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Intensive olive production at Levantine sites. New data from Fadous-Kfarabida and Khirbet-ez Zeraqon

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ABSTRACT

During the third millennium BCE, the Levant experienced an increase in social complexity, visible in the emergence of urban forms and centralised institutions. Specialised agricultural production, particularly of olives, has long been considered a key factor in this transformation. This paper uses charcoal and seed analysis of remains from the Early Bronze Age II-III sites of Tell Fadous-Kfarabida in Lebanon and Khirbet-ez Zeraqon in Jordan, alongside a comparative analysis of published data, to investigate this phenomenon. Olive was an important crop at both sites but Khirbet-ez Zeraqon is situated within a more arid inland location, away from the natural distribution of wild olive, whereas Tell Fadous-Kfarabida had a much lusher vegetation, and was within the distribution of wild olive. While important, olive was possibly not the major crop in terms of macro-nutrient supply in Khirbet-ez Zeraqon but it played a more dominant role in Fadous-Kfarabida. The measurements of the olive stones from both sites show a high variance compared to other sites. At Khirbet-ez Zeraqon this may have been due to specialization by using several cultivars and/or applying irrigation and/or fluctuations in rainfall. At Fadous-Kfarabida morphological wild olives were possibly included in the production as well, which may relate to the development of new olive strains and a likely higher engagement in experimentation. Although an overall linear trend of increasing mean olive stone length, occasionally described as “domestication syndrome”, can be detected for the southern Levant between 7 and 2 kyr BP, the Early Bronze Age measurement data from Fadous-Kfarabida and Khirbet-ez Zeraqon are outside the confidence band of the regression line and indicate that higher variability in some sites can blur a straightforward recognition of the “domestication syndrome”. There seem to have been varied local practices in cultivation and domestication in the Early Bronze Age Levant.

1. Introduction

In the Levant, olive has a long history of exploitation. Already 780,000 years ago olive and olive wood were used by hominins in the southern Levant (Goren-Inbar et al., 2000; Melamed et al., 2016). The earliest evidence for olive oil extraction and storage comes from submerged sites at the Carmel coast, dated to the sixth millennium BCE (Galili et al., 1997), while about 35 km inland at Ein Zippori olive oil remains were detected by gas chromatography and mass spectrometry of organic residues on pottery vessels dated to the 6th millennium BCE (Namdar et al., 2014). Based on the size of the olive stones found at sites from that period, it has been concluded that wild oleaster was used at that time (Kislev, 1994).

While pollen from wild and cultivated olive plants – even at very high magnifications – cannot be differentiated microscopically (Lipschitz et al., 1991), new palynological studies in combination with archaeological data suggest a rise in olive cultivation by about 4500 BCE in the southern Levant, since there were olive “peaks” in the pollen data that were not accompanied by an increase in other Mediterranean sclerophyllous trees and the archaeological/archaeobotanical data equally supports intensive olive exploitation (Langgut et al., 2019). Additionally, the presence of olive stones and charcoal at Teleilat Ghassul, north of the Dead Sea in Jordan, outside the natural distribution of oleaster, supports olive cultivation (possibly in association with irrigation) there in the 5th millennium BCE (Neef, 1990; Meadows, 2005).

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During the third millennium BCE, the Levant experienced an increase in social complexity, visible in increased site size, monumentality, and the centralised administration of agricultural production (e.g. Archi, 1992). The organizational systems of the central and the southern Levant are not fully understood, and their "truly" urban nature of the main settlements is still the object of debate (Chesson and Philip, 2003, 9; Philip, 2003, 106–108, 112; Richard, 2014, 331–334, with further references; Chesson, 2015, 52, 56). However, there is a wide consensus that the intensification and specialisation of agricultural production – including intensive olive and grape arboriculture – and the consequent need for storage, mobilization and exchange of high-value commodities, was central to the development of complex socio-political entities (Genz, 2003; Wilkinson et al., 2014, 87–89). The discovery of composite installations for oil extraction, especially at sites with large palace buildings (e.g. Tel Yarmouth: de Miroschedji, 1999, 8–9; Salavert, 2008), might substantiate the assumption of large-scale production connected with centralised units.

Although intensively investigated, the olive domestication process is still not thoroughly understood and genetic studies are hampered by difficulties in differentiating between feral (escaped from cultivation) and wild populations (Besnard et al., 2018), while similarly in archaeobotanical studies differentiating between wild and cultivated olive stones and olive wood is not straightforward (Lipschitz et al., 1991). Genetic data on olive indicate a dominant domestication event in the northern Levant (specifically the region of the Syrian/Turkish border) (Besnard et al., 2013), but archaeobotanical research in this area is limited so far.

The "domestication syndrome" in olive according to Fuller (2018) has been caused by selectively propagating more fleshy fruits that are associated with a reduction in genetic diversity and phenotypically manifested in longer and more slender olive stones (Fuller, 2018; but also Kislev, 1994; Meadows, 2005; Dighton et al., 2017). An overview of olive stone measurements summarized by Fuller (2018) shows the gradual increase in size from about 7 to 2 kyr BP, accompanied by a pronounced increase in the length/width ratio. Based on these data, it has been argued that the process of olive domestication was long and attenuated and that reproduction by seed played a role in this extended duration. Routine vegetative propagation of olive is suggested to have taken place only from 2000 BCE onwards (Fuller, 2018). The latter has also been concluded based on the seed measurement data from Pella (Dighton et al., 2017), where unexpectedly high size variance of olive stones was observed in comparison to some other earlier sites.

High shape and size variation of olive stones from an archaeological site, however, may also be an indication for specialization in olive production by using many cultivar genotypes as a conscious choice to balance risks from threats such as climate induced losses or pests (Bourgeon et al., 2018). Alongside genetic variation, environmental conditions also have an impact on variance in stone size, meaning climate change (Hammami et al., 2011) and water management such as irrigation may be important factors (e.g. Rapoport et al., 2004; Hannachi et al., 2017; Gucci et al., 2009).

In this paper we contribute to the history of olive cultivation by investigating the evidence for olive at two Levantine Early Bronze Age (henceforth EB) sites: Tell Fadous-Kfarabida in Lebanon and Khirbet-ez Zeraqon in Jordan (Fig. 1). From those sites, we analyzed the fruit and seed, as well as the charcoal remains. Additionally, measurements of olive stones from those sites and comparisons with published data have been undertaken to gain understanding of the olive domestication and specialisation history, of farming practices and climate.

2. The sites

Khirbet-ez Zeraqon is situated in northern Jordan, about 12 km NE of Irbid within the Transjordan Mediterranean belt and has received on average 159 mm rain annually over the last decade. Rainfall has fluctuated in Irbid between a maximum of about 340 mm in 2018 and a minimum of only 80 mm in 2014 over the last 10 years (weatheronline.com, accessed 30.04.2019). According to the TAVO map "A IV 4 Vorderer Orient. Mittlere Jahresniederschläge und Variabilität" long term mean precipitation for this region would have been between 300 and 400 mm annually in the period between 1955 and 1977 (Alex, 1986). However, interannual variability of total rainfall is high (Alex, 1986) and may cause considerable losses in crop yields.

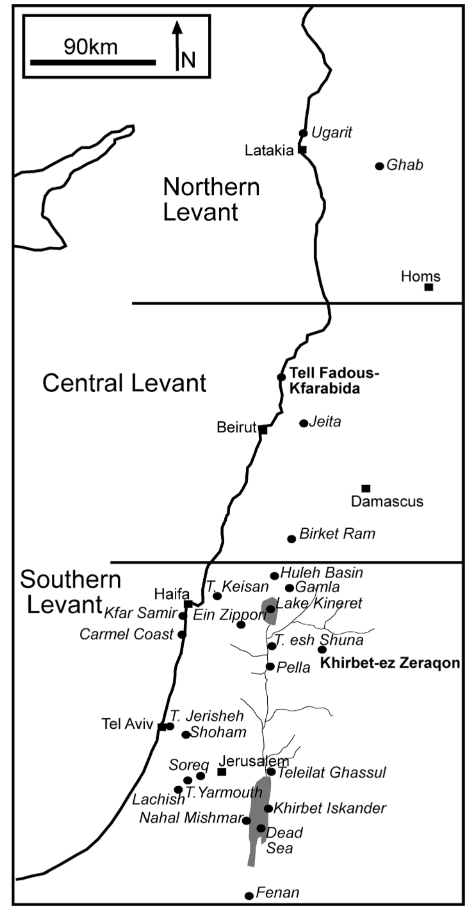

Fig. 1. Location of sites and locations mentioned in text.

The vegetation in the surroundings of Khirbet-ez Zeraqon today is heavily modified by humans. The landscape is intensively used for agriculture, amongst others for olive growing. The Irbid region produces 32% of Jordan's olives (https://data2.unhcr.org/fr/documents/download/62035, link accessed 15.01.2021). Away from the fields, half-steppe batha occurs, which is considered a man-made vegetation type composed of many taxa that are adapted against herbivores (Albert et al., 2004).

The site (8 ha) was intensively occupied during the EB II and the beginning of the EB III, from about 3100 BCE to the first half of the 29th century BCE, when the site was completely abandoned (Tumolo and Höflmayer, 2020). It can be considered as having been part of the "pattern of settlement and landscape development of the third millennium BC [...], with the explosive growth and collapse of cities, the settlement of climatically marginal lands, and an apparent increase in connectivity over the entire region" (Wilkinson et al., 2014: 46).

Archaeological investigations conducted at the site in two excavation areas (Genz, 2002, 7; Douglas 2007, 3–4) uncovered a northern upper city and a lower city to the south (Fig. 2). The upper city was characterized by public buildings, clustered into two architectural districts: the "temple complex" and the "palace complex". The lower city was excavated to a smaller extent. While Building B1.5 was a multi-purpose structure, most of the other buildings uncovered there have

Fig. 2. Maps of Khirbet-ez Zeraqon: (a) overview of the site, (b) upper town, (b) lower town (courtesy of the Khirbet-ez Zeraqon expedition).

architectural layouts consistent with domestic dwellings or residential units (B1.1–B1.4), containing domestic pottery repertoires and installations for food processing and storage. Archaeobotanical samples have been retrieved from contexts of both the upper and the lower city, belonging to all the three main stages of occupation of the EB II-III site: the "early horizon" (ca. 3100–3000 BCE), "middle horizon" (ca. 3000–2950 BCE), and "late horizon" (ca. 2950–2850 BCE), respectively dated to the EB II, the EB II-III transition, and the early EB III (Genz, 2002, 39–49, 77–88, 221; Tumolo and Höflmayer, 2020). Remains of olive wood and stones were collected from the public structures of the upper and the lower city, and from the domestic buildings of the lower city as well. The most substantial assemblages come from the lower city and mainly belong to the middle and the latest stages of occupation of the site.

Tell Fadous-Kfarabida is a small (1.5 ha) site in the coastal area of Lebanon, close to modern Batroun, with occupation evidence from the 4th to the early 2nd millennium BCE (Fig. 3). In this contribution only samples from the EB II–III (3000–2500 BCE) occupation will be discussed (Höflmayer et al., 2014; Genz et al., 2016). The region received on average 327 mm of rainfall annually over the last decade. Rainfall has fluctuated in this area with a high in 2009 of 517 mm and a low of 189 mm in 2018 (weatheronline.com, accessed 30-04-2019). According to TAVO, long-term average annual rainfall from 1955 to 1977 was between 600 and 800 mm in this region (Alex, 1986). The Pearson variation coefficient of annual precipitation is low (15–25%), when compared to the variability in the Irbid area (25–50%) (Alex, 1986). This variation coefficient is important especially considering archaeobotanical data that are assumed to be accumulations of multiple years of harvests.

Present-day vegetation in the surroundings of the site consists of a typical macchia. Further inland, at a height of 1200–1400 m a.s.L., which is about 10–20 km from the coast, the Eu-Mediterranean

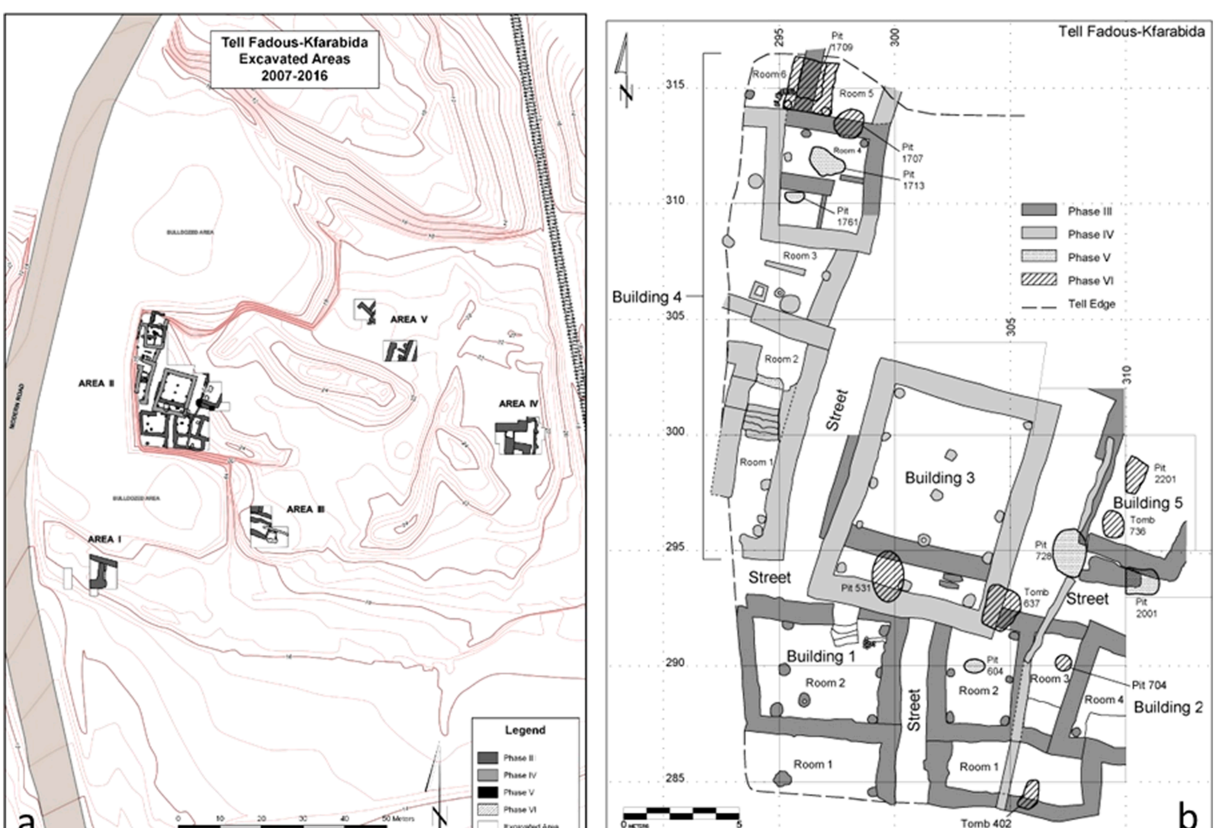

Fig. 3. (a and b) Excavation maps of Tell Fadous-Kfarabida.

vegetation is replaced by montane vegetation, including diverse coniferous trees, oak species and other trees. Nearest stands of trees occur about 5 km north of Tell Fadous-Kfarabida and consist mainly of pine (Talhouk et al., 2001). Today, cedar in Lebanon grows between 1400 and 1950 m a.s.L. in the mountains of north and central Lebanon, about 20 km east of Tell Fadous-Kfarabida (Browicz, 1982), but it has often been assumed that it covered much larger areas in the past.

Archaeobotanical samples have been retrieved from three phases of the settlement at Tell Fadous-Kfarabida. Phase II remains date to the EB II (ca. 3000–2800 BCE) and represent the beginning of an urban scale settlement at the site. All botanical samples from this phase derive from domestic contexts within rather small soundings. Phase III layers (ca. 2800–2600 BCE), contemporary with the early EB III, have been uncovered more extensively. The excavations revealed a densely built settlement with multistorey buildings. Some elite residences were investigated and yielded archaeobotanical samples. Additionally, there is also evidence for a public building, from which botanical samples were retrieved (Building 4). During phase IV (ca. 2600–2500 BCE), still within the EB III period, changes took place in the layout of the settlement. A monumental building was constructed (Building 3) from which no archaeobotanical samples have as yet been analyzed. Samples have been examined from Building 4, the adjacent building on the other side of a narrow street, which continued to be in use from the earlier Phase III. In addition, chemical analysis of a pithos (FAD10.305/295.56) from Room 3 in Building 4 revealed that it most likely contained olive oil (Genz et al., 2011, 162–163). Several finds, such as cylinder seals and a fragment of an Egyptian stone vessel, from Building 3 and 4 indicate a special function, most likely administrative (Genz et al., 2016).

Olive remains were found throughout the settlement, in both domestic and public contexts.

3. Methods and materials

3.1. Analytical methods for fruits, seeds, chaff and charcoal materials

Seed, fruit and charcoal remains have been investigated from the above-mentioned archaeological sites. At Khirbet-ez Zeraqon, 77 seed and fruit samples were investigated from the upper city, and 82 from the lower city. In total 41,370 seed, fruit and chaff remains have been analyzed. Additionally, 3 charcoal samples have been identified from the upper city (45 fragments) and 29 samples from the lower city (1965 fragments). A report on the seed and fruit results was published by Riehl (2004) and a summary of preliminary charcoal results by Engel (1990) was found amongst unpublished site documentation. In that unpublished report, results of 18 samples showed that 17 contained *Olea* (olive). These data have not been included in this manuscript since they derive from non-floated samples. Also, Neef (1990) published preliminary charcoal results from Khirbet-ez Zeraqon, mentioning the presence of *Olea*.

From the site of Tell Fadous-Kfarabida so far 3249 seed and chaff remains from 195 botanical samples were identified (Riehl, submitted). Most of the identified samples were from Phase III (representing two thirds of the identified material). All other phases were not sampled to the same degree. Furthermore, the results of 64 charcoal samples are presented here with a total fragment count of 4391, covering Phase II–IV. Preliminary reports on some of the samples have appeared in Badreshany et al. (2005, 84–88) and Genz et al. (2009, 115–116). Full sample by sample charcoal results will be published in a subsequent article (Deckers, submitted).

The charcoal and seed/fruit identification results are calculated as find and ubiquity percentages. While find percentages refer to the proportional number of charcoal fragments or seed counts of a certain taxon at the site, ubiquity percentages reflect the frequency of occurrence of a taxon in the samples. Olive management such as pruning and clearing of wild olive may be visible in the record as high olive charcoal percentages within the charcoal assemblages.

3.2. Olive stone measurements and details on the statistical analysis

Besides identification of all archaeobotanical remains (including anthracological analysis), length and width measurements have been undertaken for 188 different olive stones from Tell Fadous-Kfarabida and 30 from Khirbet-ez Zeraqon. For this, a manual vernier caliper was used with a precision of 0.02 mm. The values were however rounded to the nearest tenth mm. For some stones only a width or length could be measured because of fragmentation, but only whole lengths or whole widths were measured. At Fadous-Kfarabida, the large majority of olive stones derive from Phase III, although there were also a few from other phases. Only those from phases II–IV were included into the statistical analysis (cf. Appendix A for details on the in the statistics included samples). The majority of the measured olives from Khirbet-ez Zeraqon derive from the “middle horizon” (15), while 6 were from “early” and 7 from “late horizon”. Two further samples come from mixed contexts.

Published olive stone measurement data (except for those with fewer than 10 measurements) were gathered from other archaeological sites in the Levant, as well as present-day olives, for comparative analysis (Table 1). The chronological assignment of the published olive stone measurements was reevaluated based on current chronological knowledge of the site and the region. Published measurements of present-day Levantine olive stones appeared to be scarce. We used a study on Iranian olive stone measurements from 31 different olive genotypes to gain insight into the variance related with different cultivars (Jalali et al., 2014).

Since a decreased size variance has been mentioned as a possible indicator for domestication in Chalcolithic and EB olives (Kislev, 1994; Meadows, 2005; Dighton et al., 2017), the size variance data (for length and width) was plotted over time and a linear regression analysis was undertaken in combination with a variance analysis test. Moreover, since a previous study (Fuller, 2018) has detected a marked size increase from Neolithic to Classical time, the data for length and width were plotted over time and a linear regression analysis was undertaken on the data in combination with a variance analysis test.

Furthermore, Levene tests were undertaken to compare the variance of the length and width between sites. The Levene test checks for equal variances. Since variances between sites were unequal, subsequently a Games Howell-post-hoc-Test was undertaken on all published length and width measurements of the olive stones. The latter test provides confidence intervals for the differences between mean groups (https://statistikguru.de/spss/einfaktorielle-anova/varianzhomogenitaet-ueberpruefen.html, link accessed 15.01.2021). This allows for the analysis of differences amongst olive stones from the different sites. Those sites that are not connected by the same letter are significantly different for their length and width.

Moreover, the distribution of the olive stone measurements was investigated using the JMP software distribution platform. This allows for the detection of trends such as the bimodal distribution that may indicate the presence of two or more varieties of olives.

4. Results

4.1. Seed, fruit, charcoal proportions

Amongst the seed and fruit remains from Khirbet-ez Zeraqon, 95 taxa were identified, consisting of 13 crop plants and 82 wild plants. Emmer and barley were the main cultivated plants and were processed at the site. Lentil (*Lens culinaris*), olive (*Olea europaea*), grape (*Vitis vinifera*) and fig (*Ficus carica*) were also intensively used (for details see Riehl, 2004).

Olive pits are among the most ubiquitous crops at the site, with frequencies of 70% in the upper city and 80% in the lower city (Fig. 4). However, olive stones were mostly not present in large numbers.

The majority of the charcoal samples from Khirbet-ez Zeraqon derive

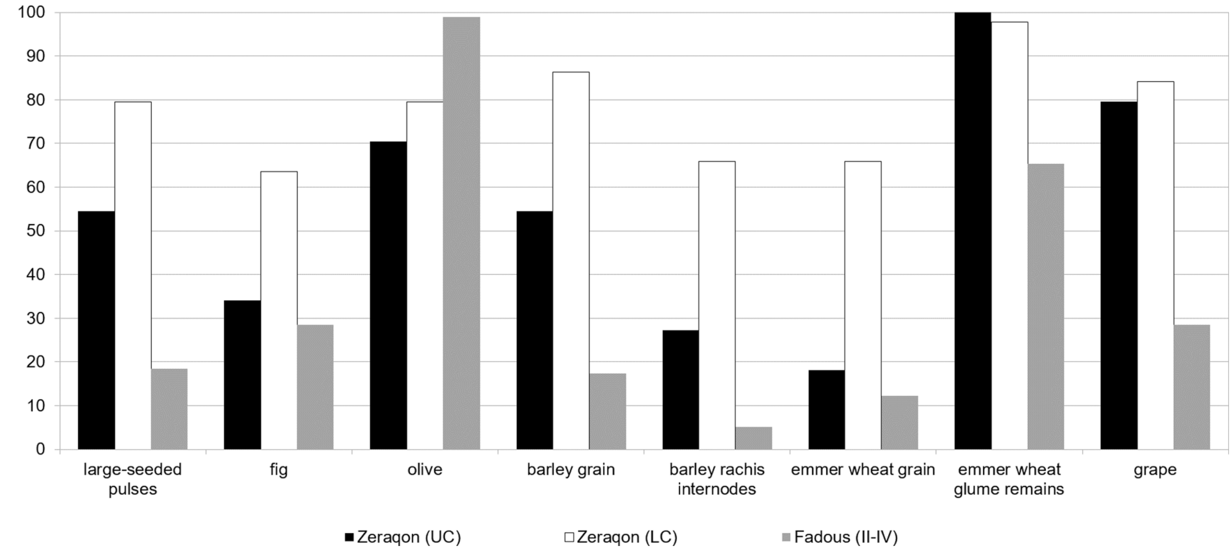

Fig. 4. Ubiquities of major crops in the upper and lower city of Khirbet-ez Zeraqon and phases II–IV at Tell Fadous-Kfarabida.

from the occupation of the lower town, being particularly abundant in association with the middle and latest phases of occupation. Olive charcoal dominates the assemblage, with ca. 78% of the fragments identified (Fig. 5). All other identified taxa were under 4%. Ubiquity percentages show about the same pattern with olive charcoal dominantly present in the samples, with ubiquities of about 88%. The other taxa with fairly high ubiquities were ash (*Fraxinus* sp.) with about 45%, as well as oak (*Quercus* sp.) and pistachio (*Pistacia* sp.) respectively with 15% and 30%.

Across the different phases of occupation at Tell Fadous-Kfarabida, emmer wheat (*Triticum dicoccum*) (47,8%) and olive (35,8%) together represent 60–80% of the assemblage. Other crops, such as grape, fig and different pulses and barley (*Hordeum sativum*) occur in small amounts. The seed assemblages of the different phases are similar.

Overall composition and abundance of particular crops at Khirbet-ez Zeraqon and Tell Fadous-Kfarabida are strikingly similar with a clear dominance of olive and emmer wheat.

The charcoal results from Tell Fadous-Kfarabida have been summarized in Fig. 5. Olive is the dominant taxon, representing ca. 62% of the investigated charcoals. This is a smaller proportion of olive charcoal than at Khirbet-ez Zeraqon, and is supplemented by larger proportions of oak, both deciduous and evergreen (ca. 12% in total), and conifers (ca. 18% in total), such as cedar (*Cedrus* sp.; 9.4%), juniper (*Juniperus* sp.; 2%) and pine (*Pinus* sp.; 4.2%), alongside pistachio (2.5%). Overall, the samples from Fadous-Kfarabida contain a greater variety of taxa, of which quite a few occur in very small proportions (all less than 1%), such as almond (*Amygdalus* sp.), thorny broom (*Calycotome villosa*), Chenopodiaceae (goosefoot family), ash (*Fraxinus* sp.), Leguminosae (legume family), Rosaceae (rose family), Monocoyledon and *Vitis vinifera*. About 4.4% of the charcoals could not be identified. Ubiquity percentages of the charcoals show a similar pattern, with olive dominant in the samples, with ubiquities of about 81%. Oak also has high ubiquities of ca. 73%. Cedar has the third largest ubiquity of about 34%. Pistachio has an ubiquity of about 27%, while juniper about 16%. All

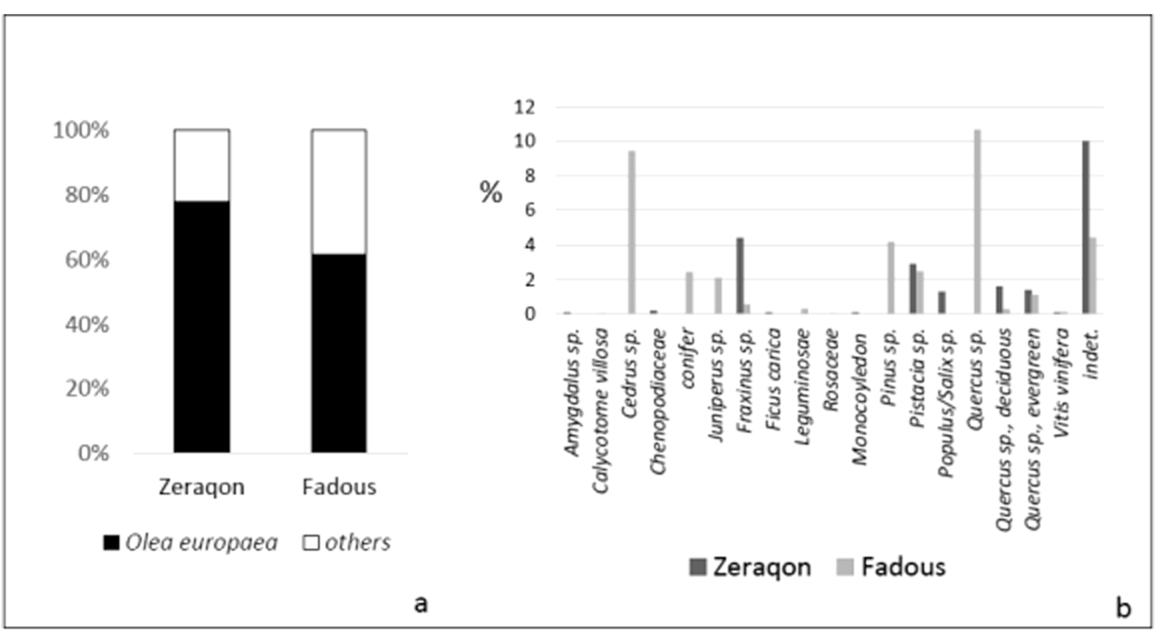

Fig. 5. Charcoal fragment percentages for Khirbet-ez Zeraqon and Fadous-Kfarabida (phases II–IV only): (a) proportion of *Olea europaea*, (b) fragment percentages of all other taxa.

other taxa have somewhat smaller ubiquities.

4.2. *Results of the olive stone measurements*

The results of the olive stone measurements from Tell Fadous-Kfarabida and Khirbet-ez Zeraqon (Appendix A and B) are compared with those available from the wider region and a range of periods (Fig. 6, Table 1). The present-day olive data have purposely been omitted from the graphs since they blur the linear trends visible between 7 kyr and 2 kyr. As Fuller (2018) has indicated, the mean length of olive stones/site shows an increase over time between the period 7 kyr and 2 kyr ago (Fig. 6a). About 51% of the variation is explained by the linear regression model. Fadous-Kfarabida however has an exceptionally small mean for olive length and lies outside the confidence band for the linear trend. Also, the Khirbet-ez Zeraqon olive stones are slightly smaller than the confidence interval of the linear regression (Fig. 6a).

A decreasing length variance over time is visible for the period from 7 kyr to 2 kyr ago. About 63% of the length variation is explained by the linear regression model. It is notable, however, that Tell Fadous-Kfarabida again is outside of the confidence band for the linear trend, demonstrating an exceptionally high variance (Fig. 6b). Present-day length variances, which were not plotted since they blurred the linear trend for the period between 7 and 2 kyr BP, are exceptionally high, higher than all variances from archaeological olive stones. The Levene test indicated that the variance of olive stones from 31 different present-day cultivars from Iran does not statistically differ from that of Late Neolithic Kfar Samir, Teleilat Ghassul and Pella, Late Chalcolithic Pella and our two investigated sites (Tell Fadous-Kfarabida and Khirbet-ez Zeraqon).

Mean olive stone widths also appear to increase in size over time, but only ca. 30% of the mean olive stone widths are explained by the linear regression model (Fig. 6c). According to the linear regression width increase appears to be related with size increase of the stones. More precisely, 51% of the width increase can be explained by size increase (Fig. 6d).

The width variance (Fig. 6e), like the length variance, decreases over time between 7 and 2 kyr BP. About 59% of the variances are predictable. The variance in width of the EB Tell Fadous-Kfarabida and Khirbet-ez Zeraqon olive stones is somewhat smaller than those from the Neolithic and Chalcolithic period and not significantly different from the one from Late Bronze Age Pella. Iron Age variances in width are even smaller. Present-day variances in width are again high. While the value from present-day Israel is highest and different from all archaeological sites, the variance value from the 31 cultivars from Iran does not statistically differ from those from Late Neolithic sites, like Kfar Samir, Pella and Chalcolithic sites like Teleilat Ghassul and Pella.

Unfortunately, only the stone by stone measurement data from Teleilat Ghassul and modern Iran could be analyzed alongside our own, since no other raw data for single olive stone measurements have been published. Games Howell-tests on the measurements provide insight into the differences between the olive stones from the different sites. The Games Howell-test on the width measurements does not show a significant difference in the means of the different sites (Table 2), with the exception of the mean width from the present-day Iran dataset compared to the Levantine archaeological sites. Additionally, the Games Howell-test showed that the mean length of the Iranian samples is significantly different from those of the Levantine sites. Moreover, the mean olive stone length from Neolithic Teleilat Ghassul is significantly different from the one from EB Fadous-Kfarabida. All other sites show some overlap. The present-day olive measurements from Iran show a normal distribution (Fig. 7), whereas the data from Khirbet-ez Zeraqon and Late Neolithic/Middle Chalcolithic Teleilat Ghassul can be best described as a mixture of two normal distributions, which may also be the case for Fadous-Kfarabida. For the latter, however, a Johnson SI, SU or shash distribution would provide a better fit than the mixture of two normal distributions. For the Late Chalcolithic stones from Teleilat Ghassul the gamma distribution fits best and second best the normal distribution.

5. Discussion

5.1. *Intensity of olive exploitation*

At both sites, Tell Fadous-Kfarabida in the coastal zone of Lebanon and Khirbet-ez Zeraqon inland in Jordan, *Olea europaea* is strongly represented amongst the charcoal. While at Fadous-Kfarabida olive

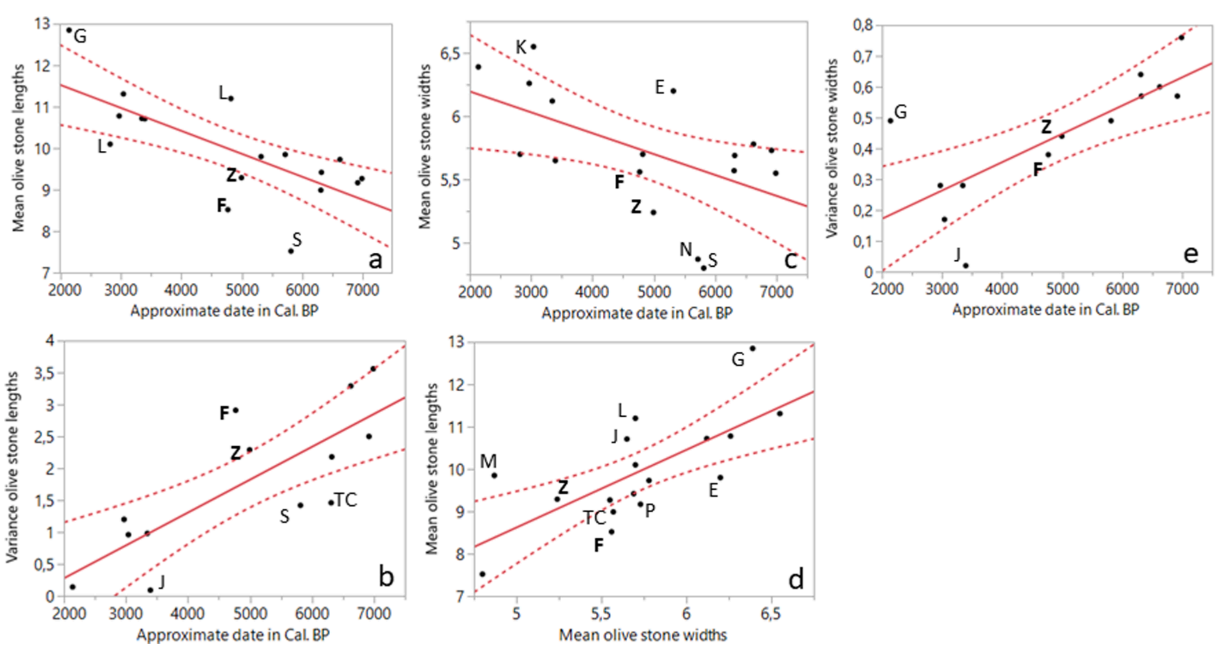

Fig. 6. Linear regressions with confidence bands for (a) mean olive stone length over time, (b) variance of olive stone lengths over time, (c) mean olive stone widths over time, (d) olive width/length relation, (e) variance of olive stone widths over time. Khirbet-ez Zeraqon and Tell Fadous-Kfarabida are labeled with respectively Z and F, as well as outliers according to the abbreviations listed in Table 1.

Table 1
List of published olive measurements with references. Unlike in Fuller (2018) only Levantine sites with more than 10 measurements are listed and used in the plots. Besides own measurement data from Khirbet-ez Zeraqon and Fadous-Kfarabida, recent measurement data as well as data from Meadows (2005) for Teleilat-Ghassul and Neolithic data for Pella (Dighton et al., 2017) was added to the Fuller (2018) chart. An approximate date was calculated for the occupation of the site as an average date for the period available, which is also used for the graphs in Fig. 6. Note that the chronological designation deviates somewhat from Fuller (2018). C = carbonized, U = uncharred, W = waterlogged, * = results were reduced by 20% to compensate for being uncharred (cf. Fuller, 2018).

Site (site abbreviation used in figures)	Country	Phase	Date range	Approximate average Cal. BP	Number of measured stones	State of stones	Mean olive stone lengths	Mean olive stone widths	Mean length/ width	Variance olive stone lengths	Variance olive stone widths	Reference	Notes
Pella (P)	Jordan	Late Neolithic	5100–4700 BCE	6920	32	C	9.17	5.73	1.60	2.5	0.57	Dighton et al. (2017)	
Teleilat Ghassul (TN)	Jordan	Late Neolithic/ Early Chalcolithic	4845–4368 BCE	6626	75	C	9.73	5.78	1.69	3.29	0.6	Meadows (2005)	
Kfar Samir (K)	Israel	Late Neolithic/ Early Chalcolithic	5567–4367 BCE	6990	100	UW	9,27*	5,55*	1,67*	3.56	0.76	Kislev (1994)	See Galili et al. (1997) for the chronology. Old dates on wood have been omitted.
Pella (P)	Jordan	Chalcolithic	4700–3900 BCE	6320	34	C	9.42	5.69	1.66	2.18	0.57	Dighton et al. (2017)	
Teileilat Ghassul (TC)	Jordan	Late Chalcolithic	4496–4085 BCE	6310	76	C	8.99	5.57	1.63	1.46	0.64	Meadows (2005)	
Tell esh Shuna (E)	Jordan	Early Bronze Age I	3600–3000 BCE	5320	70	C	9.8	6.2	1.58	not given	not given	Lipschitz et al. (1996)	
Shoham (S)	Israel	Late Chalcolithic	3942–3646 BCE	5815	23	C	7.52	4.8	1.57	1.42	0.49	Lipschitz et al. (1996)	
Nahal Mishmar (Cave of treasure) (M)	Israel	Late Chalcolithic	3800–3600 BCE	5720	58	U	9,85*	4,87*	1,92*	not given	not given	Fuller (2018) from Zaitschek (1980)	
Khirbet-ez Zeraqon (Z)	Jordan	Early Bronze Age II-III	3100–2850 BCE	4995	L (23); W (30)	C	9.29	5.24	1.77	2.29	0.44	New data	
Fadous-Kfarabida (F)	Lebanon	Early Bronze Age II-III	3000–2500 BCE	4770	L (132); W (181)	C	8.52	5.56	1.53	2.91	0.38	New data	
Lachish (L)	Israel	Early Bronze Age I-IV	3600–2000 BCE	4820	20	C	11.2	5.7	1.96	not given	not given	Helbaek (1958)	
Pella (P)	Jordan	Late Bronze Age	1500–1150 BCE	3345	41	C	10.72	6.12	1.75	0.98	0.28	Dighton et al. (2017)	
Tel Jerisheh (J)	Israel	Late Bronze Age	1550–1200 BCE	3395	28	C	10.71	5.65	1.90	0.09	0.02	Lipschitz et al. (1996)	
Tell Keisan (K)	Israel	Iron Age	1112–925 BCE	3040	100	C	11.31	6.55	1.73	0.96	0.17	Kislev (1994)	See also Finkelstein and Piasetzky (2008), Sharon et al. (2007) for the chronology
Pella (P)	Jordan	Iron Age	1100–800 BCE	2970	171	C	10.78	6.26	1.72	1.2	0.28	Dighton et al. (2017)	
Lachish (L)	Israel	Iron Age	1015–586 BCE	2820	25	C	10.1	5.7	1.77	Not given	Not given	Helbaek (1958)	See also Tufnell (1953), Garfinkel et al. (2019).
Gamla (G)	Israel	Hellenistic	300 BCE-64 AD	2140	64	C	12.85	6.39	2.01	0.14	0.49	Lipschitz et al. (1996)	
Uncultivated trees Carmel region (8 trees)	Israel	Recent	1996 CE	25	100?	U	13.93	6.47	2.15	8.11	1.52	Lipschitz et al. (1996)	
Cultivated trees, Oriental variety Surey	Israel	Recent	1996 CE	25	100	U	15.01	5.99	2.51	6.38	1.22	Lipschitz et al. (1996)	
Iran, 23 varieties of cultivated olives	Iran	Recent	2014 CE	5	31	U	14.27	6.78	2.10	2.50	0.98	Jalali et al. (2014)	

Table 2
Results of the Games Howell-Test for length and width. The sites that are not connected with the same letter differ significantly for the mean length, respectively mean width of their olives.

	Length	Width
Iran	A	A
Teleilat Ghassul Neolithic	BC	B
Teleilat Ghassul Chalcolithic	BDE	B
Khirbet-ez Zeraqon	BCD	B
Fadous-Kfarabida	DE	B

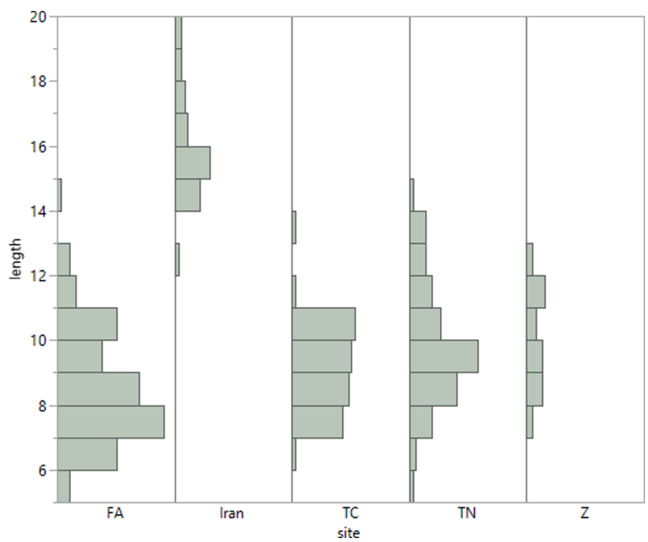

Fig. 7. Distribution of the olive stone lengths (in mm) at the different sites: FA = Fadous-Kfarabida, Iran = present-day Iran, TC = Late Chalcolithic Teleilat Ghassul Late Chalcolithic, TN = Late Neolithic/Middle Chalcolithic Teleilat Ghassul, Z = Khirbet-ez Zeraqon.

stones and emmer wheat are the most abundant crop categories, both in ubiquity and percentages, at Khirbet-ez Zeraqon olive stone percentages make up only 1% of the crops. Nonetheless, olive was important for the economy of the site, as indicated by ubiquities of stones reaching 100% in most of the settlement phases.

Both sites are located within the present-day olive cultivation belt (e.g. Cordova, 2007, Fig. 3.12, for Khirbet-ez Zeraqon see Yazbeck et al., 2018). While olive is native to the Mediterranean region, there is very little evidence for olive use before the 5th millennium BCE at inland locations such as Jordan (Neef, 1990, 1997; Meadows, 2005). An exception is the site of Pella, where the earliest olive remains date to 6200 BCE (Early Ceramic Neolithic period) (Dighton et al., 2017). The long-term regional history of olive derived from pollen diagrams fits well with the archaeobotanical data. During the Neolithic olive percentages are very low, before a marked increase from about 4800 BCE/ 4000 BCE at Birket Ram, the Dead Sea and Huleh (Schiebel, 2013). Taken together this evidence suggests olive was not prevalent in the natural vegetation of the surroundings of Khirbet-ez Zeraqon, and we would argue that olive was intensively cultivated at the site during the EB. Hence, the high length variance at Khirbet-ez Zeraqon was probably not related to any wild olive presence or intercropping, but rather to other factors.

The history of olive cultivation as seen from the pollen is also supported by the charcoal data in the southern Levant: While olive charcoal was a relatively minor proportion in charcoal assemblages before the Chalcolithic period, from the Chalcolithic to the Iron Age it occurred in higher percentages (Lipschitz, 2007). At the EB site of Tel Yarmouth, for example, high *Olea* charcoal percentages of ca. 77–67% were found in combination with other indications for olive oil production (Salavert, 2008) and an olive crop proportion of 50%. At Khirbet Iskander near the Dead Sea in Jordan, 99% of the identified charcoal volume was olive (Neef, 1990), while at Shoham it was 78% and at Ashkelon 84% (Lipschitz, 2007). Even in very arid regions further south, at sites such as Fenan 9 11% of the investigated charcoal fragments were olive, while this was about 7% in Fenan 16 (Baierle et al., 1989). Hence there appears to be a high involvement with olive pruning at that time. Pruning is known to be beneficial for various reasons, including creating the framework to support the fruit load, increasing sunlight exposure, reducing pests and rejuvenating old trees. Pruning should be light to moderate, with maximally up to 50% foliage removal to cause no significant loss in fruit production (Rodrigues et al., 2018).

Since people are assumed to have gathered wood, especially firewood, according to the principle of least effort, charcoal proportions are often interpreted to reflect the composition of the vegetation in its original proportions in the vicinity of settlements (e.g. Shackleton and Prins, 1992). According to that paradigm, the higher proportions of olive charcoal in Khirbet-ez Zeraqon compared to Tell Fadous-Kfarabida would suggest a higher presence of olive trees there compared to other woody taxa. However, the overall low fragment percentages of Mediterranean woodland taxa, like *Quercus* and *Pistacia*, at Khirbet-ez Zeraqon may be an indication of an environment with a lack of other woody resources and may relate to the location in a more arid region. This is also supported by high seed to charcoal proportions in the botanical samples, which may indicate dung as an additional fuel at Khirbet-ez Zeraqon. Sheep/goat pellets found at the site support this idea; they have a ubiquity of ca. 3%. Whilst having somewhat lower relative proportions of olive charcoal at Fadous-Kfarabida compared to Khirbet-ez Zeraqon, olive is still the dominant charcoal taxon at Fadous-Kfarabida and compared to Khirbet-ez Zeraqon there is a much larger proportion of typical Mediterranean vegetation amongst the charcoals, indicating a greater availability of other woody resources, and in general a higher diversity in species. Hence, both Khirbet-ez Zeraqon as well as Tell Fadous-Kfarabida show a high involvement with olive pruning, but the qualitative data allows no direct comparison.

5.2. "Domestication syndrome" and local practices

Since olive was cultivated for quite some time by the EB, it can be expected to show signatures of selection for cultivation. While a "domestication syndrome" trend (Fuller, 2018) is visible within the olive stones over the long-term from 7 kyr to 2 kyr BP, not all sites fit the overall line of development. Over time mean olive stone lengths increase in many cases, as well as mean olive stone widths, but length and width do not show a strong linear correlation.

Chalcolithic Shoham and Iron Age Lachish are outside the confidence band of the regression line that indicates the "domestication syndrome", with smaller and larger mean olive stone size respectively. Apart from Gamla, all those sites actually only have a small number of olive stone measurements (around 20) which may not be representative. Regarding the length variance outside the confidence band of the linear regression, Shoham is again amongst them and may be not representative. As for the high variance value for Kfar Samir, we unfortunately have no detailed stone by stone measurement data. The low variance of the olive stones from Late Chalcolithic Teleilat Ghassul may relate to the location of the site outside the natural distribution of olive and a consequent focus on cultivation of only one variety.

The sites under investigation here are also outside the confidence bands of the linear regression line: The Fadous-Kfarabida olive stones have an exceptionally small mean size and demonstrate a high variance in comparison to those from other sites along the linear regression. The Khirbet-ez Zeraqon mean olive size lies outside the confidence band of the regression line and the variance just on the edge of the confidence band. Notwithstanding the fact that most of the olives from Khirbet-ez Zeraqon are older than those from Fadous-Kfarabida, the site shows a lower length variance.

Both sites tend to show mixtures of two normal distributions for the olives, but it is unlikely that both sites had an inclusion of wild olives, since it is unlikely that wild olives occurred in the Khirbet-ez Zeraqon surroundings, as mentioned above. Fig. 6d shows that olives from Fadous-Kfarabida are on average shorter and more globular than those from Khirbet-ez Zeraqon, indicating that Fadous-Kfarabida likely contains stones that are more similar to the wild/feral populations found today with a size of less than 1 cm and a globular shape (Newton et al., 2014). Fadous-Kfarabida is well within the wild olive distribution and we cannot exclude the possibility of use of wild olives. At Late Bronze Age Ugarit in Syria, Newton et al. (2014) also found wild/feral olive morphotypes, which they detected with detailed shape analysis. They conclude that spontaneously growing olives outside the domesticated groves were possibly used as well (Newton et al., 2014). However, the presence of wild morphotypes may also reflect the search for new cultivars with valuable properties amongst wild populations. This is still an important issue for olive production. In present-day Tunisia, wild populations have been tested for their properties and may be crossed with domestic plants to increase oil production (Baccouri et al., 2011). Wild olives are also used for grafting domesticated types in modern southern Italy to increase the durability of the crops against pests, such as *Xylella fastidiosa* (pers. comm. Marco Nicolí).

It should also be noted that not all small olives today are from wild populations, but – although more exceptional – there also exist olive cultivars with short stones (Newton et al., 2014; Terral et al., 2004). Hence, the presence of short stones may also relate to a special breed of cultivated olives. Exceptionally small stones may also derive from undersized cultivated fruits (also called shotberries), but only a few stones from the investigated sites have such a small size of ca. 5 mm (cf. Fig. 6) (Costantini and Biasini, 2018, 397).

Small olive stones may also indicate water stress. Overall, water deficit causes smaller olive fruit and stones, while higher water availability -such as through irrigation- leads to larger ones (e.g. Rapoport et al., 2004; Hannachi et al., 2017; Gucci et al., 2009). As mentioned above, Khirbet-ez Zeraqon is located in a region with lower and more variable rainfall levels than the coastal area. Whether olive could have grown there without additional watering depends on the climatic conditions that prevailed during that time. At present, despite a decline in rainfall over the last decade, only about 8% of the olive trees in Lebanon and 25% of olive trees in Jordan are being irrigated (http://blog.blominvestbank.com/wp-content/uploads/2015/11/Olive-Oil-The-Bittersweet-Taste-of-Lebanon.pdf, link accessed 15.01.2021 and Talozi and Al Waked, 2016). Most palaeoclimatic records within the southern Levant indicate on average a slightly moister climate than today for the EB (e.g. Bar-Matthews and Kaufman, 1998; Bar-Matthews and Ayalon, 2011). The isotopic results on speleothems from Soreq Cave (Israel), for example, indicate that between 3200 and 2600 BCE the climatic conditions fluctuated between moister and more arid compared to today, followed by a moister period than today between 2600 and 2200 BCE. After this the climate became more arid with fewer major fluctuations (Bar-Matthews and Kaufman, 1998; Bar-Matthews and Ayalon, 2011). Additionally, Dead Sea and Lake Tiberias levels were generally high in the third millennium BCE, dropping towards the end of that period (see summary in Robinson et al., 2006, Fig. 5). The Jeita (Lebanon) stable isotopic record, in contrast, suggests drier conditions between 3800 BCE and 900 CE, interrupted by a somewhat moister phase between 2000 and 1000 BCE. The contradiction of the results with most other data from the region may have been caused by the rather low time resolution in the Jeita data (Verheyden et al., 2008). The analysis of several marine and terrestrial climate proxies shows that the period between 4600 and 4200 BP (and especially the time slice between 4400 and 4300 BP) has a peak in frequency of rainfall minima in the data (Clarke et al., 2016) to which people may have needed to adapt, e.g. by irrigation in the case of olive.

Under natural circumstances, one would expect smaller olives at Khirbet-ez Zeraqon than at Fadous-Kfarabida, but in fact the opposite is true. This may be because of additional irrigation at Khirbet-ez Zeraqon. There is some circumstantial evidence for irrigation at the latter site: stable carbon isotopic measurements on barley from Khirbet-ez Zeraqon indicate a slight water stress in some of the grains during the EB II-III, while at the same time the standard deviations were higher compared to other sites in less arid regions (up to 3.3‰ at Khirbet-ez Zeraqon compared to less than 2.25‰ at Fadous-Kfarabida), suggestive of variability in moisture conditions, perhaps caused by some additional artificial water supply for some of the barley fields (Riehl et al., 2008). Related variability in moisture availability may have affected the olives there. Stable carbon isotopic results on 10 barley grains from the Early EB III (Phase III) in Fadous-Kfarabida show no indication for drought stress (Riehl et al., 2014). Compared to Khirbet-ez Zeraqon, the region around Fadous-Kfarabida receives considerably more rain, so irrigation was likely not practiced. It is therefore also striking that the Fadous-Kfarabida olives show a greater variance in stone length.

While a part of the Khirbet-ez Zeraqon olive variance of measurements may be explained by differing water conditions for different olive plants, it may also relate to the presence of several cultivar varieties and hint at specialization and diversification. The stone measurement variance results of the present-day 31 Iranian olive genotypes show a similar high value as the stones from Khirbet-ez Zeraqon and Fadous-Kfarabida (Jalali et al., 2014). The diversification and maintenance of different olive varieties in the ancient world is visible at a 1st to 4th Century CE site in Spain, where detailed olive stone morphometry results (analysis of the shape of the whole olive stone rather than simply the maximal length and width) were compared with present-day morphotypes. This technique showed the presence of an "amazing diversity of olive varieties" (Bourgeon et al., 2018). Domesticated, wild and hybrid wild-domestic types were detected at the site. The most prevalent olive stone morphotype at the site was originally probably imported from the Central or Eastern Mediterranean, while another one that was less prevalent also has an eastern source. While they were probably locally bred at that time in Spain, the olive stone shape varieties testify for intensive contacts with other regions (Bourgeon et al., 2018) and show the conscious choice of grove owners to use a high variety of olives to protect their olive production against climatic risks and pests (Bourgeon et al., 2018). At Late Bronze Age Ugarit, similar detailed shape analysis of olive stones also indicates the use of seven different olive varieties, including also wild or feral (Newton et al., 2014).

6. Conclusion

While there is a growing body of evidence that olive cultivation started in the 5th millennium BCE, the scale of olive cultivation in the Levant appears to have increased during the EB. This may have been connected to wider transformations related to growing socio-economic complexity in the area over this period. More precisely, specialised production has been linked with economic expansion and specialisation in other areas (such as pottery) (Badreshany et al., 2019).

The occurrence of olive wood and stones at Khirbet-ez Zeraqon - in a region that was not within the wild olive distribution - indicates that domesticated olive trees were the subject of intentional cultivation during the EB II–III, but without using more sophisticated technologies such as grafting of domesticated species with wild plants. Several other factors better explain the high variance of the olive stone lengths there, including specialization by using several cultivars and/or applying irrigation and/or fluctuations in rainfall, as supported by stable carbon isotope data on barley grains from the site. Although olive was likely not the dominant food plant at the site in terms of macro-nutrient supply, its importance is evident from the distribution throughout diverse types of private and public contexts.

While olive was native to the central Levantine zone, the increase in olive charcoal there, as at Fadous-Kfarabida, suggests the practice of pruning of olive trees, implying cultivation as well. The small mean in length of the stones from Fadous-Kfarabida and the high variance of stones may indicate that wild olives were included in the production as well, since water stress was not observed for the cereals so far. Compared to the local conditions at Khirbet-ez Zeraqon, Fadous-Kfarabida is located in an area of long-term olive cultivation with abundant availability of wild olives. We might speculate that these two conditions would result in more experimentation, such as developing different olive strains.

Although an overall linear trend can be detected for olive domestication for the southern Levant, with an increasing mean length for olive stones between 7 and 2 kyr BP, the EB measurement data from Fadous-Kfarabida and Khirbet-ez Zeraqon are outside the confidence band of the linear regression. Hence, the “domestication syndrome” is not always recognizable due to a high variance, possibly related to the high micro-climatic and cultural diversity of the Levantine region. For example, new breeds may have been introduced from wild populations depending on their geographic availability and economic goals. Hence, our results indicate different local practices in cultivation and domestication.

Based on our and other data in the Mediterranean, it is likely that already by the EB different olive varieties were in use. Hence, the variance needs to be treated with caution because lots of other factors may be involved.

7. Future work

Future work will be aimed at, on the one hand, deepening the chronological and contextual resolution of the archaeobotanical evidence of Tell Fadous-Kfarabida and Khirbet-ez Zeraqon and, on the other hand, extending the comparative datasets to other sites in the area. Moreover, the incorporation of further evidence (e.g. stable isotopes analyses, dendrological measurements, pollen data, material culture, settlement pattern, etc.) is planned in order to address the topic by means of a multi-variated approach.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2021.102841.

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