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ORIGINAL ARTICLE

Crop introductions and agricultural change in Anatolia during the long first millennium CE

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Abstract

Agricultural change in first and early second millennium CE Anatolia has been largely explored to date through palynological and historical datasets. This article presents a new synthesis of published archaeobotanical data that is used to explore regional differences in agricultural practices from the Roman (1st to mid-4th century CE) through the Ottoman (14th to 17th c. CE) periods and to document the timing of crop introductions. Arboriculture was important across Anatolia through the early Byzantine period (mid-4th to mid-9th c. CE) but nearly vanished by the Late Byzantine (13th to 15th c. CE), with an emphasis on annual cereal agriculture instead, a finding mirrored in prior palynological work. The Late Byzantine period saw a further divergence in cereal agriculture between areas under Byzantine and Turkish control, a new observation. Introduced crops include *Prunus persica* (peach), *P. armeniaca* (apricot), *Morus* spp. (mulberry), *Oryza sativa* (rice), and *Gossypium arboreum/herbaceum* (cotton).

Keywords Cereal · Fruit · Fiber crops · Roman · Byzantine · Islamic

Introduction

Anatolia (modern Turkey) has been a center of archaeobotanical research for more than a century, with sites such as Troy the source of archaeologically preserved plant remains that were among the earliest published archaeobotanical studies (e.g. Wittmack 1880). Similarly, foundational work in modern quantitative archaeobotany, systematic recovery through water flotation, and ethnoarchaeological study of crop processing took place in Turkey (Helbaek 1961; French 1971; Hillman 1973). Archaeobotanical research in Turkey has expanded considerably since 1990, with an exponential increase in archaeobotanical publication (Marston and Castellano 2021; Castellano 2022). Yet even in the context of this expansion, the bulk of published archaeobotanical scholarship focuses on Neolithic, Chalcolithic, Bronze Age, and Iron Age periods: only 24 sites contain published quantitative archaeobotanical datasets that include Roman or later assemblages, in comparison to 76 such sites dating to earlier periods (Marston and Castellano 2021, p. 339). The underrepresentation of first millennium CE assemblages obscures important agricultural shifts that occurred under Roman, Byzantine, and early Islamic control of the region. The focus of this article is using the data available to address questions of agricultural economy and environmental change during this period, and to identify questions for further investigation in future archaeobotanical research.

A recent study synthesizes all published quantitative archaeobotanical remains from Anatolia, including those of the first millennium CE and the Medieval period, what we here term the "long" first millennium CE, ca. 50 BCE–1450 CE (Marston and Castellano 2021). In this article, we draw on an updated version of this dataset that includes also archaeobotanical remains of shipwrecks and non-quantitative archaeobotanical publications, expanding the range of evidence available for this period. We focus on agricultural evidence in the form of seeds, fruits, and other macrobotanical

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remains that are the primary products of agriculture, referencing pollen and wood charcoal data when relevant, but not analyzing those assemblages directly. We center our discussion on tracing large-scale regional and diachronic change in agricultural practices with special attention to the timing and circumstances of new crop introductions.

Crop introductions during the "long" first millennium CE in Anatolia

For the purposes of this study, we define the "long" first millennium CE as the 1,500-year period from the establishment of Roman rule across Anatolia, ca. 50 BCE, to the Ottoman conquest of Constantinople, ca. 1450 CE. This period saw political stability of Roman and Byzantine rule over the entirety of Anatolia until the 7th century CE, when Arab raids into eastern and central Anatolia began, followed by centuries of contested rule between Arab, Byzantine, and successive Turkic states, culminating in the fall of the Byzantine Empire in the 15th century CE and consolidation of Ottoman control of Anatolia. This same temporal framing has been widely used by other scholars with interests in Byzantine and Islamic societies (e.g. Izdebski 2013; Izdebski and Mulryan 2019; Schwarz 2022).

The history of crop introductions into Anatolia during the period of study is limited; while historical records provide a basis for considering Arab introductions of multiple South and East Asian crops into the Mediterranean, specific records for Anatolia in the first millennium CE are few (Watson 1983). Archaeobotanical data provide an alternative source of direct evidence, but only indicate a few crop introductions dating between Roman and Medieval periods: peach (*Prunus persica*), apricot (*Prunus armeniaca*), rice (*Oryza sativa*), and probably cotton (*Gossypium arboreum* or *G. herbaceum*) and mulberry (*Morus* spp.), despite single, possibly intrusive, earlier finds (Marston and Castellano 2021). The adoption of new agricultural techniques—cropping cycles and timing, irrigation systems, manuring, and field treatment—is equally important but much more challenging to reconstruct archaeologically, so remains mostly inferred from historical sources and farming treatises (Watson 1974; van der Veen 2010; Dalby 2011). For this reason, we leave this complex topic for future discussion.

Climate and geography of Anatolia

For the purposes of this study, we include in our working definition of Anatolia the territory encompassed by the modern state of Turkey, including areas in Europe and Upper Mesopotamia that differ geographically from Anatolia when narrowly defined. We address the variation in climate and vegetation communities across this region by dividing Turkey into eight eco-regions, following Atalay (2014): the Aegean, Marmara, Mediterranean, and Transitional Mediterranean (the region of upland southwestern Turkey also known as the "Lake Region"), as well as central, northern, eastern, and southeastern Anatolia (Fig. 1). We group sites according to these regions or groups of these regions.

Materials and methods

We identified sites with published archaeobotanical data through a systematic review of the published literature. Once identified, we chose sites for inclusion in our analytical dataset that: reported seed (carpological) data, presented quantitatively or semi-quantitatively; dated between the Roman and Medieval periods; are publicly available (theses and dissertations not available in online repositories were excluded); did not duplicate results previously published. These criteria are similar to those used by Marston and Castellano (2021) but include semi-quantitative data and data from shipwrecks, which we analyze separately from raw count numerical data, the primary dataset used in this article. The dataset is otherwise the same, though we added a number of sites from Byzantine Constantinople and from Amorium, which were not published or located for the earlier study. In total, we include 34 sites, some of which include assemblages dated to multiple periods (Fig. 2).

We divided the published datasets into the following chronological periods: Roman (1st to mid-4th century CE), Early Byzantine (mid-4th to mid-9th c. CE), Middle Byzantine (mid-9th to early 13th c. CE), and Late Byzantine/Seljuk/Ottoman (after 12th/13th c. CE). In cases where the chronology given for one botanical assemblage spans more than one period (e.g. Middle and Late Byzantine), the assemblage is attributed to the later period. In six instances (Table 1, ESM 1), sites are simply attributed a "Byzantine" chronology; these sites are treated as spanning indeterminate multiple chronological phases and not included in single-period analyses. Precise details of taxonomic consolidation and count standardization are reported in ESM 2. We performed simple numerical analyses following standard practices (Marston 2014; Pearsall 2015).

Results

Semi-quantitative analysis of economic plants provides a snapshot of the relative changes in individual crops and in groups of crops over time. We present these results in Table 2 by period, with sites not assigned to specific periods grouped at the bottom of the table. Several temporal trends are evident from these data. The most frequent finds are cereals, pulses, and fruits and nuts; we analyze these in

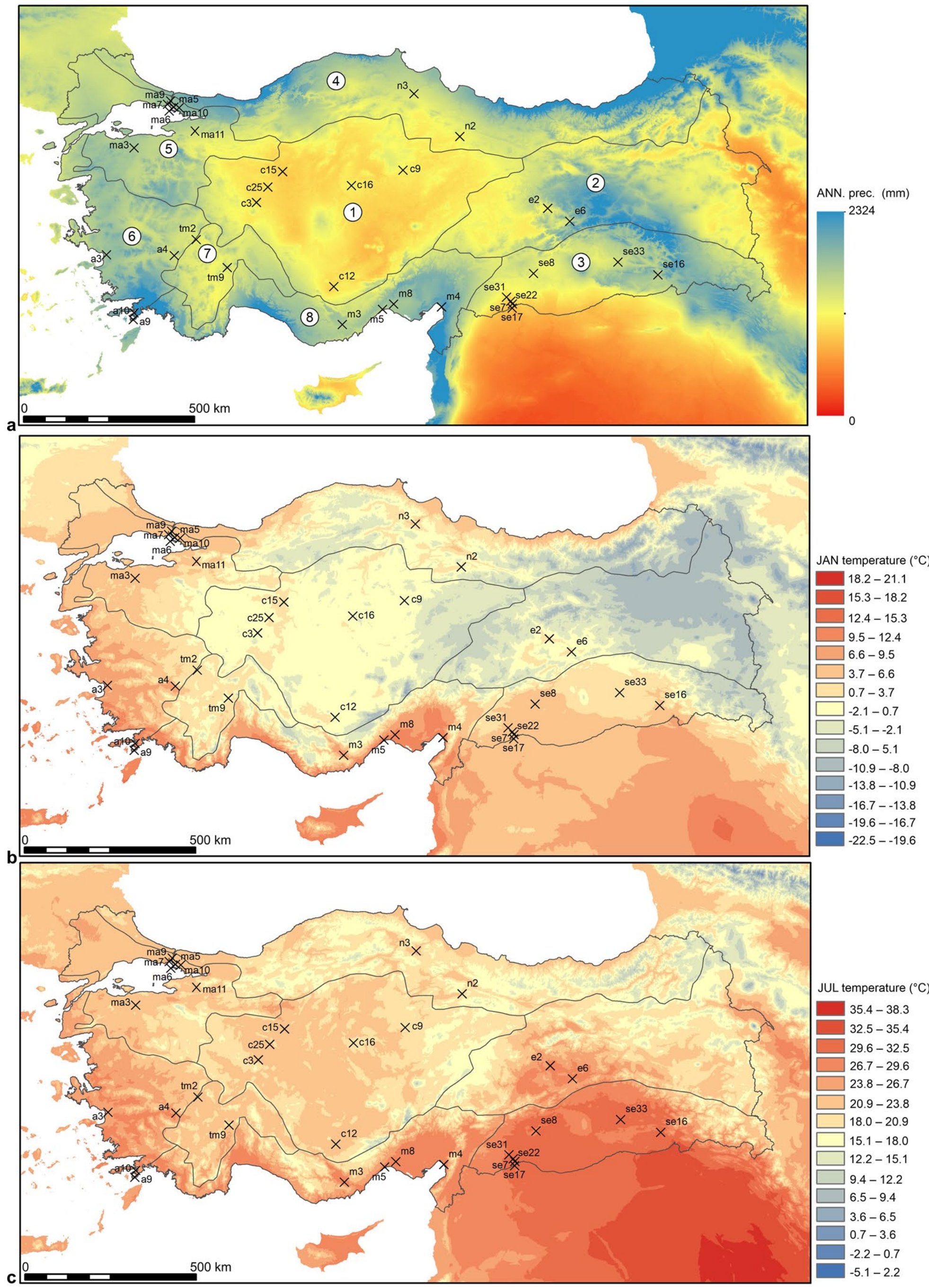

Fig. 1 Average yearly values from WorldClim2, 30-seconds, dataset (Fick and Hijmans 2017). **a** precipitation; **b** January temperature; **c** July temperature. Archaeobotanical sequences are located (codes are reported in Table 1.). Geographic macro-regions are indicated: 1 = central Anatolia, 2 = eastern Anatolia, 3 = south-eastern Anatolia, 4 = northern Anatolia, 5 = Marmara, 6 = Aegean, 7 = transitional Mediterranean, 8 = Mediterranean

more detail and present detailed numerical results of these crops below, while oil/fiber seeds and vegetables are presented only in Table 2. Oil/fiber seeds are uncommon and found only during the Middle Byzantine period and later; both cotton and flax are attested in large quantities at several sites. Culinary herbs and horticultural crops are uncommon, with only melon (*Cucumis melo*) seeds from the Yenikapı shipwreck found in numbers exceeding 100. While most of these seeds are found sporadically with one or two only at single sites, the site of Beşiktaş (Ulaş 2020) from Early Byzantine Constantinople is a notable outlier, with a large variety of fruit (tree fruit and garden fruit) and culinary herbs, alongside a complete lack of pulse and cereal remains. The identification of four seeds of squash (*Cucurbita pepo*) from this site, a species of American origin that was introduced to Europe after 1500 CE, indicates intrusion from later periods or misidentification, however.

Table 1. Anatolian archaeobotanical sequences dating from the Roman to the Ottoman period

Code	Site	t/s	Region	q/nq	Nr-s
Byzantine (generic)					
a4	Hierapolis	t	Aeg.	q	12
c9	Çadır Höyük	t	C-Anat.	nq	12
c25	Pessinonte	t	C-Anat.	q	1
m3	Kilise Tepe	t	Med.	q	6
m8	Tarsus-Gözlükule	t	Med.	nq	nr
n3	Oymaağaç	t	N-Anat.	q	4
Late Byzantine/Seljuk/Ottoman (early 13th to 16th c.)					
c3	Amorium	t	C-Anat.	q	28
c12	Can Hasan III	t	C-Anat.	nq	nr
c15	Gordion	t	C-Anat.	q	19
c16	Kaman-Kalehöyük	t	C-Anat.	q	6
e2a	Aşvan-kale	t	E-Anat.	q	19
e2b	Aşvan-Taşkun Kale	t	E-Anat.	q	3
e6	Korucutepe	t	E-Anat.	q	1
ma10	Aydos Castle	t	Marm.	q	1
ma3	Daskeleion	t	Marm.	q	15
ma11	Dikilitaş	t	Marm.	q	3
ma5	Küçükyalı	t	Marm.	q	11
n2	Komana-Pontika	t	N-Anat.	q	12
se7	Gre Virike	t	SE-Anat.	q	5
se22	Mezraa Höyük	t	SE-Anat.	q	14
Middle Byzantine (mid-9th to early 13th c.)					
a10	Bozburun	s	Aeg.	q	332
a9	Serçe Limanı	s	Aeg.	q	nr
c3	Amorium	t	C-Anat.	q	5
e2a	Aşvan-kale	t	E-Anat.	q	2
ma7	Yenikapi	s	Marm.	q	75
m4	Kinet Höyük	t	Med.	q	12
m5	Mersin-Yumuktepe	t	Med.	q	nr
n2	Komana-Pontika	t	N-Anat.	q	67
se8	Gritille	t	SE-Anat.	q	71
se17	Karkemish	t	SE-Anat.	q	1
tm2	Beycesultan	t	Tr-Med.	q	1
Early Byzantine (mid-4th to mid-9th c.)					
c15	Gordion	t	C-Anat.	q	5
c3	Amorium	t	C-Anat.	q	9
ma9	Beşiktaş	t	Marm.	q	7
m4	Kinet Höyük	t	Med.	q	1
se33	Ziyaret Tepe	t	SE-Anat.	q	29
ma6	Yassi Ada	s	Marm.	q	16
tm9	Sagalassos	t	Tr-Med.	q	19
Roman (1st to mid-4th c.)					
a3	Ephesus	t	Aeg.	q	81
c3	Amorium	t	C-Anat.	nq	nr
c15	Gordion	t	C-Anat.	q	26
c25	Pessinonte	t	C-Anat.	q	8
e2a	Aşvan-kale	t	E-Anat.	q	2
se16	Ilısu Höyüğü	t	SE-Anat.	q	4
se31	Zeugma	t	SE-Anat.	q	80
tm9	Sagalassos	t	Tr-Med.	nq	nr

Table 1. (continued)

Site code follows Marston and Castellano 2021: t/s=type of deposit (t, terrestrial site; s, shipwreck); q/nq=published with quantitative (q) or non-quantitative (nq) data; Nr-s number of samples; nr=number of samples not reported. For regions see Figs. 1 and 2, for details including spatial coordinates, dates, and references for each site see ESM 1

Cereal agriculture

We present cereal assemblages with greater than 50 caryopses identified at least to the species level in Fig. 3, in which these taxa are displayed spatially, by period. Several trends are notable. While the Roman and Early Byzantine periods show a balance between barley and free-threshing wheat, the relative abundance of free-threshing wheat increased substantially in the Middle Byzantine period. In the final period, free-threshing wheat remained abundant in the Marmara region but at most sites in other regions barley became the most numerous cereal recovered, often by a significant margin. Chaff (not depicted in Fig. 3) is numerous at all sites in central Anatolia as well as a few sites from more arid portions of southeastern Anatolia: Zeugma, Gritille, and Ziyaret Tepe. Barley, bread wheat, unspecified free-threshing wheat, and rye chaff fragments are the most numerous at those sites. The chaff does not add additional taxa but clarifies that bread wheat (*Triticum aestivum*), but not durum wheat (*T. durum*), was farmed at Roman Gordion (Marston and Miller 2014) and Late period Amorium (Giorgi 2012). Rye (*Secale cereale*) and spelt (*Triticum spelta*) were dominant at single sites; millets (*Panicum miliaceum* and *Setaria italica*) were numerous, but not dominant, at several sites restricted to central and eastern Anatolia.

Pulse agriculture

We present a spatial representation of pulse results from assemblages with at least 50 identified pulse seeds or fruits in Fig. 4. Due to the lower number of sites with sufficiently large assemblages, we include all periods together in Fig. 4. Pulses are the minority of economic remains in most assemblages; only Roman Ilısu Höyük is dominated by pulse remains, due to two large caches of chickpeas (*Cicer arietinum*) recovered from an area of burned buildings (Oybak Dönmez 2018). Lentil (*Lens culinaris*) and bitter vetch (*Vicia ervilia*) are the most ubiquitous pulses across sites and periods, with pea (*Pisum sativum*) and grass pea (or field pea, *Lathyrus sativus* and/or *L. cicera*) also present in small quantities across numerous sites; grass pea is more common in the latest period, when it is found at all sites in the southeast Anatolia and Marmara regions. Chickpea and fava bean (*Vicia faba*) are less common but present in large concentrations at some sites; common vetch (*V. sativa*) is rare. Pulses are absent in shipwreck contexts.

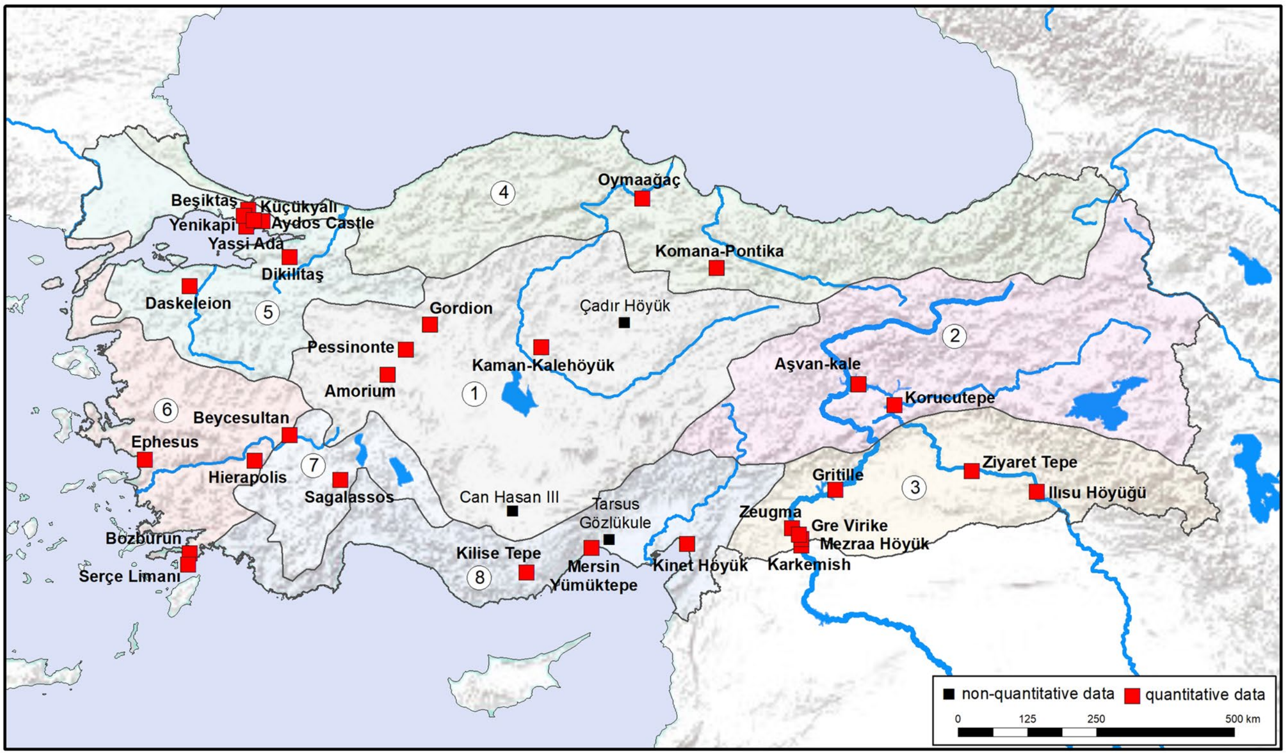

Fig. 2 Carpological records from Anatolia (modern Turkey) dating from the Roman to the Ottoman Period. Further information provided in Table 1. Geographic macro-regions are indicated: 1 = central Anatolia, 2 = eastern Anatolia, 3 = southeastern Anatolia, 4 = northern Anatolia, 5 = Marmara, 6 = Aegean, 7 = transitional Mediterranean, 8 = Mediterranean

Arboriculture and viticulture

Fruit and nut remains are described in Table 2 and a spatial representation of the primary fruit cultigens—grape (*Vitis vinifera*), fig (*Ficus carica*), and olive (*Olea europaea*)—by period is presented in Fig. 5. Fig and grape seeds are the most numerous fruit remains and are the dominant economic taxa at many sites, all of which date from the Roman to the Middle Byzantine period. Notably, the latest period in the sequence has much lower densities of fruit remains and many fewer taxa than all earlier periods. Among those late period sites, grape is the most ubiquitous fruit identified. Numerous other tree fruits are sporadically present across sites and often present together: a site is much more likely to have numerous minor fruit and nut taxa or none at all than it is to have only one or two minor taxa (Table 2). All shipwrecks are dominated by fruit remains; three of the four include five or more fruit taxa (Table 2). The spatial presentation of these results indicates the scarcity of fruit remains in central and eastern Anatolia, save a few grape and fig seeds; olive is restricted to the Marmara, Aegean, and Mediterranean regions, as well as the Roman-period site of Zeugma in the Middle Euphrates Valley (Challinor and de Moulins 2013).

Discussion

Sampling

This article provides the first comprehensive, quantitative survey of archaeobotanical data from first and second millennium CE Anatolia, but it relies on the evidence available. The samples reported in this analysis are uneven in distribution, both temporal and spatial; many site-period assemblages are represented only by a single sample (Table 1). There is little correlation, however, between

Table 2. Semi-quantitative analysis of carpological remains
Note: Only assemblages containing more than 30 economic seed/fruit remains are included; identifications at the genus level or higher are excluded from the sum. Codes: *=1; += 1-9; ++=10-49; +++=50-99; ++++=>99 specimens

		Sum - economic seed/fruit	*Hordeum vulgare*	*H. vulgare* var. *nudum*	*Triticum aestivum/durum*	*T. monococcum*	*T. dicoccum*	*T. spelta*	*Secale cereale*	*Avena sativa*	*Oryza sativa*	*Panicum miliaceum*	*Setaria italica*	*Lens culinaris*	*Pisum sativum*	*Vicia ervilia*	*V. faba*	*V. sativa*	*Cicer arietinum*	*Lathyrus sativus/cicera*	*Vitis vinifera*	*Ficus carica*	*Olea europaea*
Byzantine (unspecified)																							
C-Anat.	Pessinonte	37	++																		+		
Aegean	Hierapolis	67	++																		+		++
Mediter.	Kilise Tepe	3,081	++++		++++	++		++++				+		+	*					*	++	++++	*
Late Byzantine/Seljuk/Ottoman																							
C-Anat.	Amorium	380	+++		+				++			++									++	++	
C-Anat.	Gordion	1,848.5	++++		++++		+		+		++	+	++++	+		++					+	+	
C-Anat.	Kaman-K.	13,722	++++		++++				+++			++++		+++		++		+	++		++++	++++	
E-Anat.	Aşvan Kale	5,076	++++		++++				+			++		++	*	++++			++		++		
E-Anat.	Taşkun Kale	996	++++	*	++									+		+					+		
E-Anat.	Korucutepe	105	+++		++		+																
SE-Anat.	Gre Virike	783	++++				*							+	++					++	+		
SE-Anat.	Mezraa Höyük	3,232	++++		++++		+							++	+				*	+	++		
N-Anat.	Komana	41	+		+				*					*							++		
Marmara	Aydos castle	3,378	++++	++++	++++	++	++		++	+				++	++++		++++	++	*	++			
Marmara	Dikilitaş	35			+																+		+
Marmara	Küçükyalı	5,531	++++		++++	+	+		+	+				+	+		*			*	*	+	
Marmara	Daskeleion	324	+++		++++											++	+++			+			
Middle Byzantine																							
E-Anat.	Aşvan Kale	1,116	+++		++++				*					+	*	+					++++		
SE-Anat.	Gritille	24,133	++++		++++	++							++	++++	++++	++	++++		+		++	+++	
N-Anat.	Komana	3,557	++++		++++				++	++				+++	+	++		++		+	++++		*
Tr.Med.	Beycesultan	69	+						++														
Mediter.	Kinet Hoyuk	213	+		+																*	+	
Mediter.	Mersin-Y.	1,004			++++									+			++++					++++	
Shipwreck	Bozburun	22,997																			++++		++++
Shipwreck	Serçe Limanı	339																			++++		+
Shipwreck	Yenikapı	2,338			+																++++	++++	++++
Early Byzantine																							
C-Anat.	Amorium	31	+		*							*									+		
C-Anat.	Gordion	32	++		++								+	+									
SE-Anat.	Ziyaret Tepe	129	++		++	*	+		*							++		*	*		+	+	
Tr.Med.	Sagalassos	138	+									+		+							++	+++	
Marmara	Beşiktaş	633																			++++	++++	+
Shipwreck	Yassi Ada	181																			++++		+
Roman																							
C-Anat.	Gordion	127.5	++		++								+	+		+					*		
C-Anat.	Pessinonte	36	++				+	+							*	*					+		
E-Anat.	Aşvan Kale	229	++		+							+	++	+	+	+					++++		
SE-Anat.	Ilısu Höyük	8,740	++++		++++														++++				
SE-Anat.	Zeugma	1,621	++++		++++		+							++++			+				++++	+++	++++
Aegean	Ephesos	18,163	++		+++		++					+		+		*					+++	++++	++++

sample number and seed count, with Aydos Castle representing one extreme of a single sample with more than 3,000 identified seeds (Table 2). In general, however, the periods described here are less well sampled across Anatolia than earlier periods (Marston and Castellano 2021), mainly due to an underemphasis on archaeobotanical sampling in post-Iron Age periods across the Classical world (Lodwick and Rowan 2022). Some regions, such as northern and eastern Anatolia, are particularly undersampled. As a result, geographical patterns for these areas should be understood as less well supported than those for other

Table 2. (continued)

Punica granatum	*Prunus amygdalus (dulcis)*	*P. armeniaca*	*P. avium/cerasus*	*P. domestica*	*P. persica*	Maloideae	*Corylus* sp.	*Elaeagnus angustifolia*	*Juglans regia*	*Morus nigra*	*Celtis* sp.	*Cornus mas*	*Crataegus* sp.	*Pinus* sp.	*Pistacia* sp.	*Quercus* sp.	*Rhus coriaria*	*Rubus* sp.	*Sambucus* sp.	*Gossypium* sp.	*Linum usitatissimum*	*Allium sativum*	*Coriandrum sativum*	*Cuminum cyminum*	*Foeniculum vulgare*	*Piper* sp.	Cucurbitaceae s.l.	*Citrillus* sp.	*Cucumis melo*	*Lagenaria siceraria*	*Cucurbita pepo*	*Glycyrrhiza* sp.
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regions. This undersampling should serve as a point of emphasis for future archaeobotanical research in first and second millennium CE Anatolia.

Regional and diachronic trends

Regional trends in the results can be explained primarily by phytogeography. The restriction of most arboriculture to the circum-Mediterranean regions matches known thermal limitations of these species. Olive, for example, is cold sensitive and endocarps have not been found in highland, temperate regions of Anatolia, save a few endocarp fragments from Komana that are interpreted as imported, preserved table olives (Pişkin and Tatbul 2015, p 147; Table 2). Fig is similarly cold sensitive and its cultivation restricted to warmer Mediterranean climates, similar to the range of its wild ancestor (Flaishman et al. 2007; Zohary et al. 2012). The only fruits found frequently in central, northern, or

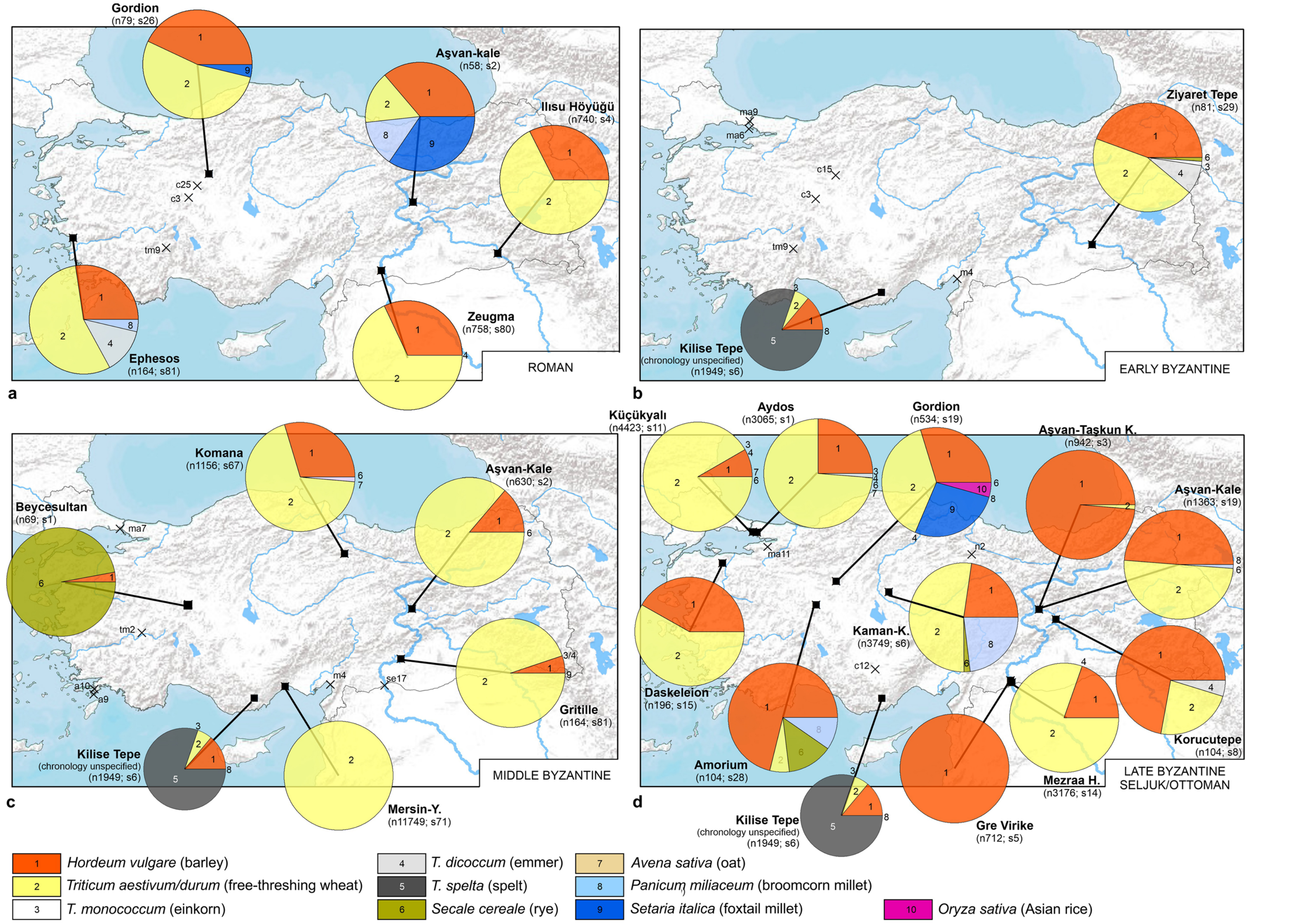

Fig. 3 Spatial depiction of cereal assemblages during each of four periods. Below the name of the site is given the total number of cereal grains identified (n) and of the samples included in the study (s). Only assemblages containing more than 50 cereal grains are included. Kilise Tepe appears within three panels as its chronology within the Byzantine period is unspecified

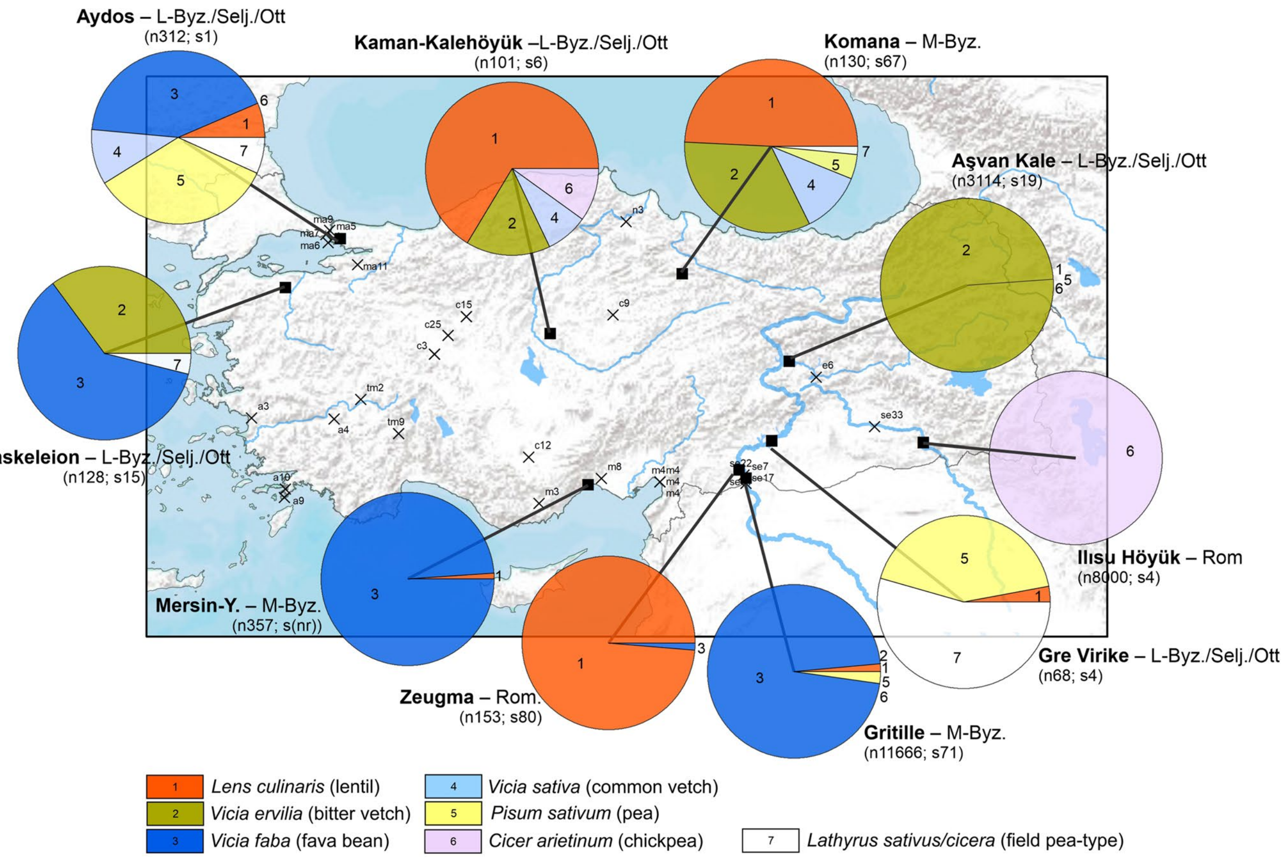

Fig. 4 Spatial depiction of pulse assemblages. Beside the site name is given the period to which the assemblage dates. Below the name of the site is given the total number of cereal grains identified (n) and of the samples included in the study (s). Only assemblages containing more than 50 pulses seeds are included

eastern Anatolia plateau are grape and, to a lesser extent, figs, which may have been imported as dried fruit or, in the case of grape, as residue in wine. Substantial evidence for local viticulture at the central Anatolian site of Kınık Höyük (Castellano 2021, 2022), however, emphasizes the viability of viticulture on the Anatolian plateau, as also seen at Aşvan Kale (Nesbitt et al. 2017, p 117) in eastern Anatolia and Komana (Pişkin and Tatbul 2015, p 148) in northern Anatolia. Fig may be overrepresented in archaeobotanical assemblages due to the large numbers of fruits per syconium, but also conversely, potentially undersampled, given the minute size of its drupelets. Nonetheless, its occasional presence in terrestrial sites where it was likely not able to be grown attest to its wide dispersal as a dried foodstuff. Taphonomic processes also contribute to the apparent underrepresentation of fruit and nut remains in most central Anatolian sites, as evidenced by rare depositional circumstances (e.g. shipwrecks, destruction layers, pits rapidly filled with food waste) that document a much wider array of fruit and nut taxa, circumstances that happen to be unmet by the large majority of contexts under consideration in this study that are terrestrial assemblages. At Gordion, for example, an Iron Age destruction context yielded diverse and abundant fruit and nut remains, including hazelnuts (*Corylus avellana*) and cherries (*Prunus avium* and *P. cerasus*), that are absent from the later archaeobotanical assemblage (Miller 2010; Marston 2017), while a singular Middle Bronze Age deposit at central Anatolian Büklükale yielded almond (*Prunus dulcis*), plum (*Prunus domestica*), bramble (*Rubus* spp.), pomegranate (*Punica granatum*), melon or cucumber (*Cucumis* spp.), as well as several herbs (Fairbairn et al. 2019), all taxa unattested or present only as single finds from sites in central Anatolia included in this survey. In this dataset, waterlogged contexts as found in the Marmara region and in shipwrecks preserve a greater array of fruits and nuts [e.g. Yenikapı (Oybak Dönmez 2010)] that do not find preservation in charred assemblages as readily as cereals, cereal chaff, and pulses, which dominate most archaeobotanical assemblages across southwest Asia (van der Veen 2007).

The primary diachronic trend visible in these data is the shift following the Middle Byzantine period in which arboriculture nearly disappears from the archaeobotanical record, save a few sites with (likely imported, at least in Central Anatolia) fig (e.g. Ottoman Kaman Kalehöyük, Kennedy 2000), and grape remains became less numerous (Table 2; Fig. 5). At the same time, a shift occurred in cereal cultivation, with an increase in barley over free-threshing wheat in every region except the Marmara (Figs. 3 and 4). It is notable that these shifts are also aligned with the shifting boundaries between the Byzantine and Muslim states, with reduced arboriculture in regions of eastern and southern Anatolia that came under Muslim control earliest, as well as more barley than free-threshing wheat cultivation (Figs. 3 and 5). This pattern mirrors that found in pollen data, as records from central and eastern Anatolia show a sharp decline in agricultural (and especially arboriculture) signatures as early as the late 7th century CE, evidence that has been used together with regional settlement surveys to infer a rural depopulation of these regions (Izdebski 2013; Roberts 2019). Whether declines in arboriculture are a direct result of reduced rural populations, changes in economic networks and market access, or a response to widespread conflict, are uncertain and require further multidisciplinary inquiry (e.g. Roberts et al. 2018).

Fig. 5 Spatial depiction of main fruit taxa (*Ficus carica, Olea europaea, Vitis vinifera*) during each of four periods covered by the study. Histograms represent semi-quantitative classes based on relative abundance, calculated using the total of identified economic seed/fruit remains. Below the name of each site is given the sum of *Ficus*, *Olea*, and *Vitis* specimens identified (n) and of the samples included in that study (s). Only assemblages containing more than 50 economic seed and fruit remains are included. Identifications at the genus level or higher are excluded. Hierapolis and Kilise Tepe appear within three panels as their chronology within the Byzantine period is unspecified ▸

Evidence for crop introductions and expansions

In an earlier examination of this dataset that included earlier periods (Marston and Castellano 2021), we identified several crop introductions dating to the Roman through Medieval periods. These include *Prunus persica*, *P. armeniaca*, *Oryza sativa*, and almost certainly both cotton (*Gossypium arboreum* or *G. herbaceum*) and *Morus* spp.; specific evidence for these finds is detailed in ESM 3. Cotton is attested only by a single seed in Hellenistic levels at Aşvan Kale (Nesbitt et al. 2017, p 117) prior to a broader appearance in the Middle Byzantine period (Table 2). The location of domestication for black mulberry (*Morus nigra*) is uncertain and may include the Aegean region, but is generally thought to have occurred further east in the Caucasus or Persia (Browicz 2000). Mulberry does not appear in Anatolian archaeobotanical assemblages until it is attested by three seeds from Hellenistic levels at Pessinonte (Peteghem 2005) and a single seed at Roman Ephesus (Heiss and Thanheiser 2016), but more abundantly by fragments of wood charcoal from Seljuk/Ottoman levels at Kınık Höyük (Castellano 2021, 2022), providing firmer evidence for a sequence of local introduction and cultivation, in keeping with broader evidence for a spread of mulberry across Europe during the Medieval period (Livarda and van der Veen 2008). Rice appears at both Gordion (Marston 2017), in the Seljuk phase dated to the 13th century CE, and at Komana (Pişkin and Tatbul 2015), dated to the Byzantine occupation of the 12th-13th centuries CE. The Komana find is of only a single partial caryopsis from a cesspit, preserved through mineralization, so may represent non-local cultivation (Pişkin and Tatbul 2015, p 143), while the Gordion remains, perhaps slightly later, are relatively numerous and ubiquitous, and charred, and thus better evidence for local cultivation.

By the Middle and Late Byzantine periods, mulberry and cotton may be considered new introductions, following the criteria laid out by Fuks et al. (2020), as they are based on multiple well-dated specimens. Although "first finds" of these species appear earlier, they are singular finds, at unique and/or possibly contaminated contexts as identified in a systematic survey of earlier sites (Marston and Castellano 2021). The single Hellenistic find of cotton is an outlier and potentially an intrusion from later levels (as suggested by the authors; Nesbitt et al. 2017, p 117); the few mulberry seeds from Hellenistic Pessinonte and Roman Ephesus could be the remains of imported fruits (likely dried). That peach, apricot, and mulberry (by the Late Byzantine period) were locally produced is supported by archaeological finds of wood of these tree crops (e.g. Castellano 2021), with textual evidence supporting their cultivation within the region of Anatolia at the times to which these finds date (e.g. Kron 2012). This is not to preclude mulberry and other crops as earlier introductions to Anatolia, but the archaeobotanical evidence is currently equivocal regarding earlier finds.

In addition to these new taxa, other crops that were available in earlier periods found renewed interested later in the first millennium CE, with rye, oat (*Avena sativa*), and millets (especially broomcorn millet, as well as foxtail millet) all more ubiquitous and numerous in the Middle and, especially, Late Byzantine periods (Table 2; Figs. 3 and 4). Spelt may also follow this trend, though is restricted to a single site, Kilise Tepe, without a clear chronological placement in the Byzantine period (Bending and Colledge 2007). We find no simple explanation for the dominance of spelt at Kilise Tepe but we note that the site is an agricultural outlier in earlier periods as well; the dominance of rye at Middle Byzantine Beycesultan may be due to that assemblage consisting of only a single sample (Table 1). The pulses fava bean and grass pea also become more common and more numerous at individual sites beginning in the Middle Byzantine period, though they were present in Anatolia in much earlier periods as well (Marston and Castellano 2021).

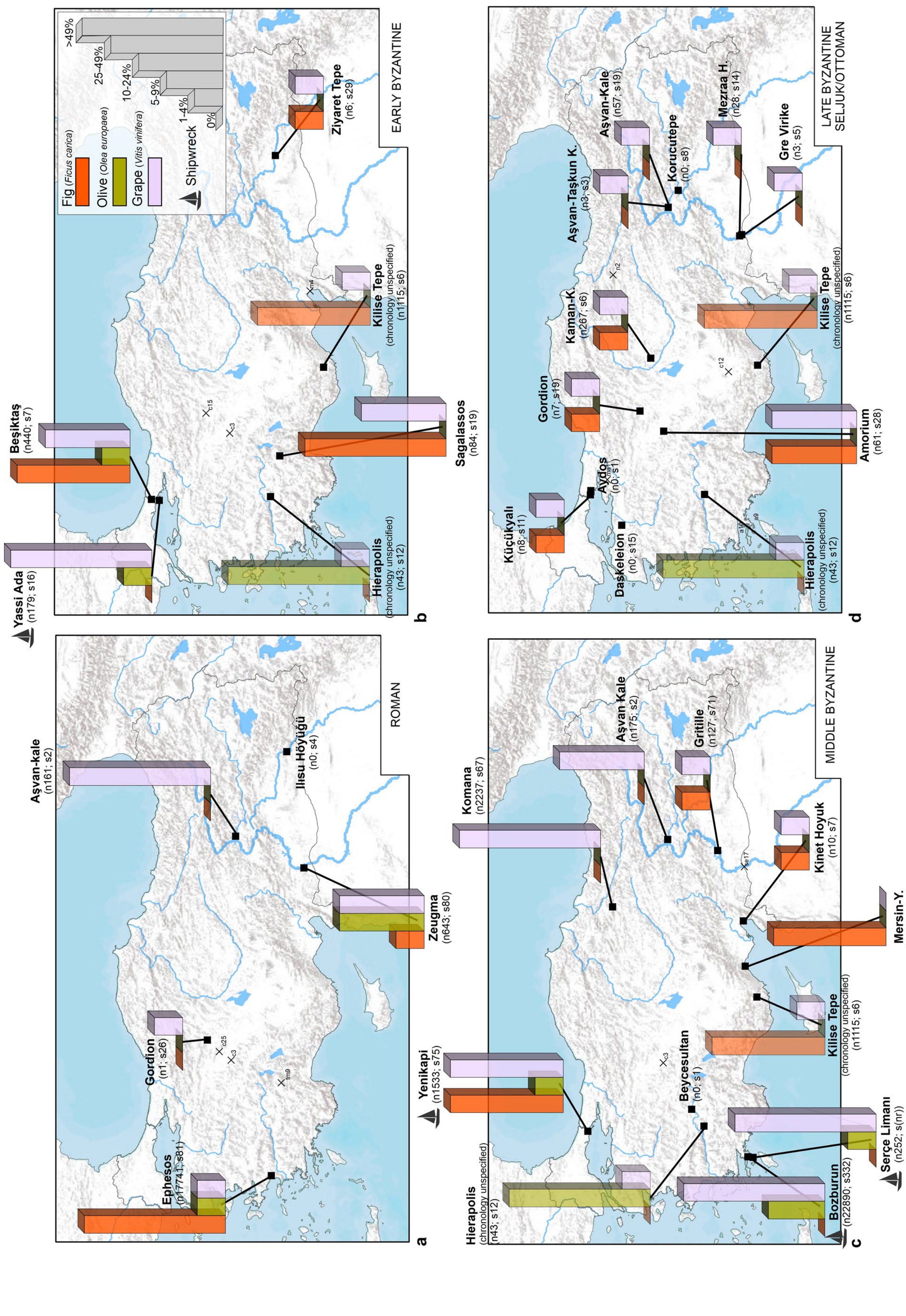

Fig (Ficus carica)
Olive (Olea europaea)
Grape (Vitis vinifera)
Shipwreck
>49%
25-49%
10-24%
5-9%
1-4%
0%
a
ROMAN
Aşvan-kale
(n161; s2)
Ilısu Höyüğü
(n0; s4)
Zeugma
(n643; s80)
Gordion
(n1; s26)
Ephesos
(n17741; s81)
b
EARLY BYZANTINE
Yassi Ada
(n179; s16)
Beşiktaş
(n440; s7)
Sagalassos
(n84; s19)
Hierapolis
(chronology unspecified)
(n43; s12)
Kilise Tepe
(chronology unspecified)
(n1115; s6)
Ziyaret Tepe
(n6; s29)
c
MIDDLE BYZANTINE
Hierapolis
(chronology unspecified)
(n43; s12)
Yenikapi
(n1533; s75)
Komana
(n2237; s67)
Aşvan Kale
(n175; s2)
Gritille
(n127; s71)
Kinet Hoyuk
(n10; s7)
Mersin-Y.
(n500*; s(nr))
Kilise Tepe
(chronology unspecified)
(n1115; s6)
Beycesultan
(n0; s1)
Serçe Limanı
(n252; s(nr))
Bozburun
(n22890; s332)
d
LATE BYZANTINE
SELJUK/OTTOMAN
Küçükyalı
(n8; s11)
Daskeleion
(n0; s15)
Aydos
(n0; s1)
Gordion
(n7; s19)
Kaman-K.
(n267; s6)
Aşvan-Taşkun K.
(n3; s3)
Aşvan-Kale
(n57; s19)
Korucutepe
(n0; s8)
Mezraa H.
(n28; s14)
Gre Virike
(n3; s5)
Amorium
(n61; s28)
Kilise Tepe
(chronology unspecified)
(n1115; s6)
Hierapolis
(chronology unspecified)
(n43; s12)

The context of crop introductions and the reorganization of agricultural regimes to include more diverse cereal and pulse taxa are likely distinct, but related. Peach (first attested at Roman Zeugma) and apricot (first attested at Middle Byzantine Komana and the Serçe Limanı shipwreck) are both east Asian domesticates that spread to central Asia during the second millennium BCE (Fuller and Stevens 2019; Spengler 2019) and appeared in the Mediterranean in limited quantities in the first millennium BCE (Zohary et al. 2012, pp 144–145). Both tree crops appear to have been easily adopted into established arboriculture systems across southwest Asia, albeit in limited densities, in part due to their similarity to tree fruit crops long cultivated in the region, including apple (*Malus domestica*), cherry, and plum. As these new fruits required little new knowledge to cultivate, their adoption was rapid once introduced to the region, as has been argued in the case of other agricultural adoptions that represent minor, incremental changes to cultivation practices (van der Veen 2010; Brite and Marston 2013).

More substantial agricultural innovation was likely needed for the adoption of rice and cotton. Rice, with both east and south Asian domestication histories, is present in charred form only at Gordion, where numerous well-preserved caryopses suggest possible local cultivation during the Seljuk period (Marston 2017); it is attested historically much earlier by Greek and Roman sources, however, and was grown elsewhere in the Roman Empire (Zohary et al. 2012, p 74). Archaeobotanical remains of cotton, a south Asian and African domesticate, have been found north of 30°N latitude only during the first millennium CE (Brite and Marston 2013); it first appears in Anatolia, in several cases alongside flax (*Linum usitatissimum*), another fiber crop, in the Middle Byzantine period (Table 2). Both rice and cotton have substantial water requirements and are thought to have been grown exclusively under irrigation in southwest Asia (Bouchaud et al. 2018; Spengler 2019; Spengler et al. 2021), with cultivation expanding under Islamic agricultural systems that adopted new irrigation technologies (Watson 1983).

Conclusions

The archaeobotanical evidence presented here highlights regional differences in diachronic change that can be aligned with shifting boundaries between the Byzantine and Turkic states throughout the later 1st millennium and early 2nd millennium CE. Areas under Muslim control indicate a decline in arboriculture and a shift from free-threshing wheat to barley as the primary cereal cultivated, possibly primarily for fodder, reflecting an emphasis on pastoral production seen in other lines of evidence (Roberts et al. 2018). Crop introductions into Anatolia over this period mirror this pattern. The two tree crops introduced both appear in Roman or Byzantine areas of control: peach is a Roman-period introduction while apricot first appears in the Middle Byzantine period in areas under firm Byzantine control at that time (northern Anatolia and the Marmara). The two annuals introduced, cotton and rice, both first appear in areas under Muslim control: southeastern Anatolia (cotton, in the Middle Byzantine) or central Anatolia (rice, in the Late Byzantine). Both are crops that require irrigation to be grown in this region and their spread into Anatolia follows the influence of new modes of agriculture under Muslim rule as first discussed by Watson (1974, 1983).

Ongoing research into this dataset will explore the changing environmental contexts and structures of political economies of the Roman, Byzantine, and Muslim states of Anatolia over the long first millennium CE, and will help to understand better the dynamic relationships between changing political structures and agricultural practices, especially during the Late Byzantine period. Future research will also help to illuminate the context of crop introductions to Anatolia and the conditions that led to increased differentiation of crop production on a regional, as well as site-specific, basis. Incorporation of additional lines of evidence, such as wood charcoal and pollen data, will help to expand the interpretation of these findings. This study, however, provides a first perspective on agricultural change and crop introductions during this dynamic period of Anatolian history and a solid grounding for future scholarship in the region.

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Declarations

Conflict of interest None.

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