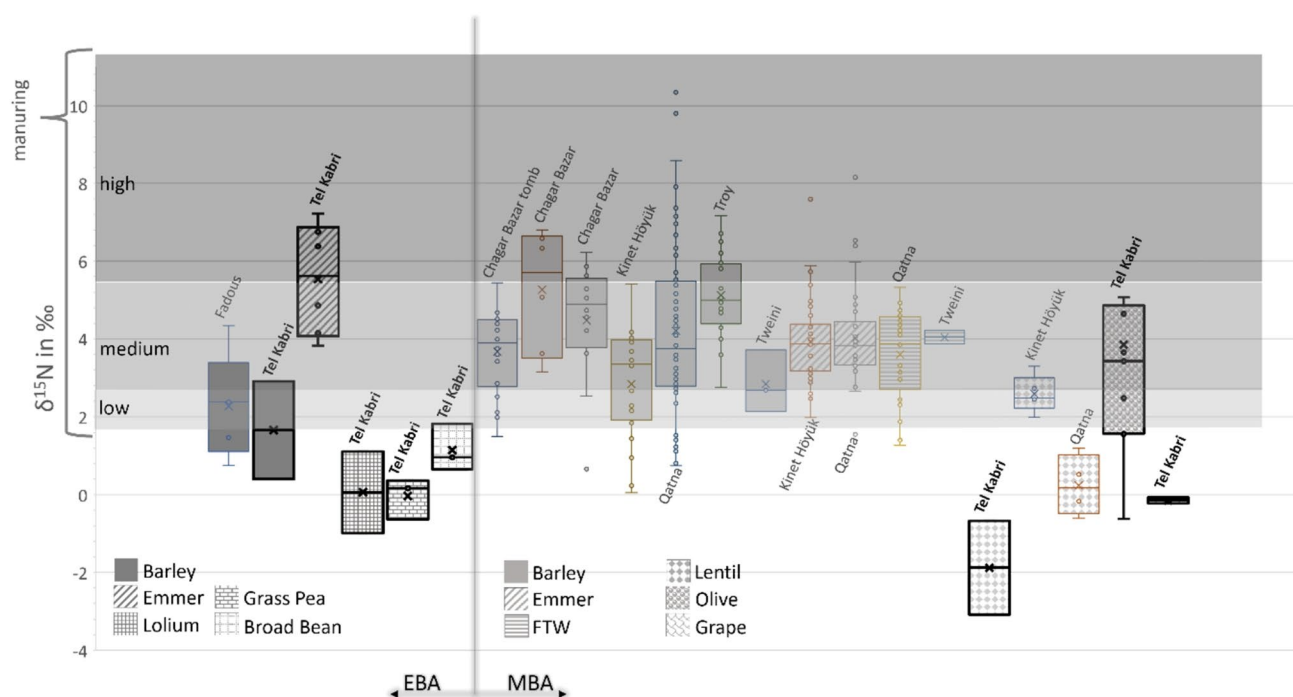


**Fig. 13**  $\delta^{15}\text{N}$  values of different crop species from several Near Eastern archaeological sites of the Early and Middle Bronze Ages

from Tel Kabri might have been elevated through aridity. Styring et al. (2017) propose a model for the relationship between cereal grain  $\delta^{15}\text{N}$  values from different manuring levels and mean annual precipitation ranges. Modern mean annual precipitation at Nahariya is 511 mm (weather-stats.com, 11.11.2021) and applying this value to the model by Styring et al. (2017), it produces the ranges for manuring indicated as gray-shaded bands in Figs. 10 and 13, still placing the emmer from Tel Kabri into a field of medium to high manure input. This raises the question why emmer might have been manured and simultaneously relinquished under high impact of aridity. Multiple scenarios are possible. If we assume that all crop species in Tel Kabri were cultivated in the closer region around the tell, it is also possible that emmer was growing unirrigated away from natural resources and indirectly manured by browsing ruminants. An alternative interpretation is that emmer was cultivated further away from the site and brought to the city or simply grew during a drier year and is the result of that single harvest.

Other crops, legumes, grape, and probably also barley were not manured as indicated by  $\delta^{15}\text{N}$  values below 2‰, whereas  $\delta^{15}\text{N}$  values for olive are highly variable (Fig. 13). High variability of  $\delta^{15}\text{N}$  values in olive pits has been interpreted to indicate manuring, in contrast to low variability in unmanured crops (Vignola et al. 2017), but this might alternatively be due to the longer period in which olive fruits develop compared

to the other crops or because they may have arrived from a variety of different cultivation plots and thereby reflect different soil conditions. The economic role of different agricultural land use zones in past agricultural systems has been discussed for Iron Age Ashkelon (Faust and Weiss 2005) but may have also been practiced in earlier times.

Considering the  $\delta^{15}\text{N}$  crop record from Tel Kabri in the wider regional comparison, apart the mentioned Tell Fadous-Kfarabida, the lack of stable nitrogen measurements from other Levantine sites limits an extensive direct comparison of the same crop species.

A striking pattern of the crop assemblages from Tel Kabri are the high number as well as high ubiquities of legumes in EBA contexts which are in strong contrast to the low numbers and ubiquities in the MBA. As previously mentioned, it is noteworthy that faba beans have been found solely in the EBA contexts; meanwhile, bitter vetch starts appearing only in the MBA samples. Overall, starting from the MBA, the ubiquity of bitter vetch increases in all the Near Eastern sites, as a drought-resistant species adapting better to the new climatic condition (Riehl 2009). As generally considered a fodder food, the increase in bitter vetch could also indicate an increased need of animal feed for this period. However, since it has been regularly found in households' contexts and storages, we cannot be certain of its solely purpose as fodder crop until later periods.

## MBA

The MBA Tel Kabri assemblage in the CA biplot is located in the first quadrant, creating a cluster with most of the other MBA sites of the southern Levant. During the MBA, barley keeps being a regular presence in the Levantine assemblages; meanwhile, the presence and frequency of emmer in the southern Levant are reduced (Fig. 8).

As the CA graph shows, Shiloh, approximately 105 km SSE of Tel Kabri in an area of around 500-mm mean annual rainfall, is a site with close affinities in terms of taxa composition and abundances (Fig. 6). Tel Kabri and Shiloh share a prominence of olive with a focus on other fruits, including grape, but are different in their dominant cereal species (Kislev 1993). The western section of the Samarian hills, where Shiloh is located (Fig. 8), is, likewise Tel Kabri, rich in springs (Cohen 2009) that may have supported fruit tree cultivation.

Beth Shean, located 65 km SSE of Tel Kabri, is thought to have been a center of trade comprising the import of crops during the Middle Bronze Age. This was proved by the presence in the botanical assemblage of wild plants species originating from other regions, including the adjacent Jezreel Valley and the fertile fields of Gilead, such as *Pistacia atlantica* and *Valerianella muricata* (Simchoni et al. 2007). Taking also into consideration that the valley around the site is poor in ground water supply, the lack of evidence of plants distinctive of irrigated field provides further support to their argument (Maeir 2016; Simchoni et al. 2007). Cereals are the main crops at Beth-Shean, free-threshing wheat followed by barley, but a small number of fruits, olive, and grapes, were also found in the MBA assemblage.

The MBA assemblage of Tel Lachish, 162 km south of Tel Kabri, also belongs to a palatial area (Nicoli' et al. 2022). No natural springs are present around Tel Lachish, except for a seasonal stream. Similar to Tel Kabri, olive has been identified as the most ubiquitous crop, but here it is followed by barley. It is during the LBA that we have an increase of species at Tel Lachish, but fruit cultivation was already present during the MBA (Nicoli' et al. 2022; Helbaek 1958). The presence of fig seeds is considerable in the MBA assemblage of Tel Lachish and in general in all the sites in the southern region (Fig. 8), which seems a phenomenon characterizing this area.

There are few published comparative  $\Delta^{13}\text{C}$  data available for MBA fruit crop taxa, but those for olive from Tell Tweini (unpublished data) indicate a  $\Delta^{13}\text{C}$  range between 15.3 and 18‰ with a mean of ca. 16.8‰ which is quite similar to the values for olives at Tel Kabri (Table 4). The MBA assemblage in Tell Tweini is dominated by grape and followed by olive but during this period barley remains have nearly the same proportion as emmer, which was the main cereal crop during the EBA (Linseele et al. 2019, Fig. 8).

Given the strong presence of barley and fig in the southern Levantine settlements of the MBA (Figs. 6 and 8), there may be a relation to the arid event at the end of the EBA (Kagan et al. 2015; Migowski et al. 2006; Langgut et al. 2015), which might have affected the sites considered here and the yield of crops with higher water requirements. Isotope analysis conducted on different crops from northern Levant, in fact, confirms an increased aridity during this time (Riehl 2007; Riehl et al. 2014).

Due to the small stable isotopic assemblage from Tel Kabri, it is problematic to draw any diachronic conclusions. However, integrating the results into the supra-regional diachronic pattern, barley appears indeed to have experienced considerable drought stress in the Middle Bronze Age compared to the Early Bronze Age. In contrast, the opposite can be noted for the wheat species, which has been previously interpreted to represent selective irrigation, possibly to counteract increasingly drier climatic conditions over time (Riehl 2017).

## LBA

Regarding the CA patterns for the LBA assemblages, the majority of the southern Levantine sites cluster in the positive part of the second axis, indicating intense fruit tree cultivation through plotting at the outer positive ends of the axes. The patterns are also supported by high percentage proportions of this crop category (Fig. 9).

The southern Levantine LBA settlements are generally distinctive to the previous MBA by high proportions in free-threshing wheat, which partially seems to replace emmer (Nesbitt and Samuel 1996; Riehl et al. 2007). Barley still plays a major role, and in some sites fig is also well-represented. One of the sites, Aphek, drops out from the general pattern through a strong dominance in grape. The site has been characterized by laying in a mesic biome (Olsvig-Whitaker et al. 2015) in a particular fertile plain, providing different remains in the botanical assemblage even though not all the sampled context reflected this grape predominance. A singular locus in Aphek provided an incredible number of grape seeds (pedicels and bunch fragments were recovered as well) that formed pomace, as a result of pressed seeds from wine production. The other remains in the LBA assemblage of Aphek reflect the general south Levantine pattern with a high number of free-threshing wheat, and the presence of barley and fruit tree remains including fig (Kislev and Mahler-Slasky 2009).

## Conclusions

As supported by correspondence analysis, the archaeobotanical assemblages from Tel Kabri reflect a regional pattern. A considerable number of olives in large ubiquity is

remarkable, reflecting the intensity of its horticulture in the southern Levant already during the EBA. Starting from this period, the cultivation of olive was crucial for the region economy since its oil was easy to store and traded or used as food and lighting resource.

The presence of emmer is notable, being the most ubiquitous cereal in both, the EBA and the MBA periods. The stable isotope measurements indicate that barley and emmer underwent considerably high drought stress in Tel Kabri, particularly critical in the case of emmer. In contrast to other crop species, emmer was likely manured, which raises questions as whether this is due to a strategy of soil fertility maintenance or a result of cultivating the crop on naturally fertile ground, which could also be further away from the site. The latter suggests that the emmer might have been a traded product.

The outcome of the MBA samples of Area DW reflects the palatial context to which they belong: fruit remains and few other crops that have been found in association with dumping and domestic waste context, hardly any wild plants seeds (excluding modern contaminations), and no chaff remains. The storage complexes yielded few botanical remains and most of the grape seeds have been found in a mineralized condition, raising speculations about the presence of unfiltered stored wine in the vessels and seeds that got soaked and preserved thanks to the acid present in the wine.

A different situation is found in Area L and the EBA layers. The rich archaeobotanical material recovered, despite the limited number of samples, reveals a range of horticulture and crops cultivation, with a focus on legumes. In the case of legumes, stable isotope measurements showed no stress signals and the same water availability for all of them. In Area L, various wild taxa have been identified, representing cereal crops weeds such as *Lolium* that may be associated with barley cultivation, as the stable isotope measurements suggest.

Continuous sampling of the EBA and MBA contexts at the site will be crucial for gathering new data concerning the agriculture and crop management of the inhabitants. Once recovered, the new types of contexts, such as residential areas, will provide a broader view of the crop husbandry management at Tel Kabri.

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## Declarations

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