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ORIGINAL ARTICLE

Bronze Age olive domestication in the north Jordan valley: new morphological evidence for regional complexity in early arboricultural practice from Pella in Jordan

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Abstract Recent research from the site of Pella in Jordan examines the process and timing of olive cultivation. The frequent presence of olive remains from the Pottery Neolithic, beginning in the Yarmoukian, suggests that exploitation of the olive dates from as early as c. 6200 cal BCE, with evidence of oil pressing from at least c. 5200 cal BCE. Morphometric data, spanning the Late Neolithic to the Middle Iron Age II, using the measurement of olive endocarp length and width, demonstrates a reduction in the size variation of olive endocarps through time, in addition to an increase in their length, likely the result of selection pressure on trees. At Pella, this change occurs sometime after the Chalcolithic and before the Late Bronze Age, probably post-dating the earliest phases of the Early Bronze Age. Domestication is thus later than Teleilat Ghassul (Jordan), which has the earliest morphological evidence for olive domestication, and suggests that olive domestication was a regionally and temporally diverse process.

Keywords Late Neolithic · Chalcolithic · Bronze Age · Iron Age · Morphometrics · Yarmoukian

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Introduction

Olive (*Olea europaea* ssp. *europaea* L.) is one of the world's most significant tree crops and has long been the symbol of the Mediterranean (Horden and Purcell 2012, p. 209), a region that still produces >90% of the 2–3 billion tonne per annum harvest (International Olive Council 2015). While today's economic production is dominated by the western Mediterranean, especially Spain, archaeological and genetic evidence both suggest that it was in the Levant in the eastern Mediterranean that olives were first domesticated (Zohary et al. 2012; Kaniewski et al. 2012; Besnard et al. 2013), though western and central Mediterranean centres of domestication have also been proposed (Terral et al. 2004; Diez et al. 2015). Within the natural distribution of the plastid E1 lineage of wild olives (*Olea europaea* ssp. *sylvestris*) from which domesticated olive was largely developed, genetic evidence suggests a northern centre of primary domestication in the Levant, on the Syrian/Turkish border (Besnard et al. 2013; Besnard and Rubio de Casas 2016), while archaeological evidence is more consistent with a southern origin in the hills around the Jordan Valley (Zohary et al. 2012).

While recent genetic advances have greatly improved the empirical understanding of the domestication process of olive, there remains much uncertainty about the specific timing of intensifying human management practices. In part, such understanding is complicated by the propensity of domestic olive varieties to interbreed freely with each other and wild olives. This means that distinguishing domestic populations is extremely difficult, and there is considerable scope for parallel and differing domestication histories in areas within and outside the regions in which wild olive is native. Also, a paucity of long-term archaeological studies leaves many local and regional domestication histories understudied. As recent discussions have concluded, all propositions concerning the domestication of olive at present constitute testable hypotheses or speculations, and require further evidence from all sources to be tested, verified or falsified (see discussion by Besnard and Rubio de Casas 2016; Diez and Gaut 2016).

While some finds of olive stones from the 7th–8th millennium cal BCE have been found in Mersin-Yumuktepe in Turkey, close to a possible northern Levantine centre of origin (Fiorentino et al. 2014), the putative southern Levant region of domestication has by far the richest and longest archaeological evidence for human exploitation of olive (see summaries by Zohary et al. 2012; Kaniewski et al. 2012). Olive wood was collected for fuel from as early as 790 ka BP at Gesher Benot Ya'aqov (Goren-Inbar et al. 2004), with evidence of possible fruit exploitation at Ohalo II at 19,000 BP (Kislev et al. 1992), though the most convincing early evidence for olive gathering comes from several Late Neolithic submerged sites on the Carmel Coast of Israel (Zohary et al. 2012, p. 120). One of these sites, the Neolithic and Chalcolithic site of Kfar Samir demonstrated evidence for olive oil processing, including thousands of olive stones, oil processing debris and equipment (Galili et al. 1997). Morphometric analysis of the olive stones showed that the stones were from wild populations rather than domestic species that have lower variability in their olive stone dimensions (Kislev 1994). Dating to the same period, there is also evidence for large-scale olive exploitation for oil from Ein Zippori in northern Israel, where residue analysis has identified olive oil use in pots dating to the 5th and 6th millennia BCE (Namdar et al. 2015). This evidence suggests that oil extraction was well established in the natural homeland of wild olives west of the Jordan River by the late 6th millennium cal BCE. Evidence for the antiquity of olive cultivation and domestication is less clear. Olive pollen fluctuates from the beginning of the Natufian period (Yasuda et al. 2000) and increasing levels have led to claims of olive cultivation in the Pottery Neolithic (Rosen 2007, p. 84), though the strongest pollen evidence is from the Ein Gedi Core in the Dead Sea where a trend towards increasing olive pollen at the end of the Pottery Neolithic becomes a significant increase only at the beginning of the Chalcolithic (Litt et al. 2012).

Cultivation was claimed in the region several decades ago at Teleilat Ghassul in the south Jordan valley (Zohary and Spiegel-Roy 1975), based on the presence of olive stones which, it was argued, could not have come from local, naturally-occurring trees, as Teleilat Ghassul is considered to have been located outside, or marginal to, the natural distribution range of olive trees (Meadows 2005, p. 241; Weiss 2015, p. 76). While a Chalcolithic date for olive domestication has been questioned (Liphschitz et al. 1991), further research on olive stones and wood charcoal from Teleilat Ghassul has led to consensus that these were the products of locally cultivated trees (Neef 1990, p. 297; Meadows 2005, p. 238; Weiss 2015, p. 76). Assemblages from Teleilat Ghassul demonstrate a significant decrease in variation in olive stone size from the Late Chalcolithic (Meadows 2005), with an earliest date estimated to fall around 4400–4300 cal BCE (Bourke et al. 2004a, b). This predates similar evidence further north at El-Khawarij by 100–200 years (Meadows 2005, Appendix F; Lovell et al. 2010). Other regional sites also demonstrate evidence for olive exploitation during the Chalcolithic period (see Lovell et al. 2010). Though lacking metric data, artefactual and archaeobotanical data from the Golan also suggest cultivation and olive oil extraction at this time (Epstein 1993).

Several hypotheses have been developed to account for the demonstrated reduction in size variation in olive stones at Kfar Samir and Teleilat Ghassul. Kislev (1994, p. 137) states that cloning of the best olive genotypes via vegetative propagation and grafting of olive trees results in a dramatic reduction in the variation of measured attributes. Meadows (2005, p. 240) suggested that the reduction in variance in olive stone lengths at Teleilat Ghassul may be the result of the more restricted growing conditions of cultivated olive trees, in addition to a "loss of genetic diversity" that may be associated with olive tree cultivation. A loss of genetic diversity may have resulted from the instigation of both transplanting of cuttings and grafting of trees.

While the archaeological results from Teleilat Ghassul are not consistent with the earliest domestication proposed by recent genetic modelling (Besnard et al. 2013), they remain the earliest known explicit archaeobotanical evidence for domestication yet produced, and suggest domestication was developed after one or more thousand years of intensive exploitation in the region. What is clear is that olive went on to become a major crop in the Bronze Age, and its oil a major trade commodity underpinning the economies of local communities, and potentially, regional states (Genz 2003; Lovell 2008; Salavert 2008).

While archaeobotanical and genetic studies have provided an outline history of olive domestication, much remains uncertain and further archaeological studies are required to test existing observations. This paper presents new long-term data for olive exploitation from the site of Pella in Jordan, located on the eastern side of the north Jordan Valley. It aims to trace the history of olive exploitation at the site from the Pottery Neolithic to the Middle Iron Age II (6200–800 BCE), and evaluate when olive exploitation and cultivation first emerged there. Of specific interest is determining whether there is evidence for olive domestication in the Chalcolithic, comparable to that from Teleilat Ghassul, in the south of the Jordan Valley.

Materials and methods

The archaeology of Pella in Jordan

The archaeological site of Pella is situated in the eastern foothills of the north Jordan Valley, 5 km east of the Jordan River and approximately 30 km south of Lake Kinneret (Smith 1973; see Fig. 1). The main tell of Pella (Khirbet Fahl) is an 8 ha, sub-rectangular, largely artificial mound rising around 30 m above the current valley floor of the adjacent Wadi Jirm. Earliest occupation at the base of the main tell of Khirbet Fahl dates from the early Late Neolithic period (ca. 6200–6000 BCE), and probably consisted of a small village community with a population of up to 300 people (Bourke et al. 2004b; Bourke 2007). There is strong evidence for occupational continuity from the later Late Neolithic into the Early Chalcolithic period (ca. 4900–4500 BCE). Between the Late Chalcolithic phases (ca. 4500–4000 BCE) and Early Bronze Age horizons at the site (ca. 3500–2800 BCE) there is a gap in occupation on the main tell of approximately 500 years. Although only fragmentary remains of the Early Bronze Age re-settlement strata have been found to date on the main mound, due mainly to disturbance by later building activities, there was sufficient evidence to suggest a densely-packed settlement (Bourke 2000, pp. 233–235). After a further approximately 500-year gap in occupation spanning the later Early Bronze Age, the second millennium BCE strata of the Middle and Late Bronze Age date featured massive mud-brick fortification walls and a large rectilinear stone-built fortress temple, which remained in use until the entire site was destroyed at the end of the Bronze Age around 1150 BCE (Bourke et al. 2006; Bourke 2012, pp. 182–184). The settlement was re-occupied, and the temple rebuilt in the Iron Age (ca. 1100–800 BCE); a major new civic/administrative complex dominates the central tell area west of the temple (Bourke 2005, pp. 117–118). Iron Age occupation was brought to a halt by a second site-wide destruction event around 800 BCE. Thereafter, occupation was intermittent until the major Hellenistic period re-settlement subsequent to Alexander's conquest of the region. Pella displays extensive Classical and Late Antique period occupational strata, for which the site is more generally known (McNicoll et al. 1992, pp. 103–197).

Two off-tell excavation areas are relevant to this discussion (see Fig. 2 for locations). The first of these lies on the lower north-western slopes of Jebel Sartaba (Area XIV), around 1 km SE of the main mound, and the other is on the eastern summit of nearby Tell Husn (Area XXXIV), 500 m across the Wadi Jirm from the main mound of Khirbet Fahl. In Area XIV on Jebel Sartaba, an isolated farmstead dating to the Late Chalcolithic period (c. 4000 BCE) was excavated between 1981 and 1983 (McNicoll et al. 1992, p. 31; Bourke 1997). The Husn summit excavations (Area XXXIV) form the major focus of Early Bronze Age explorations at Pella, as here Early Bronze Age strata are extensive and relatively close to the surface (Bourke et al. 1999; Gibbins 2008; Bourke 2014, 2016). Inside a complex of massive stone and mud-brick fortification walls, a network of paved streets and courtyards, storage areas and domestic structures have been uncovered (Gibbins 2008).

Pella is situated in the ecotone between the Mediterranean vegetation of the Jordan Valley floor and the Irano-Turanian steppe, itself transitional to the more desertic regions to the east (Cordova 2007, p. 102; McNicoll et al. 1992, p. 14). It is unclear whether naturally-occurring wild

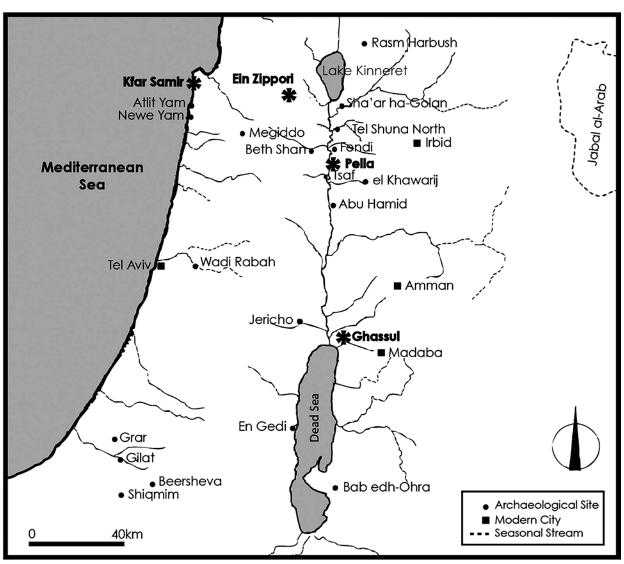

Fig. 1 Regional map showing sites discussed in the text

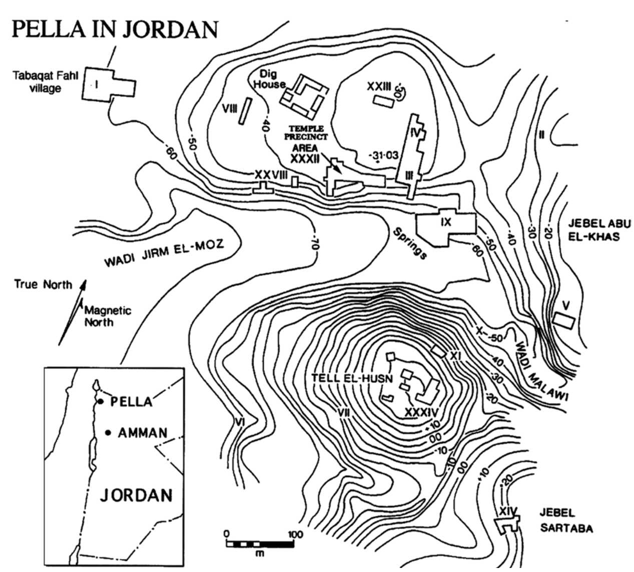

Fig. 2 Pella excavation areas mentioned in text

olive trees were present in in the Pella environs in prehistory as it is not in the current distribution zone of wild olive (Zohary et al. 2012). Interestingly, a range of archaeological evidence suggests Pella saw considerable interaction with the olive from early in its occupation, including provisional archaeobotanical analysis from a Late Chalcolithic farmstead on Jebel Sartaba, identified as a specialised activity area for olive processing (Willcox 1992, p. 255), and storage facilities on Tell Husn potentially used for oil storage (Bourke 2014). Given this evidence and a long occupation history (Smith 1973; McNicoll et al. 1992; Bourke 2005, 2011, 2016), Pella provides a suitable place to investigate the timing and process of early human use of olive within one of the putative hearths of olive domestication.

Field and laboratory methods

The aim of this analysis was to investigate the evidence for the timing of olive exploitation at Pella, and using the method developed by Kislev (1994) and Meadows (2005), to establish whether the change and variation in olive size over time followed the same pattern as at Teleilat Ghassul, where decreased variation in the Late Chalcolithic signals the first morphological sign of domestication (Meadows 2005). Olive stones from Tell Husn (Area XXXIV) and Khirbet Fahl (Area XXXII) were analysed for the study, recovered over the last 12 field seasons (1994 onwards) using machine flotation of soil samples (Meadows 2005).

The presence and abundance of olives was established through an initial laboratory survey using low-powered microscopy to identify samples containing whole and fragmented olives. Specimens were grouped by archaeological period, dated on the basis of the associated artefacts (predominantly ceramics) in their depositional contexts, with some contexts dated directly through radiocarbon analysis drawn from short-life botanical samples (Table 1) (Bourke et al. 2004b).

Following earlier work (Kislev 1994; Meadows 2005), maximum length and width, the main metrics used to evaluate changing size and size variation, were measured on whole olive stones recovered from the Pella assemblage using digital Vernier callipers. Kruskal–Wallis tests were carried out to determine whether median lengths and widths differed across assemblages. Mann–Whitney pairwise tests were then conducted to determine which phased assemblage may have been driving any demonstrated change. F tests were carried out to determine how the variance of both variables differed through time.

Results

Charred olive endocarp (Fig. 3) remains were present in 94 of 277 samples (33.9%) from Pella (Table 2), being present in all archaeological periods from the Early Neolithic onwards. The majority of Neolithic contexts contained olive remains, these being present in 93.21% of Early Neolithic and 81.25% of Late Neolithic contexts as fragmented or whole olive stones. One Late Neolithic pit context (32G 509.1) contained 784 olive stone fragments (Fig. 3b), in addition to the four complete stones. Many fragments lacked the sharp edges of post-depositional breaks (Fig. 4) indicative of having been broken prior to charring, suggesting that they are derived from *jift*, the by-product of olive oil processing consisting of broken olive stones, which is known to be used as a supplementary fuel (Margaritis and Jones 2008; Neef 1990; though note observations by; Braadbaart et al. 2016).

The proportion of contexts containing olive remains changed dramatically through the excavated sequence, being lower in all phases subsequent to the Neolithic. Values ranged between 30 and 50% in the Chalcolithic (48%), Late Bronze Age (47%) and Iron Ages (36%)—with much lower values in the Early (6%) and Middle Bronze Age

Table 1 Pella phasing and associated relative and absolute dates (Bourke et al. 2004b)

Phase	Area excavated	Sample code	AMS result	Age (ca. cal BC)
Early Ceramic Neolithic/Yarmoukian-Lodian	Area XXXII 5×5 m	OZD 017 OZD 015	7,215±85 7,040±70	6300–5800
Late Ceramic Neolithic/'Ziqlabian'	Area IV/XXXII 5×20 m	OZD 019 OZD 016	5,935±95 5,870±65	5100–4700
Early Chalcolithic/'Tsafian'	Area XXVIII/XXXII 5×30 m	OZD 020 OZD 022 OZD 018 OZD 021 OZG 609	5,745±65 5,730±85 5,725±85 5,655±90 5,590±50	4700–4300
Late Chalcolithic/'Sartaban'	Area XIV/XXXIV 5×60 m	SUA 2391 OZJ 221 OZJ 220 OZM 239	5,430±60 5,330±70 5,300±60 5,200±45	4100–3900

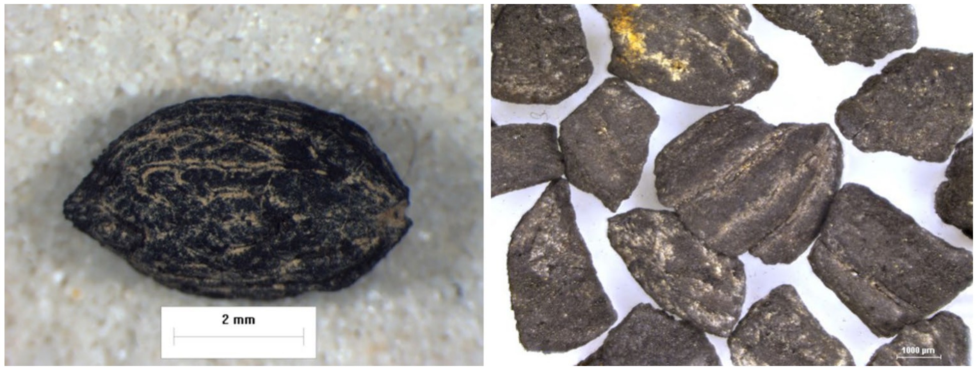

Fig. 3 Olive stone from Late Neolithic Pella (*left*) and olive fragments from a Late Neolithic phase pit (32G 509.1, *right*)

Table 2 Summary of data on the Pella olive stone assemblages

	Contexts examined	Contexts containing olive	% contexts containing olive	Whole olive stones	Mean/median length (mm)	Mean/median width (mm)	Variance (length)	Variance (width)
Pottery Neolithic (Early)	13	12	92.31	0	–	–	–	–
Pottery Neolithic (Late)	16	13	81.25	32	9.17/8.94	5.73/5.84	2.5	0.57
Chalcolithic	50	24	48	34	9.42/9.27	5.69/5.57	2.18	0.57
Early Bronze Age	31	2	6.45	5	9.5/9.81	6.34/6.18	1.3	0.37
Middle Bronze Age	66	1	1.52	1	8.99	5.29	–	–
Late Bronze Age	51	24	47.06	41	10.72/10.67	6.12/6.03	0.98	0.28
Iron Age	50	18	36	171	10.78/10.82	6.26/6.23	1.2	0.28
Total	277	94	33.9%	284	–	–	–	–

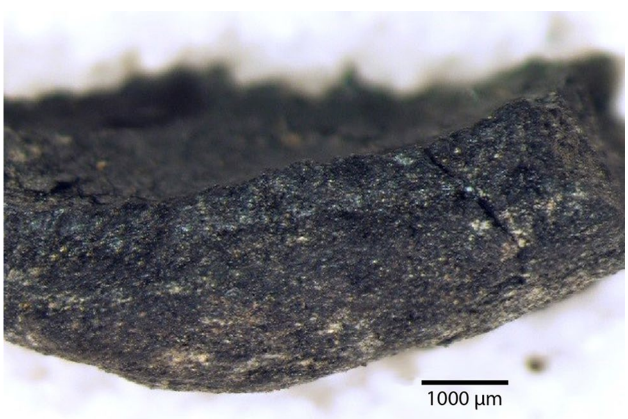

Fig. 4 Fracture face of probable *jift* fragment (Area XXXIIG Locus Level 509.1)

(2%) levels. This may be a result of changing spatial organisation at the site, combined with a thoroughgoing destruction of some horizons by later activity, as when a major phase of Middle Bronze Age building activity removed much of the underlying Early Bronze Age deposits (see discussion below).

A total of 284 whole, measurable olive stones were recovered, representing all excavated phases except the Early Neolithic, and four of the six phases (namely Late Neolithic, Chalcolithic, Late Bronze Age and Iron Age) provided sufficiently large samples to allow a robust analysis of diachronic olive exploitation at the site (Table 2). Comparative percentage distributions of length and width data from these phases showed that the length distribution of the whole olive stones is bi-modal (Fig. 5a). The first peak groups the Neolithic and Chalcolithic assemblages, with most lengths falling between 8 and 9 mm. The second peak links the Late Bronze Age and Iron Age assemblages, with larger overall lengths falling between 10 and 11 mm. In contrast, differences in width distributions are less patterned, with the Iron Age having the widest stones (Fig. 5b). The small sample size of the Early Bronze Age assemblage ($n = 5$) precludes secure visual interpretation of the pattern illustrated in Fig. 5, but the statistical treatment provided below is more informative.

Kruskal–Wallis tests demonstrated that there were significant differences in median lengths and widths for all periods assessed (length: $p < 0.001$; width: $p < 0.001$). In terms of length, Mann Whitney pairwise comparisons show that this is driven by higher median values for the Late Bronze and Iron Ages (Table 3a, b). These are similar to each other, but differ significantly from the Late Neolithic and Chalcolithic periods. They are also significantly

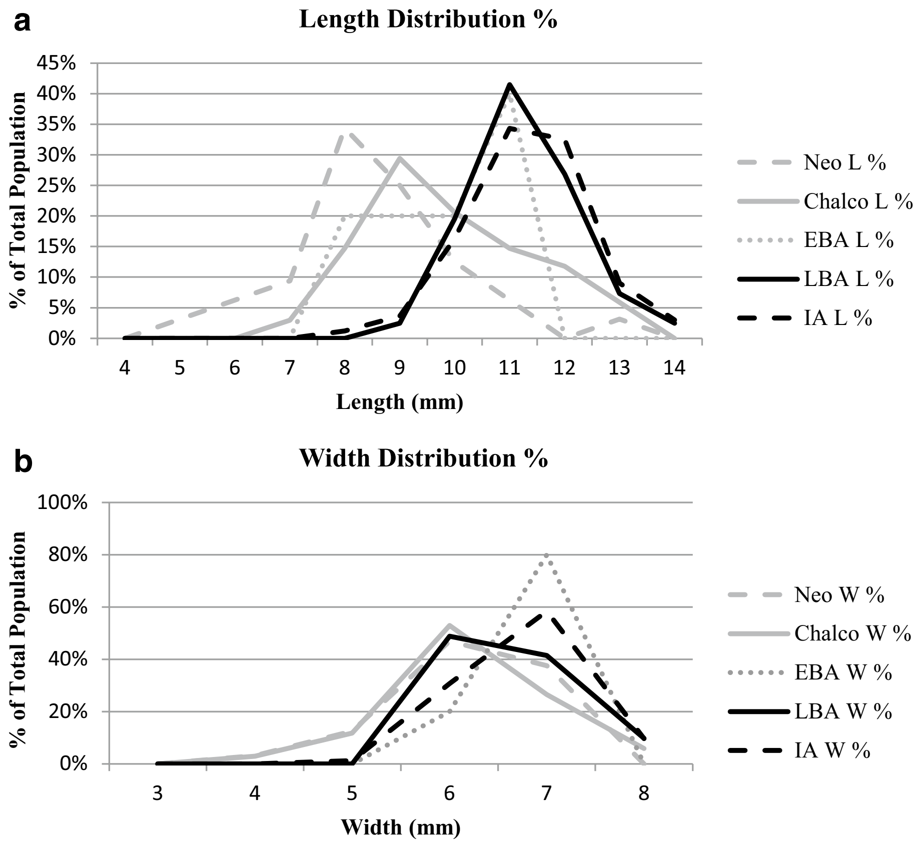

Fig. 5 **a** Length, **b** width distributions for olive stone dimensions (mm) across all phases

Table 3 p values for Mann Whitney pairwise tests for median endocarp length (a), width (b) by period at Pella

	Late Neolithic	Chalcolithic	EBA	LBA	Iron Age
a					
Late Neolithic		0.608	0.464	0.001	0.001
Chalcolithic			0.785	0.001	0.001
EBA				0.061	0.046
LBA					0.469
Iron Age					
b					
Late Neolithic		0.457	0.059	0.068	<0.001
Chalcolithic			0.030	0.004	<0.001
EBA				0.244	0.722
LBA					0.047
Iron Age					

longer (or nearly so) compared to the Early Bronze Age period. As demonstrated with the percentage distributions above (Fig. 5), patterning is less clear in the width analysis. Mann Whitney pairwise comparisons demonstrate that the significant difference in median widths across the phases is again driven largely by the Late Bronze and Iron Ages. These assemblages are significantly larger (or nearly so) compared to those of the Late Neolithic and Chalcolithic. In contrast to length, there is no significant difference in median width between the Early Bronze Age and the two later phases, but there is a significant difference with the Chalcolithic and nearly so with the Late Neolithic. The median width of the Chalcolithic differs significantly from all three later phases, and as with length, does not differ from the Late Neolithic phase.

The analysis of length and width metrics indicated that the sample set could be split into two broad groups: the Neolithic and Chalcolithic samples were similar to each other and differed from the Late Bronze Age and Iron Age samples, whose olives were much longer and generally wider. Clearly there were major changes in olive stone morphology between the Chalcolithic and Late Bronze Ages. While the Early Bronze Age sample is small, demanding a cautious interpretation, these analyses suggest that widths are larger than in the preceding phases whereas the lengths are smaller than in the later phases.

The increase in median length and width diachronically is accompanied by a significant reduction in the variation of the olive endocarp length and width diachronically. When the Late Neolithic and Chalcolithic samples are aggregated and compared to the aggregated Late Bronze and

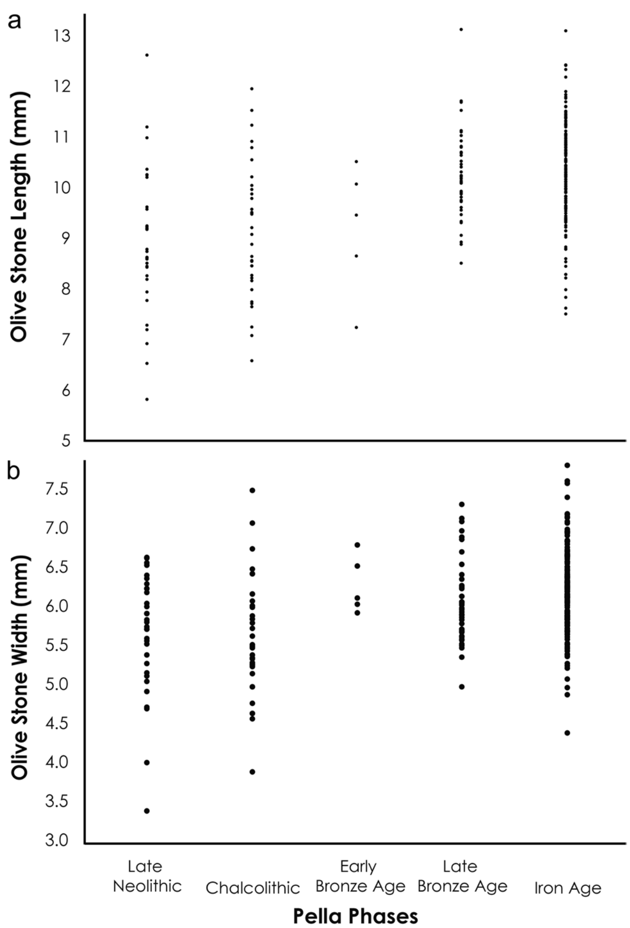

Fig. 6 Olive stone, **a** length, **b** width variations across all phases at Pella

Iron Age samples, there is a significant reduction in variation between the earlier and later periods (length $F=2.002$, $p<0.001$; width $F=2.118$, $p<0.001$). The Early Bronze Age sample is excluded from this analysis, given that different patterns are suggested for length (different to succeeding phases) and width (different to preceding phases). Because of its small sample size, however, inclusion in either of the two aggregates does not change the outcome of the analysis. Figure 6 below demonstrates the increasing uniformity of olive stone length through time, accompanied by an increase in the overall length.

The Chalcolithic sample was initially analysed as a single group, showing no statistical difference with the Late Neolithic samples (Table 3). To further investigate comparisons with Teleilat Ghassul during what is a broadly contemporary time period, the assemblage was split into Early Chalcolithic ($n=10$) and Late Chalcolithic ($n=24$) samples. The initial patterning is maintained with Kruskal–Wallis and F tests demonstrating that there was no significant difference between the samples from the Early Chalcolithic and the Late Chalcolithic phases (length $p=0.791$; width $p=0.748$; length variance $F=1.403$, $p=0.616$; width variance $F=2.428$, $p=0.083$).

Discussion

Research presented here demonstrates that olive fruits were exploited at Pella from c. 6200 cal BCE into the Iron Age and well beyond (Willcox 1992), being preserved in every sampled cultural level. The presence of olive remains in the majority of samples from the Yarmoukian (Early Pottery Neolithic) contexts suggests that exploitation occurred in that period, and constitutes the earliest evidence for olive exploitation in the southern Levant. Further, one sample (Area 32G 509.1) from the Late Pottery Neolithic horizon at Pella contains possible evidence for *jift* (the remains left over from olive fruit pressings) which suggests oil production. While the reliability of using rounded breakage surfaces to argue for the presence of pre-charring oil extraction has been questioned (Braadbaart et al. 2016), the common presence of fragments in the Neolithic and the large quantities in context 509.1 are both consistent with its presence (Braadbaart et al. 2016, p. 427). If this is the case, these stones and fragments constitute the first archaeobotanical evidence for olive oil processing at Pella and among some of the earliest in the world.

The continued presence of olive through the Chalcolithic, Bronze and Iron Age occupations suggests that the fruit was of ongoing economic importance through the ages. The significance of the lower incidence of olive remains in the Early and Middle Bronze Age phases most likely reflects assemblage formation processes and should not be taken to be a simple indicator of relative economic significance or of a break in occupation at the site. The Middle and Late Bronze Age sequence at Pella is among the most complete in the Jordan Valley. The 5 m thick Middle Bronze Age sequence has produced more than 20 ^{14}C dates, which document occupation beginning at c. 2000 cal BCE, with the sequence continuing throughout the Middle and Late Bronze Ages, without any observable breaks.

Among possible influences for the low incidence of olive in the Early and Middle Bronze Age phases are differing formation processes affecting the excavated deposits during these periods. The Early Bronze Age contexts have been severely impacted by the construction activity of the later Middle Bronze fortress temple. The religious precincts of this temple were kept scrupulously clean and were unlikely to accumulate rubbish from olive processing and consumption (Bourke 2012, pp. 169–170). The low incidence of olive in these phases also may reflect changing use of civic space over time, perhaps indicating the processing of olive in the Neolithic in domestic structures, with later processing off-site, where olive presses are increasingly common features of the rural landscape. Further analysis is required to understand this pattern.

A clearer pattern of change is identified in the metric data. Firstly, there was a statistically significant increase in the length and width of the olive stones diachronically at some time after the Chalcolithic and before the Late Bronze Age, with no significant difference demonstrated between the Late Neolithic and Chalcolithic occupation phases. While the sample is small, the Early Bronze Age assemblage provides some direct evidence to help resolve when the transformation took place. Those data present a contrasting picture; lengths align with the earlier phases at the site, but widths align with the later phases (Fig. 6), suggesting that various aspects of size change occurred both during and after the earliest phases of the Early Bronze Age and before the Late Bronze Age. Caution must be expressed here as the Early Bronze Age assemblage is very small and further samples are required to evaluate its veracity.

Across the sequence, the increase in size went in tandem with a statistically significant reduction in the variation of olive stone size between the earlier (Neolithic and Chalcolithic) and later (Bronze and Iron Age) phases, though there was no significant difference in variation between the Late Neolithic and Chalcolithic phases, or within the Chalcolithic (Early vs Late) phases. Increasing size and uniformity in olive stone metrics are considered to be two morphological indicators of domestication, signifying selection for larger fruit and, via use of vegetative propagation, reducing phenotypic variability in populations. Pella gives strong evidence that the cultivation of domesticated forms post-dated the Chalcolithic and predated the Late Bronze Age.

Thus, the pattern of change at Pella post-dates that seen in the south Jordan Valley at Teleilat Ghassul, where a statistically significant reduction in size variation occurred between the Early and Late Chalcolithic (Table 4; Fig. 7), currently the earliest known archaeobotanical evidence for olive domestication (Meadows 2005, p. 239).

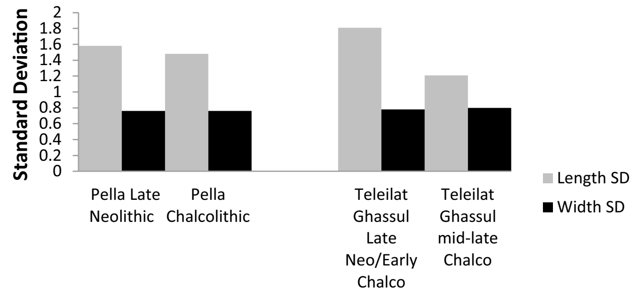

Fig. 7 Comparison of standard deviations of Pella and Teleilat Ghassul phases

The Pella evidence suggests a much later emergence of olive domestication and signifies regional variation in the history of selection and domestication of olive with the population of Pella in the earliest phases at the site exploiting the fruits while seemingly not undertaking artificial selection of the trees that produced them. Several explanations for this phenomenon are possible. Initial analysis of a small sample of the wood charcoal from Neolithic and Chalcolithic levels at Pella has indicated the presence of burnt olive wood at the site (Dighton 2011), suggesting that trees were locally available for use as fuel, implying that the fruit was not supplied from a source or sources elsewhere. If locally available, the Neolithic population may simply have been exploiting naturally occurring and regenerating wild stands of olive trees found on the hills around Pella. Several authorities consider Pella to be outside the natural distribution of wild olive (Zohary and Spiegel-Roy 1975; Lavee and Zohary 2011; Zohary et al. 2012). Modern wild olive tree stands are reported from the valleys of the Ajlun Mountains on the east side of the north Jordan Valley (Cordova 2007, p. 74; Neef 1990, p. 297), which suggests the possibility that wild olive trees may have formed a constituent part of the original Mediterranean woodland

Table 4 Pella and Teleilat Ghassul (after Meadows 2005, p. 378) olive stone assemblage summary data

Phase	Late Neolithic	Chalcolithic (total sample)	Early Chalcolithic	Late Chalcolithic	Late Neolithic—Middle Chalcolithic	Late—very Late Chalcolithic
Pella						
L/W mean (mm)	9.17/5.3	9.42/5.68	9.53/5.75	9.38/5.66		
L/W, St Dev	1.58/0.76	1.48/0.76	1.32/1.01	1.56/0.65		
L/W, variance	2.50/0.57	2.18/0.57	1.74/1.02	2.44/0.42		
Teleilat Ghassul						
L/W mean (mm)					9.73/5.78	8.99/5.57
L/W, St Dev					1.81/0.78	1.21/0.80
L/W, variance					3.29/0.60	1.46/0.64

in the Pella region, though there is some disagreement over whether these olive stands are genuinely wild or feral (Cordova 2007, p. 74). Regional climatic reconstructions suggest that the early Holocene saw increased precipitation levels from the preceding periods (Rosen 2007) and it is possible that Pella was an early location into which olive spread from refugia elsewhere at the end of the last glacial period. Pollen evidence from Hula supports expansion of olive at around c. 6200 cal BC (Rosen 2007, p. 84). If correct, this suggests that the Neolithic population of Pella may simply have been utilising a newly available resource.

Late Chalcolithic archaeological evidence of an olive processing facility on Jebel Sartaba at Pella (Willcox 1992; Bourke 1997, 2007) suggests intensification of olive exploitation in this period, but the archaeobotanical evidence presented here does not support the presence of human selection of tree stocks in this period. The evidence is thus similar to that from Kfar Samir on the Carmel Coast where intensive olive oil production was based on the exploitation of wild trees (Galili et al. 1997). Several alternative management scenarios are also possible that would produce the observed pattern. Rather than using vegetative propagation, the stands of olive may have been simply replenished/extended by planting seed, which would have maintained genetic diversity and swamped any early attempts at selection, making its archaeological identification more difficult. This contrasts with the situation in the drier southern Jordan Valley, where there may have been fewer available stands of wild trees meaning that the selection of desirable cultivars in populations may have been more successful and more immediately visible at Teleilat Ghassul (Meadows 2005).

While these management scenarios may explain the Pella evidence, it remains possible that there was no dramatic change in either olive exploitation or tree management practices at Pella in the Late Neolithic–Chalcolithic periods. If the wild trees in the Pella environs provided an abundant source of fruit there may have been no driver for intensive management of the trees and their selection. Furthermore, gradual removal of competing, less productive trees may have occurred as part of generic forestry practices which could have promoted a very gradual increase in the wild olive tree population and available fruit, rather than sudden and intensive management. This stands in contrast to Teleilat Ghassul, the location of which may have favoured early olive cultivation initiatives (grove creation with transplanted selections), as there was more motivation to "protect and propagate valuable wild olive trees" (Meadows 2005, p. 242). At Pella, minimal tree management (i.e. gathering and pruning) may not have had sufficient impact to cause drastic phenotypic change in the form of a reduction in olive stone size variation, thereby delaying the signal for morphological domestication of olive trees until much later than at Teleilat Ghassul. Recent discussions have questioned the search for simple, rapid domestication histories focusing on single centres of origin for crops in southwest Asia. Rather than looking for single centres of origin from which crops were domesticated and from which they spread, annual crops are now thought to have developed over several thousand years in a widely dispersed region connected by trade and other socially mediated relationships (see Fuller et al. 2011; Asouti and Fuller 2013). The Pella evidence suggests that, much like annual seed crops, domestication of the olive could have had a lengthy period of development. The demonstrated morphological change in the olive endocarps post-Chalcolithic and pre-Late Bronze Age at Pella suggest a significant change in economic practices for which several scenarios may be considered in interpreting these changes. The significant change that occurred in the size and size variation of the olive endocarps occurred at a time when the settlement patterns of Pella were changing, possibly as a result of population increase. Such change could have been accompanied by a concomitant clearance of the forests in the Pella environs, possibly for grove creation, which would have provided a level of management of olive trees in the environs such that the phenotypic change in the olive population became visible archaeologically. It is also possible that these events were accompanied by the introduction of new, domesticated forms of olive. Earlier domestication events have been claimed in both the northern and southern Levant (Meadows 2005; Besnard et al. 2013) and the late introduction of domestic stocks and management techniques provides one possible explanation for the observed patterns in the Pella olive assemblage. The introduction of new cultivars to the region may have formed part of a long, stepwise process that led to the uptake of widespread olive cultivation with domesticated populations, in this case as part of the development of a commodity-driven economy. Clearly the morphometric evidence for olive exploitation at Pella requires strengthening through further sampling of the Bronze Age horizons. However current archaeological evidence suggests that local factors may have outweighed regional ones in the initiation of intensive olive management. We can thus see olive domestication being taken up as a result of a range of contingent historical factors and not simply as a universal response to the availability of domestic stocks and techniques.

Conclusions

Archaeobotanical analysis of olive remains from the long settlement sequence at Pella spanning the Neolithic to Iron Age suggests that early olive exploitation was not based on the exploitation of domesticated trees, but rather on the exploitation of wild stocks. Exploitation of olives for oil dates from the Pottery Neolithic with increasingly intensive exploitation of olives evidenced through time. Metric indicators of domestication are not present before the Early Bronze Age, appearing much later than at Teleilat Ghassul. The results suggest a contrast between a gradually intensifying exploitation of olive trees in the northern Jordan Valley beginning in the early Pottery Neolithic, with domestication introduced relatively late, and a more dramatic interventionist management practice in the southern Jordan Valley from some stage in the Late Chalcolithic period. In the regional context, the study demonstrates, as recently shown with annual crops, the necessity for seeing olive domestication as a temporally and regionally diverse process, and one that should not be viewed in a "one-size-fits-all" framework with broadly simultaneous management trajectories.

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