ARTICLE

Olive Oil Pressing Waste as a Fuel Source in Antiquity

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The recovery of large quantities of fragmented carbonized olive stones from archaeological sites around the Mediterranean indicates that olive oil pressing waste (pomace) was used as a domestic and industrial fuel source throughout antiquity. Olive pomace burns at a high and constant temperature, making it an ideal fuel for heating and cooking as well as firing pottery and lime kilns. The Roman period is characterized by an expansion in pomace use both quantitatively and geographically. Beginning in the first century C.E., pomace fuel was introduced into new urban markets and began to play a larger role in industrial production. This article highlights the history of pomace use in antiquity, focusing primarily on the changes that took place during the Roman period. The article also seeks to establish a set of identification criteria that will enable archaeologists to distinguish pomace residue from other sources of carbonized olive stones, including ritual and table waste.[1]

INTRODUCTION

While wood and charcoal were undoubtedly the most widespread and commonly used fuels in antiquity, they were not the only sources of fuel, nor were they always the least expensive or the most favored. Cereal chaff, dung, coal, and animal fats, among others, were also used.[2] There is growing scholarly recognition of the use of secondary fuels in the ancient world, particularly with reference to the production of a specific good, such as pottery.[3] Olive oil pressings—so-called press cake, or pomace,[4] the solid material that remains after the oil is collected—provide an underrated yet highly archaeologically observable example of these secondary fuels. The carbonization process turns material into a mass of carbon that does not decompose, is impervious to microbial attack, and does not react with other minerals and chemicals.[5] Thus, the burning of pomace leaves behind fragments of carbonized olive stone, which are durable and invulnerable to decay.

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[2] Dearne and Branigan 1995; Wikander 2008, 139; Wilson 2012, 149.

[3] Smith 1998; Monteix 2009; Lewit 2011, 318–22.

[4] Olive oil pressings are also commonly referred to as *jift* (Arabic) or *grignons* (French) in many ethnographic studies, while modern scientific articles often refer to them as olive pomace or olive mill cakes (Galili et al. 1997; Tekin and Dalgiç 2000; Mekki et al. 2006). For a detailed list of olive pressing waste terminology, see Niaounakis and Halvadakis 2006, table 1.5.

[5] Hillman et al. 1993, 95; Fraser et al. 2013, 4755.

Large quantities of carbonized olive stones, usually acknowledged as a sign of pomace fuel use, have been recovered from sites throughout the Mediterranean and Middle East. Pomace began to be used as a fuel source in the Early Bronze Age (see the section "Archaeobotanical Finds of Pomace Fuel from the Pre-Roman Period" below), was used continuously throughout antiquity, and is still used even up to the present day. Yet not all peoples and civilizations in antiquity used pomace fuel in the same way and to the same extent. The Roman period, defined here as the second century B.C.E to the fourth century C.E., differs from previous eras in that it saw an increase in pomace fuel use due to greater demand, particularly for industrial purposes. By synthesizing and combining the existing data with new information from Herculaneum, this article focuses on the industrial and domestic uses of pomace within the Roman empire, thus enhancing the way we understand the exploitation of this by-product geographically, chronologically, and economically. Moreover, the article looks at the historical record and published archaeobotanical material to clarify the criteria required for the recognition of pomace fuel use in the field.

Pomace is composed of olive flesh, skin, stones (endocarp), and seeds (fig. 1), containing 3.5–12.0% olive oil and 20–30% water.[6] It is generated in large quantities during olive oil production, with the pressing of 1 ton of olives producing 350–400 kg of pomace and 200 liters of olive oil.[7] While both the Roman authors and ethnographic studies have shown that pomace can be used as fertilizer for olive groves and as fodder for livestock, the chief use for pomace in modern olive oil producing regions, including Jordan, Israel, Spain, and Tunisia, is as a source of fuel.[8]

Turning pomace into a viable fuel source is a simple procedure and, as pomace is a by-product of olive oil production, it requires no extra effort on the part of the manufacturer. After olive pressing, pomace is sun dried to reduce the high water content. Drying is done either by spreading the pomace flat or by shaping it into bricks or balls. In present-day Jordan and Israel, pomace is pressed by hand into 8–12 cm balls and dried on floors or rooftops.[9] Covering pomace with fresh or salted water in a pit will prevent it from becoming rancid for up to six months.[10] The water not only preserves the olive waste but also prevents large piles of pomace from spontaneously combusting. In modern Syria, olives are pressed in the winter and stored in water to be dried in the heat of summer.[11] Pomace can be preburned and turned into charcoal pomace, although according to ethnographic studies of the 1960s and 1970s, this method does not seem to have been widespread.[12] In Moknine (Tunisia), potters occasionally used preburned pomace.[13] Whether charcoal pomace was used during the Roman period remains uncertain.[14]

In modern times, dried pomace is far more common than charcoal pomace, as it is more manageable with respect to use and transport. Dried pomace can be used for cooking and heating when placed on open grills or braziers. It has a calorific value of 5,360 kcal/kg, and although this is lower than wood charcoal (7,350 kcal/kg), when used in a small stove, 4–5 kg of pomace will burn for 12 hours.[15]

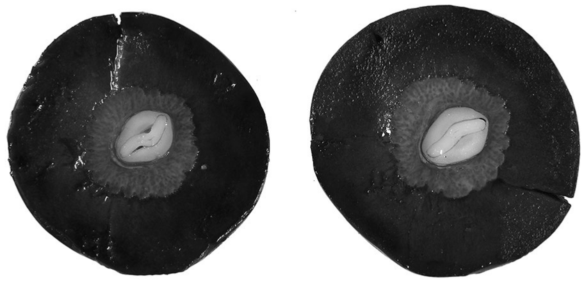

FIG. 1. Cross-section of an olive (*Olea europaea* L.), showing, from the exterior to the interior, the epicarp (skin), mesocarp (flesh), endocarp (stone), and seed (Cappers and Neef 2012, fig. 71; courtesy R.T.J. Cappers).

[6] Karapmar and Worgan 1983, 185; Cappers and Neef 2012, 241. Ancient and modern presses are equally as efficient at extracting the olive oil. Modern presses are faster only because they can exert more pressure on the press bed (Mattingly 1988a, 182).

[7] Mekki et al. 2006, 1419; Niaounakis 2011, 414.

[8] Cato, *Agr.* 37.2; Attom and Al-Sharif 1998, 220; Niaounakis and Halvadakis 2006, 15; Cuomo di Caprio 2007, 490.

[9] Warnock 2007, 48–51.

[10] Avitsur 1994, 127.

[11] M. Moutot, "Syrians Make Olive Fuel for Winter Heating," *The Daily Star*, 19 September 2012, www.dailystar.com.lb/News/Middle-East/2012/Sep-19/188505-syrians-make-olive-fuel-for-winter-heating.ashx.

[12] Sethom 1964; Matson 1972.

[13] Sethom 1964.

[14] New research using reflectance testing will, it is hoped, be able to differentiate between dried pomace fuel and charcoal pomace. This would enable us to determine whether olives recovered from the early Herculaneum excavations were carbonized before or during the 79 C.E. eruption of Vesuvius. For a list of early carbonized finds from Herculaneum, see Borgongino 2006.

[15] Warnock 2007, 47–51. Warnock does not specify whether this energy content is for dried or charcoal pomace, although it is likely for dried pomace. Since charcoal has a higher energy content than raw wood, it can be assumed that charcoal pomace would also have a higher energy content than dried pomace.

The burning properties of dried pomace make it a viable alternative to charcoal and in some cases even the preferred type of fuel. Pomace flame burns at a high and more consistent temperature for a longer period of time than wood charcoal.[16] It also burns with an odorless and almost smokeless fire, which is a desired characteristic when used indoors for cooking or heating.[17] Ethnographic work by Sethom and Matson found that the modern potters in Messenia (Greece) and Moknine (Tunisia) preferred pomace over wood charcoal when firing their kilns, as the pomace burns with little ash and the high temperature reduces firing time.[18] At Thrapsano in Crete, potters stated that 2.5 tons of olives will fuel a kiln 2.5 m in diameter for 10 hours at 1,000°C.[19] Finally, in Turkey, where much of the olive oil is still produced using traditional methods, the pressing waste is used as a fuel in the olive oil mills and in bakeries.[20] Thus, pomace has been, and still is, used in a range of industrial and domestic activities.

IDENTIFICATION OF POMACE IN THE ARCHAEOLOGICAL RECORD

When pomace is used as fuel, it leaves readily identifiable traces in the archaeological record. Carbonization experiments have demonstrated that the burning of whole olives and dried pomace causes the olive flesh and skin to turn to ash, usually leaving behind only the carbonized endocarp.[21] The question becomes, how is pomace fuel to be distinguished from olives burned for ritual purposes or as table waste or carbonized during accidental fires?

When combined, the key identifying features of pomace fuel are the fragmentary nature of the endocarps, the concentration of the fragments, and, of course, their context.[22] Cato (*Agr.* 66.1) and Columella (*Rust.* 12.52.6–7) both claimed that crushing the olive stones during milling would spoil the flavor of the oil. However, modern experimental work has proven that crushing the stones has no effect on the flavor of the oil and furthermore that it is impossible to use a *trapetum*, or rotary-type mill, without crushing most of the stones.[23] Thus, finds of carbonized, fragmented olive stones can indicate olive oil production. However, olive stones could also become fragmented in antiquity as a result of postdepositional factors such as trampling and/or may be broken during modern recovery when undergoing flotation.[24] Additional experimentation on modern and archaeological olive stone specimens has suggested that the presence of rounded edges on the endocarp fragments indicates breakage prior to deposition, while sharp edges indicate breaks that occurred during excavation and sample processing.[25] Recent work by Marinova et al. has attempted to determine the impact of heat on the endocarp fragment edges, but their results are in the early stages and are not yet conclusive.[26]

Consequently, it is the quantity of carbonized fragments that helps confirm the presence of pomace fuel. It is important to note that many of the endocarp fragments will turn to ash during the burning process, and subsequently, from an archaeological perspective, the few fragments that survive represent only a small proportion of the total amount of pomace that was originally burned.[27] Thus, the accumulation of large quantities of olive stones probably represents repeated burning events on a habitual basis. While it would be pointless to try to assign a minimum number of fragments as an indicator of fuel, the presence of a concentrated quantity of carbonized fragmented endocarps in a single sample, context, or area of the site helps suggest the burning of pomace fuel rather than discarded table olives, food preparation, or ritual waste.[28] For example, 4,033 olive stone fragments were recovered from a single 40 liter soil sample from the Cardo V sewer in Herculaneum (fig. 2), while almost all of the 2,195 olive remains found during the cleaning of Bakery 1.12.1–2 at Pompeii were recovered from a single room (contexts described in the section "The

[16] Warnock 2007, 47–8.

[17] Brun 2003, 183.

[18] Sethom 1964; Matson 1972.

[19] J.-P. Brun, pers. comm. 2014.

[20] Doymaz et al. 2004, 214. During olive oil production, pomace is used to heat the water that is poured over the press beds to release additional oil (Foxhall 2007, 133–34). In pottery production, it is used to fire the kilns.

[21] Adam-Veleni and Mangafa 1996; Margaritis and Jones 2008a, 2008b. The pulp and epidermis can survive, but it is rare, and the epidermis will often disintegrate during flotation (Margaritis and Jones 2008a, 397).

[22] Neef 1990; Adam-Veleni and Mangafa 1996; Margaritis and Jones 2008a; Margaritis 2013, 749.

[23] Tyree and Stefanoudaki 1996; Warnock 2007, 75–8; Margaritis and Jones 2008a, 397–99. Since milling will crush most but not all of the stones, a sample containing a mixture of whole and fragmentary olives should not immediately be ruled out as evidence for olive oil pressing waste.

[24] Bookidis et al. 1999, 20; Margaritis and Jones 2008a, 397. In some cases, fragmentation can occur as a result of both milling and trampling, as in the olive stones recovered from the flour-milling rooms in the bakeries at Pompeii (Monteix 2009).

[25] E.g., breaks that would occur during flotation (Neef 1990, 298).

[26] Marinova et al. 2011.

[27] Mason 2007, 333; Warnock 2007, 47.

[28] Margaritis and Jones 2008a, 397. The presence of scatters of carbonized olive stone fragments is discussed in the section "Domestic Uses of Pomace."

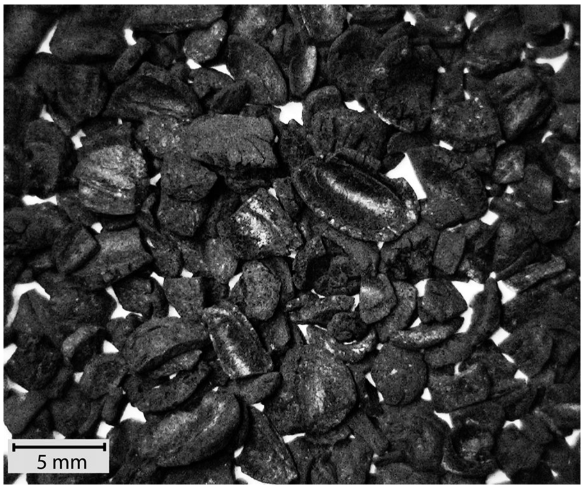

FIG. 2. Fragments of carbonized olive stones from the Cardo V sewer, Herculaneum.

Use of Pomace in the Roman World").[29] Only 1.35% and 1%, respectively, of the olive stones recovered from these two assemblages were whole. The quantities of endocarps are too large to represent either table waste or burnt offerings, while the high degree of fragmentation is indicative of milling during olive oil production.

Finally, the context must be considered. Is there evidence for olive oil production nearby? Is the context associated with a known location of pomace use, such as kilns, oil presses, or domestic spaces? Is this the only context to produce charred and fragmented olive stones? How likely is it that the olive stones from this context were subject to postdepositional trampling? Addressing this final question is important, as there are times when it is impossible to distinguish trampled table waste from fuel waste.

The archaic site of Azoria in Crete is a prime example of the way in which the use of pomace and the consumption of table olives can be distinguished from each other in the archaeological record. A single olive press supplied the town with olive oil. Fragmentary carbonized olive endocarps were found in a hearth in the oil press room as well as on the floor surfaces of houses throughout the site. The olive remains from the press room were found in a context associated ethnographically and historically with pomace fuel use; in addition, they were numerous and highly fragmented with dull, rounded edges, almost certainly indicating fuel waste. The olives found on the floors of the houses, while also fragmented, were present in smaller quantities and were recovered along with grains, pulses, and grapes.[30] While it is probable that pomace was being used as fuel in the houses,[31] trampling cannot be ruled out as a possible source of fragmentation, and thus in the household assemblages it cannot be known for certain which olives represent food debris and which represent fuel waste. Consequently, although fragmentation, quantity, and context are key indicators of pomace fuel use, each assemblage of olive stones must be evaluated on an individual basis.

The interchangeability of wood charcoal and dried pomace means that pomace can appear in almost any context in which it is reasonable for charcoal to appear.[32] While the use of pomace expanded during the Roman period both geographically and quantitatively, secure archaeobotanical evidence for pomace fuel on Roman sites is heavily biased toward industrial contexts. Although the ratio of domestic to industrial contexts demonstrating the use of pomace fuel is beginning to equalize, it is important to recognize that the full range of Roman-period contexts has not yet been uncovered. Pomace use during the pre-Roman period and the associated archaeological contexts are better understood and more varied than for Roman-period sites, probably because of more extensive sampling for archaeobotanical remains. Thus, the following section, highlighting pomace use in antiquity up until the Roman period, is intended to aid the reader in distinguishing, as much as possible, pomace fuel residue from other contexts containing carbonized olive stones.[33]

ARCHAEOBOTANICAL FINDS OF POMACE FUEL FROM THE PRE-ROMAN PERIOD

This section reviews archaeobotanical finds of pomace fuel from around the Mediterranean; evidence dating from the third millennium B.C.E. to the second century B.C.E. is considered so that pomace use during the Roman period can be understood against this broader chronological background. The list, as shown in table 1, is by no means exhaustive, and only

[29] Monteix 2009, 331; Coubray et al. 2013.

[30] Haggis et al. 2011, 7–11, 43–6.

[31] Scarry et al. 2013.

[32] The only exception is iron smelting, as iron has a melting point of 1,538°C. Biomass fuels, including dried pomace, can reach a maximum furnace temperature of only 1,400°C, while charcoal can reach temperatures of more than 1,600°C (Rehder 2000, 7).

[33] It should be kept in mind that meeting these three criteria is not always enough to distinguish pomace fuel use from dining waste, especially in contexts where postdepositional trampling is a possible cause of fragmentation. For a good example where fragmented olive stones could be fuel or kitchen waste, see Bookidis et al. 1999, 26.

TABLE 1. Sites with archaeobotanical evidence for pomace fuel use.

Site and Location	Date	Use of Pressings	Reference(s)
Tel Yarmouth, Israel	3100–2300 B.C.E.	D	Salavert 2008
Chamalevri-Tzambakas House, Crete	2160–1900 B.C.E.	D	Sarpaki 1999
Tell Tweini, Syria	1600–1100 B.C.E.	D	Bretschneider and Van Lerberghe 2008; Marinova et al. 2011
Tufariello (Buccino), Italy	1800–1400 B.C.E.	P	Holloway 1975
Mochlos, Crete	1700–1400 B.C.E.	D	Hamilakis 1996; Sarpaki and Bending 2004
Maroni (Vournes), Cyprus	1300 B.C.E.	O	Hadjisavvas 1996
Azoria, Crete	630–480 B.C.E.	O/D	Haggis et al. 2011
Ayia Varvara-Almyras, Cyprus	600 B.C.E.	D	Fasnacht et al. 1996; Kassianidou 1998
Vrasna, Macedonia	500–300 B.C.E.	O	Adam-Veleni and Mangafa 1996
Kopetra (Mari), Cyprus	500–300 B.C.E.	O	Hadjisavvas 1996
Corinth, Greece	450–400 B.C.E.	S/D	Bookidis et al. 1999
Tria Platania, Greece	4th–2nd c. B.C.E.	D	Margaritis and Jones 2008a
Maresha, Israel[a]	2nd c. B.C.E.	O	Kloner and Sagiv 2003
Pergamon, Turkey[a]	2nd c. B.C.E.–6th c. C.E.	P	Erdemgil and Ozenir 1982
Karanis, Egypt[a]	late 1st–mid 3rd c. C.E.	D?	Husselman 1952; Ault 1999
Leptiminus (site 290), Tunisia[a]	late 1st–3rd c. C.E.	P	Smith 2001; Stirling and Ben Lazreg 2001
Pompeii (bakeries I.12.1–2, VII.1, 25.46–47), Italy[a]	1st c. B.C.E.–79 C.E.	B	Monteix 2009; Coubray et al. 2013
Pompeii (Insula VI.1), Italy[a]	2nd c. B.C.E.–79 C.E.	D	Ciaraldi 2007; Murphy et al. 2013
Herculaneum (Cardo V sewer), Italy[a]	69–79 C.E.	D	Robinson and Rowan 2015
La Garde (Roman villa), France[a]	late 1st/early 2nd–mid 3rd c. C.E.	O/BA	Brun et al. 1989
Carthage, Tunisia[a]	mid 2nd–6th c. C.E.	P (lime?)	Ford and Miller 1976
Leptiminus, Tunisia[a]	late 3rd–4th c. C.E.	P	Smith 1998
Sepphoris, Israel	363–640 C.E.	G	Fischer 1999
Carthage, Avenue Habib Bourguiba, Tunisia	439–533 C.E.	D	Stewart 1984; van Zeist 1994
Carthage, Tunisia	later 5th–early 7th c. C.E.	D	Hoffman 1981, 1982
Leptiminus, Tunisia	6th c. C.E.	P	Smith 1998
Oudhna, Tunisia	late 6th–7th c. C.E.	P	Barraud et al. 1998; Lewit 2011
Androna (al-Andarin), Syria	mid 6th c. C.E.	P	Mango 2011

B = bakery; BA = bath complex; D = domestic context; G = glass furnace; O = olive oil pressing; P = pottery kiln; S = sanctuary

[a] Site dates to the Roman period.

sites that contain a sufficient number of carbonized olive stone fragments, within a proper context, have been included (fig. 3).[34] The precise number of whole and fragmented olive stones is not always recorded in the publications, but whenever possible, the listed sites are those in which the excavators themselves believe there to be sufficient evidence for pomace fuel use.

The differences between wild and domesticated olives cannot be determined by charcoal, olive stones, or pollen analysis (although new genetics research is ongoing),[35] and therefore at early sites it is helpful to have evidence of large-scale pressing equipment if the remains of carbonized olive stones are to confirm the association with fuel use rather than food consumption.[36] The first observable instance of pomace as a regular fuel source comes from the Early Bronze Age site of Tel Yarmouth in Israel. Three areas of the site were extensively sampled, and the olive stone material (whole and fragmented endocarps) constituted 31% of the total archaeobotanical assemblage. The sampled areas included two domestic and one palatial complex, suggesting that even at this early date, pomace fuel was being used for domestic purposes.[37]

Olive cultivation and olive oil production spread throughout the eastern Mediterranean during the Bronze Age (see fig. 3).[38] Archaeological and archaeobotanical evidence indicate that pomace, in addition to acting as a domestic fuel source, was now being used in oil, pottery, and even bronze production. The Protoapennine B (ca. 1800–1400 B.C.E.) site of Tufariello in Buccino (Italy) had an ashy layer containing 15 hearths related to pottery production. The recovery of olive fragments (ca. 85 olive stones) in a single environmental sample from this ashy layer suggests that pomace fuel was being used to fire the pottery.[39] Similarly, at the Late Minoan I site of Mochlos in Crete, a large concentration of fragmented olive stones was found inside a room used for bronzeworking, leading to the hypothesis that pomace was used to heat the metal.[40] The Late Cypriote IIC (ca. 1300 B.C.E.) site of Maroni on Cyprus is an early example of the use of pomace in the production of olive oil, as olive stones were found in an ashy layer on the floor of a press room next to the trough used to collect the oil.[41] Interestingly, at a Hellenistic olive oil press site in Kopetra, Cyprus, a large quantity of carbonized olive stones was also found on the floor of a press room near the collecting vats, indicating the continued use of pomace fuel in association with olive oil production in Cyprus throughout the centuries.[42]

There is a notable decline in the number of sites producing large quantities of carbonized olive stones during the Iron Age. The decline might be due to several historical factors, the collapse of the Mycenaean palaces and so forth, but it is equally probable that it is the result of excavation bias.[43]

The use of pomace as fuel in the production of olive oil continued during the Hellenistic period, as illustrated by the site of Vrasna in Macedonia.[44] Pomace also continued to be used in a variety of domestic settings, including a rock shelter at Ayia Varvara-Almyras (Cyprus) and the dining rooms at the Sanctuary of Demeter and Kore at Corinth.[45] The large rural farmstead at Tria Platania in Greece, although it had no press of its own, was using pomace for cooking and heating. Approximately 2,976 fragments were recovered from a single sample, while more than 13,868 fragments were recovered from a single pit. The absence of press equipment at the site suggests that pomace was available for sale in rural areas and that there was beginning to be a market for this by-product.[46] Thus, by the start of the second

[34] The chart does not include sites where only artifactual or structural evidence for olive oil production has been identified, although even in the absence of botanical finds it is probable that pomace was used nearby in some capacity. See, e.g., Mattingly 1988b; Ault 1999; Fentress 2001; Riley 2002.

[35] Runnels and Hansen 1986; Liphschitz et al. 1991; Terral et al. 2004; Simchoni and Kislev 2006; Breton et al. 2009.

[36] Smaller forms of equipment, such as a mortar and pestle, could be used to crush the olives, although olive oil produced on such a small scale would not generate enough pomace to be used as a regular source of fuel (Warnock 2007, 72–5).

[37] Salavert 2008, 55–8.

[38] Although the wild olive (*Olea europaea* var. *sylvestris*) is native to certain regions of Spain, there is little evidence to suggest that olives were cultivated there before the Roman period. Much of the recent work on the spread of the olive and olive oil cultivation in Spain has focused on using morphometric analysis to distinguish between the wild and cultivated varieties, and thus details concerning the creation of an assemblage of carbonized olives are often absent from publications (Rodríguez-Ariza and Moya 2005, 2010).

[39] Holloway 1975, 56, 77–80.

[40] Hamilakis 1996, 3; Sarpaki and Bending 2004, 126.

[41] Hadjisavvas 1996, 64.

[42] Hadjisavvas 1996, 67.

[43] In Greece, only 16 sites, dated to between 1050 and 500 B.C.E., have been subject to archaeobotanical investigation (Megaloudi 2006, 77–9; Margaritis 2007).

[44] Adam-Veleni and Mangafa 1996; Foxhall 2007, 133. Evidence of pomace has also recently been found in the pressroom of a Classical/Hellenistic-period olive oil press in Keos, Greece (Karnava et al. [forthcoming]).

[45] Fasnacht et al. 1996, 102; Kassianidou 1998, 234; Bookidis et al. 1999, 26. It is possible the sanctuary remains represent a combination of fuel and food waste.

[46] Margaritis and Jones 2008a, 399. Olives may have been grown at Tria Platania and pressed elsewhere. We do not know

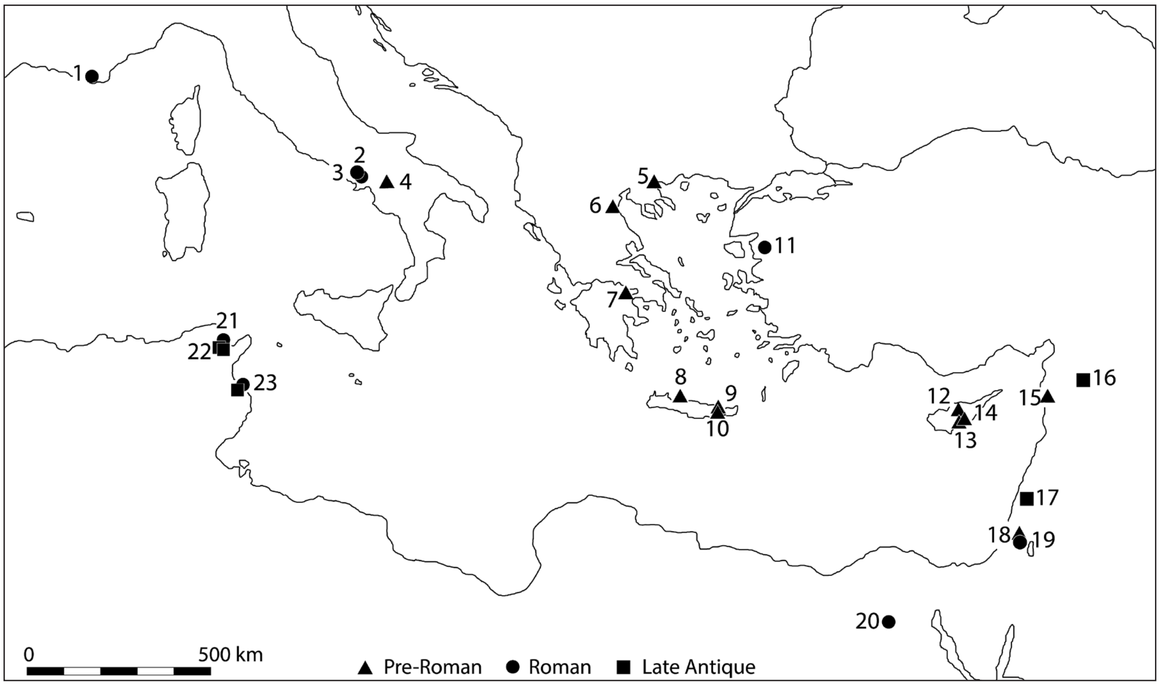

FIG. 3. Sites throughout the Mediterranean demonstrating evidence for pomace fuel. Spain is notably absent from this map. Other gaps in the map, particularly Algeria, are probably due to an absence of survey, excavation, and recording of environmental samples: *1*, La Garde, Var; *2*, Herculaneum (Cardo V sewer); *3*, Pompeii (bakeries and Insula VI.I); *4*, Tufariello (Buccino); *5*, Vrasna; *6*, Tria Platania; *7*, Corinth; *8*, Chamalevri-Tzambakas House; *9*, Azoria; *10*, Mochlos; *11*, Pergamon; *12*, Maroni (Vournes); *13*, Ayia Varvara-Almyras; *14*, Kopetra (Mari); *15*, Tell Tweini; *16*, Androna (al-Andarin); *17*, Sepphoris; *18*, Tel Yarmouth; *19*, Maresha; *20*, Karanis; *21*, Carthage; *22*, Oudhna; *23*, Leptiminus.

century B.C.E., pomace already had an established use in a wide range of domestic settings as well as in the production of olive oil and pottery.

THE USE OF POMACE IN THE ROMAN WORLD

As this brief review of the evidence makes clear, the use of pomace is by no means restricted to the Roman period. What sets the Roman period apart is the interrelationship between pomace use, increased olive oil production, economic growth, and the increase and expansion of industries with substantial fuel requirements. Pomace continued to serve the same domestic and industrial functions that it had for centuries. However, the production pressures exerted by the population of the empire meant that pomace fuel was introduced into new urban markets and began to play a larger role in industrial production.

Industrial Uses of Pomace

Secure examples of the industrial uses of pomace during the Roman period are restricted to pottery, mortar, olive oil, and bread production. During excavations at a late first- to third-century C.E. kiln at Leptiminus, five amphoras filled with carbonized olive stones (possibly charcoal pomace), all found lying next to the kiln, were recognized as the fuel source. It was then acknowledged that the relationship between olive oil and pottery production in the Roman empire was more interconnected than previously thought.[47] It has recently been suggested that the Tunisian African Red Slip pottery production sites were located near the inland olive oil presses so that the potters could take advantage of the large volumes of pomace generated during each pressing season.[48] Although the topic is still debated,[49] the close relationship between olive oil and pottery production helps explain why a pottery style destined for maritime export was produced in an area that required the finished products to be shipped overland to the coast. It is beyond the scope

whether it was the owner of the olives or the owner of the olive press who kept the pomace (Foxhall 1998, 39).

[47] Smith 2001, 435; Lewit 2011, 319–20. The amphoras also contained twigs and other unidentifiable burned material, suggesting that the contents were a mixture of fuel sources (Stirling and Ben Lazreg 2001, 227–28).

[48] Lewit 2011, 320; Wilson 2012, 150.

[49] Leitch 2010, 2011; Lewit 2011; Hobson 2012.

of this article to comment on the debate except to state that the chronological and geographical history of the use of pomace in pottery kilns, coupled with the shortage of wood in central and southern Tunisia, should eliminate any questions concerning pomace as a probable fuel source in African Red Slip production (no African Red Slip kilns have actually been excavated). The excavation of 17 kilns at Pergamon, in use from the second century B.C.E. to the sixth century C.E., uncovered large quantities of olive stones in the ash layer of some of the stoke pits.[50] Thus, the association of pottery production sites with areas of olive oil production is not limited to North Africa. Further archaeobotanical sampling will no doubt produce additional evidence of this relationship in the other olive oil producing regions of the Roman empire.[51]

Kilns designed to produce mortar from limestone also used pomace fuel. At Carthage, carbonized olive stones were found within mortar samples taken from walls associated with the House of the Greek Charioteers. The olive stones would have become incorporated into the lime during the burning process. The samples date from the second century C.E. to the sixth century C.E., which suggests that the use of pomace to fire the lime kilns was a long-standing practice in Carthage.[52]

The evidence for pomace fuel in olive oil production during the Roman period is scant but nonetheless present. At the second-century B.C.E. site of Maresha (Israel), 35 fragmentary and intact olive stones were found in a socket in a subterranean olive press room. The socket probably served as part of a heating installation for the presses.[53] Built in the first century B.C.E., the villa of Saint-Michel à La Garde (France) contained at least six olive oil presses, installed in the early second century C.E., and a large masonry press room with four heating installations. During excavation, all the heating installations were found to contain large quantities of fragmented carbonized olive stones mixed with charcoal.[54] The excavators believe that the pomace and charcoal were used to heat the room and the water required for pressing. Archaeobotanical evidence for heating the press room with pomace is in accordance with the claims of the ancient authors that pomace fuel was the best way to keep the press room warm but free of smoke and soot.[55] Although at the moment the number of secure Roman-period examples is limited, based on the numerous finds of pomace fuel in oil presses from pre-Roman sites, it is highly probable that pomace was used at Roman olive oil pressing installations around the Mediterranean.

The data for the use of pomace fuel in bread production come from the "Pistrina—Recherches sur les Boulangeries de l'Italie Romaine" project. Between 2008 and 2011, 32 bakeries in Pompeii were cleaned and four were excavated.[56] A total of 1,818 liters of soil were processed from two of the four excavated bakeries (see fig. 3), and carbonized olive stone fragments were found to dominate the assemblages. The number of fragments ranged from 832 to 2,763, while approximately 4% of the stones were found intact. The high degree of fragmentation, in addition to their location near the ovens, led the excavators to conclude that the olive stones must have been used as fuel for the ovens.[57]

The Pompeii material is the first example of recognized pomace use in bakeries from the Roman empire and directly reflects increasing fuel demands due to economic and industrial growth. The advent of large-scale urban bakeries, where the majority of the populace would have purchased ready-made bread, did not occur until the first century B.C.E.[58] Large bakeries would have required a substantial amount of fuel, thus increasing the demand for raw wood and charcoal. Dried pomace would have been an acceptable and potentially cheaper alternative.[59] By the time of the 79 C.E. eruption, there was clearly a market for pomace in the Bay of Naples. The large quantities of olive stones, scattered throughout the bakeries in multiple preeruption contexts, indicate that this was not a single event and that there was probably an established relationship between the producers and consumers of pomace in the Vesuvian region. Unlike the African Red Slip pottery kilns, bakeries in the Bay of Naples were not directly linked either spatially or economically to olive oil production. The bakeries did not produce olive oil and thus did not generate their own pomace. The need to import pomace into the bakeries suggests that it had to be purchased.

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[50] Erdemgil and Ozenir 1982.

[51] Lewit 2011, 319.

[52] Ford and Miller 1976.

[53] Kloner and Sagiv 2003, 53–9. Although the number of olives is quite small, it is possible that this assemblage represents the final burning event and that the socket was cleaned out after each use.

[54] Brun 2005, 88–92. Unfortunately, the precise number of fragments is not provided (Brun et al. 1989, 113–14).

[55] Cato, *Agr.* 65; Columella, *Rust.* 12.52; Plin., *HN* 15.22.

[56] Monteix et al. 2012.

[57] Monteix 2009, 2010a; Monteix et al. 2011, 2012; Coubray et al. 2013.

[58] In the first century B.C.E. evidence for cereal processing within Pompeii disappears, and subsequently grain is brought into the town, having been processed elsewhere (Robinson 1999, 101; Ciaraldi 2007, 148–50).

[59] The reason that pomace would have been cheaper than charcoal is discussed in the following section.

Baking was not the only urban activity that required large quantities of fuel. The construction and heating of baths, often on an enormous scale, would have put further pressure on fuel resources, especially in drier climates.[60] Unfortunately, we have extremely little evidence for the use of pomace at baths, as baths, and especially those in the more arid areas of the empire, have historically not been subjected to the same environmental sampling procedures as occupation levels and kilns.[61] Nevertheless, we should begin to entertain the idea that baths situated in scarcely wooded areas, and especially the larger complexes, such as the Antonine baths at Carthage, were fueled by pomace. The pressure to produce enough charcoal to heat the baths would have been an enormous and unnecessary expense if pomace was readily available.

Domestic Uses of Pomace

It is not surprising that if pomace was being used as fuel in the bakeries of Pompeii it was also being used in the houses of Pompeii and Herculaneum. Evidence for the domestic use of pomace is extremely rare in the Roman empire, probably because very few domestic dwellings have been excavated in the major olive oil producing regions, such as North Africa. The lack of data, therefore, makes the finds of fragmented olive stones from Herculaneum, and to a lesser extent Pompeii, all the more important. Not only do they come from secure contexts, particularly at Herculaneum, but the remains also establish the use of pomace in an urban setting that had easy access to wood for charcoal.

Between 1995 and 2006, the Anglo-American Project in Pompeii (AAPP) excavated all possible ground surfaces of Insula VI.1. Their extensive sampling strategy, taking a soil sample from each excavated context, meant that all types of deposits and surfaces were sampled, including garden soil, ritual deposits, and roads. Although found in low concentrations, carbonized olive stones were by far the most ubiquitous item (along with grape pips), identified in almost every sample and from all properties except the Via Consolare. The presence of so many endocarps led the excavators to refer to the olive stones as "background noise," and they have suggested that the stones could represent either kitchen waste or domestic fuel.[62] The concentrated deposit of olive fragments from a pit in the garden of the House of the Wedding of Hercules almost certainly represents fuel waste.[63]

The Herculaneum material comes from the Cardo V sewer, a large, elongated cesspit that ran beneath the shops and apartments of Insula Orientalis II (fig. 4). Based on pottery analyses, the material in the sewer probably accumulated in the decade prior to the eruption of 79 C.E.[64] The sewer does not have an outflow point or surface water collection drains and thus was fed exclusively by eight latrine shafts and three small rainwater drains that extended down from the roof.[65] In 2007, the contents of the north–south branch of the sewer were excavated by the Herculaneum Conservation Project to allow for modern piping to be fitted to the roof of the tunnel.[66] The north–south branch is 86.3 m long and, although it was partly explored by Maiuri in 1949, approximately 53 m of material remained undisturbed.[67] The sewer was divided into 53 quadrants, each measuring 1 m^2, for ease of collection, but the entire sewer was excavated stratigraphically.[68] Since the tunnel, like the street above, slopes with an approximate 8% gradient toward the sea, there was a downward shift of the material, and thus the sewer must be regarded as a single archaeological context.[69] During excavation, 1,140 liters of material were processed through sieving and flotation. The residue was sorted with 1 mm and 2 mm sieves, while a 0.5 mm sieve was used for the flot.[70] The sorted and identified material comes from all the stratigraphic layers present in six quadrants that are spread along the length of the sewer (see fig. 4). A total of 30% of the processed material, equaling 220 liters, or 3% of the entire sewer contents, has been examined by the author.

Carbonized olive stones made up 94.3% of the carbonized assemblage. A total of 88 whole olive stones and 6,426 fragments were recovered. As most of the olive stones will have burned to ash, this assemblage represents only a small fraction of what was once used.

If the Herculaneum assemblage represents one of the first recognized instances of the urban domestic use of pomace fuel in the Roman period, then it is especially important to establish that the olive stones represent fuel used for heating and cooking and were not carbonized as a result of other formation processes—

[60] Wilson 2013, 260.

[61] Carbonized olive stones were found in the praefurnium of the bath complex at the Roman villa at La Garde (Brun et al. 1989, 126).

[62] Murphy et al. 2013, 415.

[63] Ciaraldi 2007, 147.

[64] P. Roberts, pers. comm. 2011.

[65] Camardo 2006–2007; J. Andrews, pers. comm. 2012.

[66] The site had been subject to water damage, and it was decided that using the Roman tunnel would be the least destructive way to drain water from the site (Pesaresi and Castaldi 2006, 228).

[67] Camardo 2011. The east–west branch of the sewer was also excavated by Maiuri (1958, 467–69), and none of the environmental finds was kept or recorded.

[68] Camardo 2006–2007.

[69] Camardo et al. 2006, 190 n. 24; Camardo 2008, 419.

[70] Robinson 2007a.

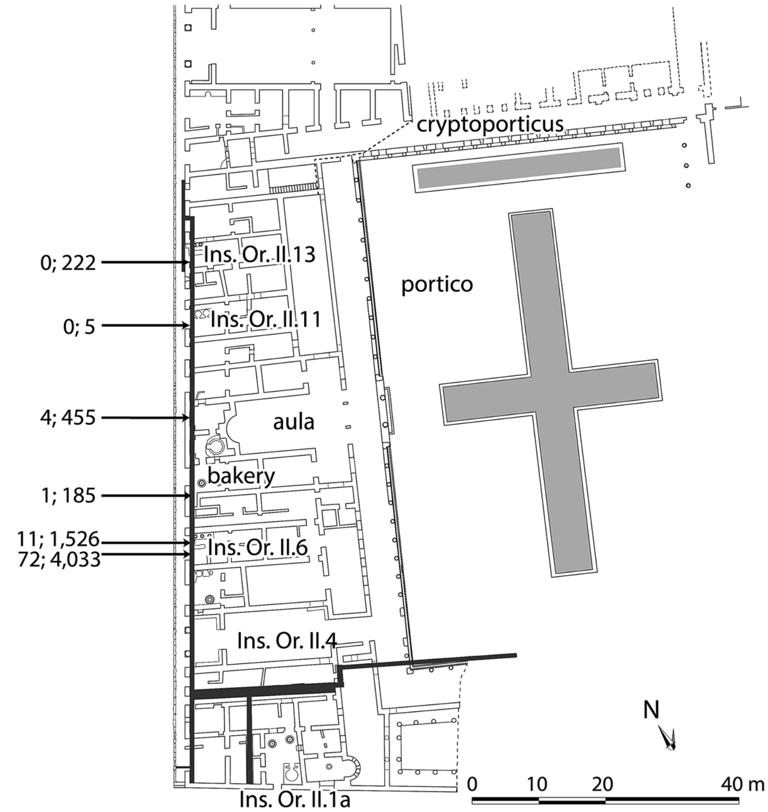

FIG. 4. Plan of Insula Orientalis II, showing the Cardo V sewer running beneath the shops and apartments, and the adjacent palaestra with its cross-shaped pool. Arrows point to the location of the study quadrants along the north–south branch of the sewer. The first number refers to the number of whole carbonized olive stones, while the second refers to the number of fragments. Units situated directly above each study quadrant have been labeled (modified from Monteix 2010b, pl. 5).

namely, the 79 C.E. eruption, the burning of table waste, and the burning of offerings. Eliminating the eruption as a factor is relatively straightforward for both the Herculaneum and Pompeii material. As Insula VI.1 at Pompeii had already been excavated to the 79 C.E. levels during the 1770s, most of the AAPP material is from preeruption contexts.[71] In Herculaneum, the botanical assemblage from the Cardo V sewer contained vast quantities of delicate mineralized material that would not have survived if the contents of the sewer had been carbonized during the eruption. The limited number of entry points into the sewer meant that the ash from the eruption filtered in slowly and did not cause the full carbonization of the material. Thus, the Herculaneum assemblage also represents preeruption material.

There is no doubt that people in the Vesuvian region ate olives. Pliny (*HN* 15.16) claims that imported olives were better for consumption than Italian olives. It is the fragmentary nature of the Herculaneum assemblage that suggests that most olives were not consumed whole but were crushed during the milling stage of olive oil extraction.[72] Only 1.35% of the olives are whole, and one would expect a greater proportion of whole stones if they had been used as food. Most whole stones thrown into the sewer would probably have remained intact since the material was not subjected to postdepositional fragmentation caused by trampling. The Cardo V assemblage also contains mineralized olive seeds, which, like most of the other mineralized material from the sewer, represent foodstuffs that would have passed through the human digestive tract intact before entering the sewer as human waste. Thus, the mineralized olive seeds represent food waste, while the majority of the carbonized olive stones represent fuel use.

[71] Murphy et al. 2013, 410.

[72] Ciaraldi 2007, 147. Some were no doubt also eaten.

It is the quantity of olive stones that distinguishes this assemblage from those associated with ritual burnt offerings. At the House of the Greek Epigrams, three burnt offering pits contained a total of 10 olives.[73] Other ritual deposits from Pompeii have produced equally small numbers of carbonized olive stones, including the street-front shrine VI.1 (n=1), the House of the Vestals (n=1), the House of the Wedding of Hercules (n=3), and the House of Amarantus (n=1).[74] The sheer quantity of olive fragments from the Herculaneum sewer (n=6,426) appears to be more closely related to the numbers of olive stones found at sites such as Tria Platania (n=13,868), Carthage (Avenue Habib Bourguiba, n=1693), or Leptiminus (site 250, n=454) rather than ritual garden pits in Pompeii.[75] The number of stones is also too large and ubiquitous to have resulted from accidental burning. Moreover, the stones were distributed throughout the length of the sewer, and although the distribution was uneven, this does suggest that shops and apartments, other than the bakery at Insula Orientalis II.8, were generating pomace waste. Pomace fuel is therefore the most probable explanation for the presence of such a large volume of olive stones in the Cardo V assemblage at Herculaneum.

LATE ROMAN AND LATE ANTIQUE POMACE USE

Olive pomace continued to be used in the centuries following the Roman period, although the geographical range of sites decreased (see fig. 3). Most of the evidence for Late Roman and Late Antique pomace use comes from North Africa and the Middle East. At Carthage, pomace continued to be used for domestic purposes during the Vandal and Byzantine occupations. The botanical assemblages from three cisterns at Carthage, one dating to the later fifth century C.E. and two to the late sixth to early seventh centuries C.E., were dominated by carbonized olive stone fragments, representing redeposited domestic table and fuel waste.[76] Additional excavations along Carthage's Avenue Habib Bourguiba uncovered Vandal layers that contained 1,655 carbonized olive fragments.[77] Based on the contexts of the finds (in pits used as rubbish dumps) and the large number of olives relative to other botanical remains, the excavators concluded that the olive stones represented redeposited fuel waste from domestic fires.[78] The scarcity of trees around the city, even in the Punic period, suggests that pomace was constantly being brought into the city from the surrounding farms.[79]

In addition to being used in domestic contexts, pomace continued to serve as fuel for industrial processes into the Late Antique period. When the ash layer around a sixth-century C.E. kiln at Leptiminus was sampled, it was found to contain ceramic waste and more than 1,000 carbonized olive stones.[80] Similarly, at Oudhna, burned olive stones were found inside a late sixth/seventh-century C.E. kiln.[81] Olive stones were also recently recovered from a mid sixth-century C.E. kiln in Androna, Syria.[82]

The Israeli site of Sepphoris produced glass vessels during the Byzantine I (363–451 C.E.) period. A large depression containing hundreds of carbonized olive stones as well as charcoal and glass waste was identified as a glassmaking furnace. Pomace was used to make the charcoal burn hotter and achieve the high temperatures (1,030–1,200°C) required for melting the glass and blowing the vessels.[83] Although carbonized olive stones have not yet been identified at Roman-period glassmaking sites, there is a high probability that the Romans also used a combination of pomace and charcoal for glass production.

POMACE AND CHARCOAL

Regarding the Roman period, the domestic and industrial uses of olive pomace at Herculaneum and Pompeii appear at first sight unusual. The Campanian region, which extended inland to the slopes of the Apennine and Lattari Mountains, had more available woodland than large parts of North Africa and the Middle East, and thus charcoal was available.[84] The presence of wood charcoal in every sample from the Cardo V sewer at Herculaneum and the vast quantities recovered from the AAPP excavations at Pompeii indicate that pomace acted as a supplement to charcoal, not as a replacement.[85] There is very little evidence

[73] Robinson 2007b.

[74] Ciaraldi and Richardson 2000, 80; Robinson 2002, 95–6; Ciaraldi 2007, 100, 117–19; Murphy et al. 2013, suppl. 1.

[75] Stewart 1984; Rife 2001, 301; Smith 2001, 434; Margaritis and Jones 2008a, 395.

[76] Raw data for the number of olives are available in Hoffman 1981, 261–65; 1982, 193–96.

[77] Stewart 1984.

[78] Hurst and Roskams 1984, 17–19, 116. In the three analyzed samples, the olive stones constituted 71% of the total archaeobotanical assemblage (Stewart 1984).

[79] van Zeist and Bottema 1983.

[80] Smith 1998, 193–94.

[81] Lewit 2011, 319. There is no mention of the quantity of olives found (Barraud et al. 1998, 145).

[82] Mango 2011, 108.

[83] Fischer 1999, 896, 903.

[84] Except for Pergamon and La Garde, all the Roman sites with evidence for pomace use are located in areas with arid climates.

[85] Veal 2012, 23.

from Pompeii and no evidence from Herculaneum for olive oil production within the towns, and pomace would have had to be delivered from the nearby farms.[86] Why, then, did inhabitants of Pompeii and Herculaneum use pomace as well as charcoal if charcoal was readily available?

The question can be answered in terms of both the practical benefits and the economic advantages. In Herculaneum, the structure and arrangement of the shops and apartments of Insula Orientalis II would have made dried pomace a highly desirable type of fuel. Most residents of Insula Orientalis II would have lived behind and/or above shops that had an average floor space of only 34 m^2. The upper-floor rooms had small windows for light and ventilation and no chimneys.[87] Since pomace burns at a high temperature for longer and with less smoke than charcoal, it would have been the ideal fuel source for use in braziers, particularly in the winter when the shutters would have been closed to retain the heat.[88]

Except for the large apartment at Insula Orientalis II.7, none of the upper-floor apartments had evidence for raised hearths or kitchens.[89] However, the presence in the Cardo V assemblage of raw foodstuffs that require cooking before consumption, such as pulses, cereal grains, and fish, strongly suggests that cooking was done even in the smaller apartments. If cooking was done on the floor, possibly with the use of a stone slab supporting a small tripod or brazier, then pomace cakes would have been more manageable and efficient than raw wood or charcoal. Raw wood, even in Roman houses that had hearths, would have been nearly impossible to use as the primary cooking fuel.[90] Too much raw wood is required to create a fire hot enough to even boil water and fit beneath a tripod. Similarly, it may have been difficult for the bakeries to use raw wood because of space limitations in and around the ovens. As the bakeries at Pompeii were using pomace, it is possible that the bakery at Herculaneum in Insula Orientalis II.8 also used pomace as fuel for the bread oven, which may explain the higher concentration of olive stones at the southern end of the sewer, where the bakery is located (see fig. 4).

In addition to the practical benefits of pomace, cost probably played a significant role in ensuring its use in Herculaneum. While there is no way to determine whether all the apartments at Insula Orientalis II used pomace, the ubiquity of the burned olive stones suggests that pomace use was widespread in the insula regardless of shop or apartment size. Although the catchment of the Vesuvian towns included woodland, it is probable that pomace was actually cheaper than charcoal, especially at particular times of the year.[91] Olive oil was produced in the area, and while local production occurred on a significantly smaller scale than in areas such as Baetica or Tripolitania, it was not limited to personal use. Pollen analyses from the Naples harbor have indicated that large numbers of olive trees were growing in the region in the first century C.E.; olive and oak were the most abundant taxa found in samples.[92] The AAPP data have demonstrated an increase in the quantity of olives recovered from first-century B.C.E. to first-century C.E. deposits, also suggesting that there was an increase in olive oil production in the Vesuvian region.[93] Among the numerous nearby villas, at least three were in operation in 79 C.E. and have produced archaeological evidence of oil production in the form of presses and/or a *trapetum*: San Rocco, Villa Pisanella at Boscoreale, and Casa dei Miri at Gragnano.[94] The presence of at least two presses at San Rocco and Casa dei Miri suggests that large quantities of olive oil, and therefore pomace, were being produced.[95] It is probable that some of the pomace was used for future pressings as well as for fertilizing the olive groves. The excess pomace could easily have been transported into Pompeii and Herculaneum in amphoras, but it was more likely transported in skins or barrels or even loose in carts.[96] It is also possible that pomace cakes were formed and dried at the villas and then sold in the towns.

The amount of time and effort required to prepare dried pomace cakes for burning is minimal relative to the effort required to create charcoal. Wood for charcoal is often cut in the winter and then allowed to dry for six months. The charring process then takes

[86] Brun 2004, 12–27. A *trapetum* has also been found at the House of the Ship Europa (I.15.2–4, I.15.6) in Pompeii, although without any associated pressing equipment.

[87] Andrews 2006, 1:108–9; Monteix 2010b.

[88] Brun 2003, 183; Warnock 2007, 47–8.

[89] Andrews 2006, 2:101.

[90] Veal 2012, 26–7. However, it was probably used as kindling.

[91] For the wealthy Romans who owned both rural agricultural land and urban commercial or domestic properties in the Campanian region, pomace could have acted as an almost free fuel source, shipped directly from their farms for use on their urban properties.

[92] Allevato et al. 2010, 2368.

[93] Murphy et al. 2013, 416.

[94] Ruggiero 1881, 325; Rossiter 1981, 358–59; Brun 2004, 14, 20–1.

[95] Brun 2004, 20–1; see also the Oxford Roman Economy Project's Olive Oil and Wine Presses Database (http://oxrep.classics.ox.ac.uk/databases/olive_oil_and_wine_presses_database/).

[96] Peña 1998, 166–71; Marlière 2002.

five to seven days for larger logs, and the fire must be tended during the entirety of this time.[97] In addition to the labor input, the transportation of the charcoal would have increased the cost. Veal looked at 3,911 fragments of charcoal ranging in date from the third century B.C.E. to the first century C.E. from four different sites around Pompeii and found that after the second century B.C.E., 60% of the charcoal was made from beech (*Fagus sylvatica*).[98] Beech grows at elevations greater than 500 m, although ideally between 1,200 and 1,600 m. The nearest sources of beech were 15–25 km from Pompeii,[99] while Villa Pisanella, which produced olive oil, was only 2 km from Pompeii and 12 km from Herculaneum. The shorter distance the pomace had to travel would have reduced the shipping costs of this already less fragile product. The price of charcoal would have also varied by season, being the least expensive in the mid to late summer, just after the charcoal had been created.[100] Olive oil production takes place in the late autumn and winter, which is exactly when the charcoal supply would have been at its lowest. Thus, in the Bay of Naples, it is probable that in the winter pomace was less expensive than charcoal since it was more abundant, while charcoal was cheapest in the summer.

WIDER IMPLICATIONS

The archaeological evidence reviewed here suggests that olive pomace was an important source of fuel in the Mediterranean in antiquity. The arid climate in many areas meant that trees were scarce and, as a readily available by-product of olive oil production, pomace took on the role of charcoal in both domestic and industrial settings. The Romans were not unique or different in their pomace fuel use; they simply used it for a larger range of activities in a greater number of places than their chronological predecessors. In the history of pomace use, there is a high degree of continuity between the Roman empire and the centuries of peoples and cultures that came before and after them. However, the economic importance of pomace fuel during the Roman period represents a significant departure from the past. It allowed for an increase in the manufacture of goods that required significant fuel resources in their production without putting a strain on the charcoal supply and raising the cost of production. The volume of olive oil produced in the empire each year, and thus the volume of pomace, enabled this secondary fuel source to become a market commodity in its own right. Pomace was generated in such quantities that it could force a shift in manufacturing activities, enabling cost-effective larger-scale ceramic production in semiarid zones and perhaps even encouraging the co-location of ceramic production with olive oil production. It could also compete with charcoal as a fuel source even in densely forested areas.

The high volume of olive oil production and trade that took place in the Roman period, combined with vast quantities of surviving material culture in the form of presses and amphoras, puts us in a strong position to begin to assess the economic impact of this fuel source on an empire-wide scale. It is beyond the scope of this article to create a model for pomace production in the Roman world. However, I provide some rough estimates of pomace output so that the productive capacity of this by-product can be more readily understood and conceptualized. Estimates for olive oil production have been created for the Roman empire, and thus the amount of pomace can be extrapolated from those numbers.[101] Mattingly suggests an empire-wide output of ca. 500,000 to 1 million metric tons (543 million to 1.09 billion liters) of olive oil each year.[102] If every 200 liters of olive oil generates between 350 and 400 kg of pomace, the average annual amount of pomace produced in the Roman empire would be between 951,000 tons and 1.9 million tons (table 2).[103] That quantity of pomace could have provided 2.29–4.57 billion hours of heat.[104] To generate that much energy using charcoal would require roughly 2.7–5.5 million tons of raw wood. As many of the major centers of olive oil production in the empire were in arid regions, the availability of a viable charcoal alternative must have been crucial if high levels of productivity, particularly with respect to pottery production, were to be maintained and large-scale deforestation was to be avoided.

That the Roman empire could display such historical continuity but stand out economically has a significant impact on how we view and understand pomace use in the Roman world. First, the continued use of pomace throughout the Roman period means that we can assume that wherever olive oil was produced, pomace was also used. Subsequently, as the scale of olive oil production increased both quantitatively and

[97] Veal 2009, 143–46.
[98] Veal 2009, 71–83, 131–33. The sites were Insulae VI.1, VIII.7, V.2.g, and VIII.1.
[99] Veal 2009, 3–7, 168.
[100] Veal 2009, 209.

[101] Mattingly 1988c, 34; 1993; Hitchner 2002, 72–3; De Sena 2005.
[102] Mattingly 1988c, 34.
[103] Niaounakis 2011, 414.
[104] According to Warnock (2007, 51), 0.41 kg will provide heat for a single hour.

TABLE 2. Pomace and charcoal energy values based on high and low estimates of annual olive oil production within the Roman empire.

	Low Output	High Output
Volume of olive oil produced per annum (metric tons)	500,000 metric tons	1 million metric tons
Volume of pomace generated per annum (350 kg/200 liters)	951,000 metric tons	1.9 million metric tons
Volume of raw wood required to match volume of charcoal[a]	2.7 billion metric tons	5.5 billion metric tons
Overall calorific value of the pomace (5,360 kcal/kg)	5.09×10^{12} kcal	1.02×10^{13} kcal
Total hours of heat at 5 kg/12 hours (0.416 kg/hour)	2.29 billion hours	4.57 billion hours
Volume of charcoal required to match total volume of pomace (7,350 kcal/kg)	694,000 metric tons	1.39 million metric tons
Volume of olive oil produced per annum (liters)[b]	543 million liters	1.087 billion liters

[a] The calculation is based on a 1:4 efficiency ratio, where 4 kg of raw wood produce 1 kg of charcoal (Veal 2009, 146).
[b] One liter of olive oil weighs 0.92 kg (Marzano 2013, 99).

geographically during the Roman period,[105] we should expect to see the uses of pomace expand as well. Recognizing deposits of carbonized olive stones as pomace waste and being able to differentiate them from table or ritual waste will help clarify the types of fuels used at a particular site or for a particular industry. The presence of olive stones in the bakeries at Pompeii suggests that we may need to reassess our understanding of the fuels used in other industrial activities, such as glassmaking. Archaeologists should not immediately assume charcoal was the sole or primary fuel source, nor that it was necessarily always the first choice.

CONCLUSIONS

As a by-product of olive oil pressing, olive pomace was generated in enormous quantities each year without significant additional labor. The consistent generation of so much fuel has significant implications for our estimates of total fuel use and cost in the Roman empire. Moreover, the growing use of pomace in the Roman period relative to the rest of antiquity, particularly in industrial activities, raises new questions concerning fuel consumption and availability. Was the increased exploitation of pomace the result of an increase in olive oil production or a generally increased demand for fuel as a consequence of population growth, or did the use of pomace as a fuel source expand because of the growing number of industries and activities within the Roman empire that required large energy inputs? Is the use of pomace in Herculaneum and Pompeii a result of organized fuel management, or does it reflect a response to fuel shortages and price increases? Is there a relationship between the increased use of pomace during the Roman period and an absence of deforestation, in spite of the increase in the manufacture of goods during this period? Evidence of deforestation does not appear until the Middle Ages.[106] Understanding the extent of pomace use, its role in the different regions of the empire, and its relationship to both charcoal and other secondary fuel sources is crucial if we wish to understand the careful balance the Romans achieved between widespread fuel consumption and fuel sustainability and management.

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Works Cited

Adam-Veleni, P., and M. Mangafa. 1996. “Αρχαίο ελαιοτριβείο στα Βρασνά νομού Θεσσαλονίκης.” In *Ελιά και Λάδι, Καλαμάτα, Τριήμερο εργασίας της 7–9 Μαΐου 1993*, edited by A.E. Elias, 92–104. Athens: ETBA.
Allevato, E., E.R. Ermolli, G. Boetto, and G. Di Pasquale. 2010. “Pollen-Wood Analysis at the *Neapolis* Harbour Site

[105] Hitchner 2002.

[106] Kaplan et al. 2009, 3029.

(1st–3rd Century AD, Southern Italy) and Its Archaeobotanical Implications." *JAS* 37:2365–75.
Andrews, J. 2006. "The Use and Development of Upper Floors in Houses at Herculaneum." 2 vols. Ph.D. diss., University of Reading.
Attom, M.F., and M.M. Al-Sharif. 1998. "Soil Stabilization with Burned Olive Waste." *Applied Clay Science* 13:219–30.
Ault, B.A. 1999. "Koprones and Oil Presses at Halieis: Interactions of Town and Country and the Integration of Domestic and Regional Economies." *Hesperia* 68:549–73.
Avitsur, S. 1994. "Olive Oil Production in the Land of Israel: Traditional to Industrial." In *History and Technology of Olive Oil in the Holy Land*, edited by R. Frankel, S. Avitsur, and E. Ayalon, 91–156. Tel Aviv: Eretz Israel Museum.
Barraud, D., M. Bonifay, F. Dridi, and J.-F. Pichonneau. 1998. "L'industrie céramique de l'Antiquité tardive." In *Oudhna (Uthina): La redécouverte d'une ville antique de Tunisie*, edited by H. Ben Hassen and L. Maurin, 139–67. Mémoires 2. Bordeaux: Ausonius.
Bookidis, N., J. Hansen, L. Snyder, and P. Goldberg. 1999. "Dining in the Sanctuary of Demeter and Kore at Corinth." *Hesperia* 68:1–54.
Borgongino, M. 2006. *Archeobotanica: Reperti vegetali da Pompei e dal territorio vesuviano.* Studi della Soprintendenza archeologica di Pompei 16. Rome: L'Erma di Bretschneider.
Breton, C., J.-F. Terral, C. Pinatel, F. Médail, F. Bonhomme, and A. Bervillé. 2009. "The Origins of the Domesticated Olive Tree." *Comptes Rendus Biologies* 332:1059–64.
Bretschneider, J., and K. Van Lerberghe. 2008. *In Search of Gibala: An Archaeological and Historical Study Based on Eight Seasons of Excavations at Tell Tweini (Syria) in the A and C Fields (1999–2007). Aula orientalis* Suppl. 24. Barcelona: Editorial AUSA.
Brun, J.-P. 2003. *Le vin et l'huile dans la Mediterranée antique: Viticulture, oléiculture et procédés de transformation.* Paris: Errance.
———. 2004. *Archéologie du vin et de l'huile dans l'Empire romain.* Paris: Errance.
———. 2005. *Archéologie du vin et de l'huile en Gaule romaine.* Paris: Errance.
Brun, J.-P., G. Rogers, P. Columeau, M. Thinon, and M. Gérard. 1989. "La villa gallo-romaine de Saint-Michel à La Garde (Var): Un domaine oléicole au Haut-Empire." *Gallia* 46:103–62.
Camardo, D. 2006–2007. "Ercolano: Lo scavo della fogna dell'Insula Orientalis II." Unpublished report. Ercolano: Herculaneum Conservation Project.
———. 2008. "Lo scavo della fogna di *Insula Orientalis* II." In *Nuove ricerche archeologiche nell'area vesuviana (scavi 2003–2006): Atti del convegno internazionale, Roma, 1–3 febbraio 2007*, edited by P.G. Guzzo and M.P. Guidobaldi, 415–21. Studi della Soprintendenza archeologica di Pompei 25. Rome: L'Erma di Bretschneider.
———. 2011. "Case Study: Ercolano. La ricostruzione dei sistemi fognari." In *Roman Toilets: Their Archaeology and Cultural History*, edited by G.C.M. Jansen, A.O. Koloski-Ostrow, and E.M. Moormann, 90–3. *BABesch* Suppl. 19. Leuven: Peeters.
Camardo, D., M. Castaldi, and J. Thompson. 2006. "Water Supply and Drainage at Herculaneum." In *Cura Aquarum in Ephesus: Proceedings of the Twelfth International Congress on the History of Water Management and Hydraulic Engineering in the Mediterranean Region, Ephesus/Selçuk, Turkey, October 2–10, 2004*, edited by G. Wiplinger, 183–91. *BABesch* Suppl. 6. Dudley, Mass.: Peeters.
Cappers, R., and R. Neef. 2012. *Handbook of Plant Palaeoecology.* Groningen Archaeological Studies 19. Groningen: Barkhuis.
Ciaraldi, M. 2007. *People and Plants in Ancient Pompeii: A New Approach to Urbanism from the Microscope Room. The Use of Plant Resources at Pompeii and in the Pompeian Area from the 6th Century BC to AD 79.* Accordia Specialist Studies on Italy 12. London: Accordia Research Institute, University of London.
Ciaraldi, M., and J. Richardson. 2000. "Food, Ritual and Rubbish in the Making of Pompeii." In *Proceedings of the Ninth Annual Theoretical Roman Archaeology Conference, Durham 1999*, edited by G. Fincham, G. Harrison, R.R. Holland, and L. Revel, 74–82. Oxford: Oxbow.
Coubray, S., V. Zech-Matterne, and N. Monteix. 2013. "Of Olives and Wood: Baking Bread in Pompeii." Paper read at the Conference "Fuel and Fire in the Ancient Roman World," 8–9 March, Rome.
Cuomo di Caprio, N. 2007. *La ceramica in archeologia.* Vol. 2, *Antiche tecniche di lavorazione e moderni metodi di indagine. StArch* 144. Rome: L'Erma di Bretschneider.
Dearne, M.J., and K. Branigan. 1995. "The Use of Coal in Roman Britain." *AntJ* 75:71–105.
De Sena, E.C. 2005. "An Assessment of Wine and Oil Production in Rome's Hinterland: Ceramic, Literary, Art Historical and Modern Evidence." In *Roman Villas Around the Urbs: Interaction with Landscape and Environment. Proceedings of a Conference at the Swedish Institute in Rome, September 17–18, 2004*, edited by B.S. Frizell and A. Klynne, 1–15. Swedish Institute in Rome Projects and Seminars 2. Rome: Swedish Institute in Rome.
Doymaz, I., O. Gorel, and N.A. Akgun. 2004. "Drying Characteristics of the Solid By-Product of Olive Oil Extraction." *Biosystems Engineering* 88:213–19.
Erdemgil, S., and S. Ozenir. 1982. "Preliminary Report on the Kilns Excavated in Ketios Valley." *RdA* 6:109.
Fasnacht, W., J. Kunz, C. Deslex, K. Zubler, P.O. Boll, V. Kassianidou, A. Connolly, and T. Maradi. 1996. "Excavations at Agia Varvara-*Almyras*: Fifth Preliminary Report." *RDAC* 1996:95–126.
Fentress, E. 2001. "Villas, Wine and Kilns: The Landscape of Jerba in the Late Hellenistic Period." *JRA* 14:249–68.
Fischer, A. 1999. "Glass Production Activities as Practised at Sepphoris, Israel (37 BC–AD 1516)." *JAS* 26:893–905.
Ford, R.I., and N. Miller. 1976. "Paleoethnobotany I." In *Excavations at Carthage, 1976, Conducted by the University of Michigan.* Vol. 4, edited by J.H. Humphrey, 181–87. Ann Arbor: Kelsey Museum, University of Michigan.
Foxhall, L. 1998. "Snapping Up the Unconsidered Trifles: The Use of Agricultural Residues in Ancient Greek and Roman Farming." *Environmental Archaeology* 1:35–40.
———. 2007. *Olive Cultivation in Ancient Greece: Seeking the Ancient Economy.* Oxford: Oxford University Press.
Fraser, R.A., A. Bogaard, M. Charles, A.K. Styring, M. Wallace, G. Jones, P. Ditchfield, and T.H.E. Heaton. 2013. "Assessing Natural Variation and the Effects of Charring, Burial and Pre-treatment on the Stable Carbon and Nitrogen Isotope Values of Archaeobotanical Cereals and Pulses." *JAS* 40:4754–66.
Galili, E., D.J. Stanley, J. Sharvit, and M. Weinstein-Evron. 1997. "Evidence for Earliest Olive-Oil Production in Submerged Settlements off the Carmel Coast, Israel." *JAS* 24:1141–50.
Hadjisavvas, S. 1996. "An Introduction to Olive Oil Produc-

tion in Cyprus." In *Olive Oil in Antiquity: Israel and Neighbouring Countries from the Neolithic to the Early Arab Period*, edited by D. Eitam and M. Helzer, 63–75. History of the Ancient Near East Studies 7. Padua: Sargon.

Haggis, D.C., M.S. Mook, R.D. Fitzsimons, C.M. Scarry, L.M. Snyder, and W.C. West III. 2011. "Excavations in the Archaic Civic Buildings at Azoria in 2005–2006." *Hesperia* 80:1–70.

Hamilakis, Y. 1996. "Wine, Oil and the Dialectics of Power in Bronze Age Crete: A Review of the Evidence." *OJA* 15:1–32.

Hillman, G.C., S. Wales, F. McLaren, J. Evans, and A. Butler. 1993. "Identifying Problematic Remains of Ancient Plant Foods: A Comparison of the Role of Chemical, Histological and Morphological Criteria." *WorldArch* 25:94–121.

Hitchner, R.B. 2002. "Olive Production and the Roman Economy: The Case for Intensive Growth in the Roman Empire." In *The Ancient Economy*, edited by W. Scheidel and S. von Reden, 71–86. Edinburgh: Edinburgh University Press.

Hobson, M.S. 2012. "The African Boom? Evaluating Economic Growth in the Roman Province of Africa Proconsularis." Ph.D. diss., University of Leicester.

Hoffman, E.S. 1981. "Palaeoethnobotany II: Plant Remains from Vandal and Byzantine Deposits in Three Cisterns." In *Excavations at Carthage, 1977, Conducted by the University of Michigan*. Vol. 6, edited by J.H. Humphrey, 259–68. Ann Arbor: Kelsey Museum, University of Michigan.

———. 1982. "Paleoethnobotany III: Charcoal Analysis from Vandal and Byzantine Deposits in Two Cisterns." In *Excavations at Carthage, 1978, Conducted by the University of Michigan*. Vol. 7, edited by J.H. Humphrey, 193–200. Ann Arbor: Kelsey Museum, University of Michigan.

Holloway, R.R. 1975. "Buccino: The Early Bronze Age Village of Tufariello." *JFA* 2:11–81.

Hurst, H.R., and S. Roskams, eds. 1984. *Excavations at Carthage: The British Mission*. Vol. 1, pt. 1, *The Avenue du President Habib Bourguiba, Salammbo: The Site and Finds Other Than Pottery*. Sheffield: University of Sheffield, Department of Prehistory and Archaeology.

Husselman, E.M. 1952. "The Granaries of Karanis." *TAPA* 83:56–73.

Kaplan, J.O., K.M. Krumhardt, and N. Zimmermann. 2009. "The Prehistoric and Preindustrial Deforestation of Europe." *Quaternary Science Reviews* 28:3016–34.

Karapmar, M., and J.T. Worgan. 1983. "Bioprotein Production from the Waste Products of Olive Oil Extraction." *Journal of Chemical Technology and Biotechnology* 33:185–88.

Karnava, A., E. Kolia, E. Margaritis, and P. Martzavou. Forthcoming. "A Classical/Hellenistic Oil Pressing Installation in Foti-Vroskopos, Keos." In *Proceedings of the International Conference Olive Oil and Wine Production in the Eastern Mediterranean During Antiquity, Izmir, Turkey, 17–19 November 2011*, edited by A. Diler, K. Şenol, and Ü. Aydınoğlu, 107–23. Izmir.

Kassianidou, V. 1998. "Small-Scale Mining and Smelting in Ancient Cyprus." In *Social Approaches to an Industrial Past: The Archaeology and Anthropology of Mining*, edited by A.B. Knapp, V.C. Pigott, and E.W. Herbert, 226–41. London: Routledge.

Kloner, A., and N. Sagiv. 2003. "Subterranean Complexes 44 and 45." In *Maresha Excavations Final Report*. Vol. 1, edited by A. Kloner, D.T. Ariel, and I. Rashut ha-'atikot, 51–73. Jerusalem: Israel Antiquity Authority.

Leitch, V. 2010. "Production and Trade of Roman and Late Roman North African Cookwares." Ph.D. diss., University of Oxford.

———. 2011. "Location, Location, Location: Characterizing Coastal and Inland Production and Distribution of Roman African Cooking Wares." In *Maritime Archaeology and Ancient Trade in the Mediterranean*, edited by D. Robinson and A. Wilson, 169–96. Oxford Centre for Maritime Archaeology Monograph 6. Oxford: Oxford Centre for Maritime Archaeology.

Lewit, T. 2011. "Dynamics of Fineware Production and Trade: The Puzzle of Supra-regional Exporters." *JRA* 24:313–32.

Liphschitz, N., R. Gophna, M. Hartman, and G. Biger. 1991. "The Beginning of Olive (*Olea europaea*) Cultivation in the Old World: A Reassessment." *JAS* 18:441–53.

Maiuri, A. 1958. *Ercolano: I nuovi scavi (1927–1958)*. Rome: Istituto Poligrafico dello Stato, Libreria della Stato.

Mango, M. 2011. "Byzantine Settlement Expansion in North Central Syria: The Case of Androna/Andarin." In *Le Proche-Orient de Justinien aux abbassides: Peuplement et dynamiques spatiales. Actes du Colloque "Continuités de l'occupation entre les périodes byzantine et abbasside au Proche-Orient, VIIe–IXe siècles," Paris, 18–20 octobre 2007*, edited by A. Borrut, M. Debié, A. Papaconstantinou, D. Pieri, and J.-P. Sodini, 93–122. Bibliothèque de l'Antiquité Tardive 19. Turnhout: Brepols.

Margaritis, E. 2007. "Archaeobotanical Investigations at the Geometric Site of Krania, Southern Pieria in Macedonia, Greece." *Talanta* 38–39:123–32.

———. 2013. "Distinguishing Exploitation, Domestication, Cultivation and Production: The Olive in the Third Millennium Aegean." *Antiquity* 337:746–57.

Margaritis, E., and M. Jones. 2008a. "Olive Oil Production in Hellenistic Greece: The Interpretation of Charred Olive Remains from the Site of Tria Platania, Macedonia, Greece (Fourth–Second Century BC)." *Vegetation History and Archaeobotany* 17:393–401.

———. 2008b. "Crop Processing of *Olea europaea* L.: An Experimental Approach for the Interpretation of Archaeobotanical Olive Remains." *Vegetation History and Archaeobotany* 17:381–92.

Marinova, E., J.M.A. van der Valk, S.M. Valamoti, and J. Bretschneider. 2011. "An Experimental Approach for Tracing Olive Processing Residues in the Archaeobotanical Record, with Preliminary Examples from Tell Tweini, Syria." *Vegetation History and Archaeobotany* 20:471–78.

Marlière, É. 2002. *L'outre et le tonneau dans l'Occident romain*. Monographies instrumentum 22. Montagnac: Editions Monique Mergoil.

Marzano, A. 2013. "Agricultural Production in the Hinterland of Rome: Wine and Olive Oil." In *The Roman Agricultural Economy: Organization, Investment and Production*, edited by A. Bowman and A.I. Wilson, 85–106. Oxford: Oxford University Press.

Mason, J.R. 2007. "Experimenting the Manufacture of Nabataean Fine-Ware Pottery." In *The World of the Nabataeans: Volume 2 of the International Conference, The World of the Herods and the Nabataeans, Held at the British Museum, 17–19 April 2001*, edited by K.D. Politis, 327–35. Stuttgart: Franz Steiner.

Matson, F.R. 1972. "Ceramic Studies." In *The Minnesota Messenia Expedition: Reconstructing a Bronze Age Regional Environment*, edited by W.A. McDonald and G.R. Rapp, 219. Minneapolis: University of Minnesota Press.

Mattingly, D.J. 1988a. "Megalithic Madness and Measurement: Or How Many Olives Could an Olive Press Press?" *OJA* 7:177–95.

———. 1988b. "The Olive Boom: Oil Surpluses, Wealth and Power in Roman Tripolitania." *LibSt* 19:21–42.

———. 1988c. "Oil for Export? A Comparison of Libyan, Spanish and Tunisian Olive Oil Production in the Roman Empire." *JRA* 1:33–56.

———. 1993. "Maximum Figures and Maximizing Strategies of Oil Production? Further Thoughts on the Processing Capacity of Roman Olive Presses." In *La production du vin et de l'huile en Méditerranée/Oil and Wine Production in the Mediterranean Area*, edited by M.C. Amouretti, J.-P. Brun, and D. Eitam, 483–98. *BCH* Suppl. 26. Athens: École Française d'Athènes.

Megaloudi, F. 2006. *Plants and Diet in Greece from Neolithic to Classic Periods: The Archaeobotanical Remains. BAR-IS* 1516. Oxford: Archaeopress.

Mekki, H., M. Anderson, E. Amar, G.R. Skerratt, and M. BenZina. 2006. "Olive Oil Mill Waste Water As a Replacement for Fresh Water in the Manufacture of Fired Clay Bricks." *Journal of Chemical Technology and Biotechnology* 81:1419–25.

Monteix, N. 2009. "Pompéi, *Pistrina*: Recherches sur les boulangeries de l'Italie romaine [2008]." *MÉFRA* 121:322–35.

———. 2010a. "Pompéi, *Pistrina*: Recherches sur les boulangeries de l'Italie romaine [2009]." *MÉFRA* 122: 275–83.

———. 2010b. *Les lieux de métier: Boutiques et ateliers d'Herculanum. BÉFAR* 344. Rome: École Française de Rome.

Monteix, N., S. Aho, A. Coutelas, L. Garnier, V. Matterne, and S. Zanella. 2011. "Pompéi, *Pistrina*: Recherches sur les boulangeries de l'Italie romaine [2010]." *MÉFRA* 123:306–13.

Monteix, N., S. Zanella, S. Aho, R. Macario, and E. Proudfoot. 2012. "Pompéi, *Pistrina*." *Chronique des activités archéologiques de l'École française de Rome*. http://cefr.revues.org/954.

Murphy, C., G. Thompson, and D.Q. Fuller. 2013. "Roman Food Refuse: Urban Archaeobotany in Pompeii, Regio VI, Insula 1." *Vegetation History and Archaeobotany* 22:409–19.

Neef, R. 1990. "Introduction, Development and Environmental Implications of Olive Culture: The Evidence from Jordan." In *Man's Role in the Shaping of the Eastern Mediterranean Landscape*, edited by S. Bottema, G. Entjes-Nieborg, and W. van Zeist, 295–306. Rotterdam: A.A. Balkema.

Niaounakis, M. 2011. "Olive-Mill Wastewater in Antiquity: Environmental Effects and Applications." *OJA* 30:411–25.

Niaounakis, M., and C.P. Halvadakis. 2006. *Olive Processing Waste Management: Literature Review and Patent Survey*. 2nd ed. Oxford: Elsevier.

Peña, J.T. 1998. "The Mobilization of State Olive Oil in Roman Africa: The Evidence of Late 4th–c. Ostraca from Carthage." In *Carthage Papers: The Early Colony's Economy, Water Supply, a Public Bath, and the Mobilization of State Olive Oil*, edited by by J.T. Peña et al., 116–238. *JRA* Suppl. 28. Portsmouth, R.I.: Journal of Roman Archaeology.

Pesaresi, P., and M.M. Castaldi. 2006. "Conservation Measures for an Archaeological Site at Risk (Herculaneum, Italy): From Emergency to Maintenance." *Conservation and Management of Archaeological Sites* 8:215–36.

Rehder, J.E. 2000. *The Mastery and Uses of Fire in Antiquity*. Montreal: McGill-Queen's University Press.

Rife, J.L. 2001. "Excavations Adjacent to the House of the Venus Mosaic (Site 250): The Human Remains from Site 250. Catalogue of Burials from Site 250." In *Leptiminus (Lamta): The East Baths, Cemeteries, Kilns, Venus Mosaic, Site Museum and Other Studies. Report No. 2,* edited by L.M. Stirling, D.J. Mattingly, and N. Ben Lazreg, 293–324. *JRA* Suppl. 41. Portsmouth, R.I.: Journal of Roman Archaeology.

Riley, F. 2002. "Olive Oil Production on Bronze Age Crete: Nutritional Properties, Processing Methods and Storage Life of Minoan Olive Oil." *OJA* 21:63–75.

Robinson, M. 1999. "The Macroscopic Plant Remains." In *Towards a History of Pre-Roman Pompeii: Excavations Beneath the House of Amarantus (I. 9.11–12), 1995–8*, edited by M. Fulford and A. Wallace-Hadrill, 95–102. *PBSR* 67. London: British School at Rome.

———. 2002. "Domestic Burnt Offerings and Sacrifices at Roman and Pre-Roman Pompeii, Italy." *Vegetation History and Archaeobotany* 11:93–100.

———. 2007a. "Preliminary Report on the Processing of Samples from Herculaneum Cardo V Fogna." Unpublished report. Ercolano: Herculaneum Conservation Project.

———. 2007b. "Botanical Remains: House of the Greek Epigrams." Unpublished excavation report. Rome: Swedish Pompeii Project.

Robinson, M., and E. Rowan. 2015. "Roman Food Remains in Archaeology and the Contents of a Roman Sewer at Herculaneum." In *A Companion to Food in the Ancient World*, edited by J. Wilkins and R. Nadeau. Chichester: Wiley-Blackwell.

Rodríguez-Ariza, M.O., and E.M. Moya. 2005. "On the Origin and Domestication of *Olea europaea* L. (Olive) in Andalucia, Spain, Based on the Biogeographical Distribution of Its Finds." *Vegetation History and Archaeobotany* 14:551–61.

———. 2010. "Paisaje y gestión de los recursos vegetales en el yacimiento romano de Gabia (Granada) a través de la Arqueobotánica." *ArchEspArq* 83:85–107.

Rossiter, J. 1981. "Wine and Oil Processing at Roman Farms in Italy." *Phoenix* 35:345–61.

Ruggiero, M. 1881. *Degli scavi di Stabia dal 1749 al 1782: Notizie raccolte e pubblicate.* Naples: Tipografia dell'Academia Reale delle Scienze.

Runnels, C.N., and J. Hansen. 1986. "The Olive in the Prehistoric Aegean: The Evidence for Domestication in the Early Bronze Age." *OJA* 5:299–308.

Salavert, A. 2008. "Olive Cultivation and Oil Production in Palestine During the Early Bronze Age (3500–2000 BC): The Case of Tel Yarmouth, Israel." *Vegetation History and Archaeobotany* 17:53–61.

Sarpaki, A. 1999. "What Did They Produce?" In *Minoans and Mycenaeans: Flavours of Their Time,* edited by Y. Tzedakis and H. Martlew, 35–43. Athens: Kapon Editions.

Sarpaki, A., and J. Bending. 2004. "Archaeobotanical Assemblages." In *Mochlos IC: Period III, Neopalatial Settlement on the Coast. The Artisans' Quarter and the Farmhouse at Chalinomouri. The Small Finds,* edited by J.S. Soles et al., 126–31. Prehistory Monographs 9. Philadelphia: INSTAP Academic Press.

Scarry, C.M., D.C. Haggis, and M.S. Mook. 2013. "Reconstructing Olive Oil Processing at Azoria (ca. 600–500 B.C.), an Early Greek City on Crete." Paper read at the

16th Conference of the International Workgroup for Paleoethnobotany, 17–22 June, Thessaloniki.

Sethom, M. 1964. "Les artisans-potiers de Moknine." *Revue tunisienne de sciences sociales* 1:53–70.

Simchoni, O., and M.E. Kislev. 2006. "Charred By-products of Olive-Oil Production in the Iron Age." In *Excavations at Tel Beth-Shean 1989–1996.* Vol. 1, edited by A. Mazar and N. Amitai-Preiss, 679–85. Jerusalem: Institute of Archaeology, the Hebrew University of Jerusalem.

Smith, W. 1998. "Fuel for Thought: Archaeobotanical Evidence for the Use of Alternatives to Wood Fuel in Late Antique North Africa." *JMA* 11:191–205.

———. 2001. "Environmental Sampling (1990–1994)." In *Leptiminus (Lamta): The East Baths, Cemeteries, Kilns, Venus Mosaic, Site Museum and Other Studies. Report No. 2*, edited by L.M. Stirling, D.J. Mattingly, and N. Ben Lazreg, 420–41. *JRA* Suppl. 41. Portsmouth, R.I.: Journal of Roman Archaeology.

Stewart, R. 1984. "Carbonized Seeds." In *Excavations at Carthage: The British Mission.* Vol. 1, pt. 1, *The Avenue du President Habib Bourguiba, Salammbo: The Site and Finds Other Than Pottery*, edited by H.R. Hurst and S. Roskams, 257. Sheffield: Sheffield University, Department of Prehistory and Archaeology.

Stirling, L., and N. Ben Lazreg. 2001. "A Roman Kiln Complex (Site 290): Preliminary Results of Excavations, 1995–98." In *Leptiminus (Lamta): The East Baths, Cemeteries, Kilns, Venus Mosaic, Site Museum and Other Studies. Report No. 2*, edited by L.M. Stirling, D.J. Mattingly, and N. Ben Lazreg, 220–35. *JRA* Suppl. 41. Portsmouth, R.I.: Journal of Roman Archaeology.

Tekin, A.R., and A.C. Dalgiç. 2000. "Biogas Production from Olive Pomace." *Resources, Conservation and Recycling* 30:301–13.

Terral, J.-F. et al. 2004. "Historical Biogeography of Olive Domestication (*Olea europaea* L.) as Revealed by Geometrical Morphometry Applied to Biological and Archaeological Material." *Journal of Biogeography* 31:63–77.

Tyree, L., and E. Stefanoudaki. 1996. "The Olive Pit and Roman Oil Making." *Biblical Archaeologist* 59:171–78.

van Zeist, W. 1994. "Botanical Remains." In *Excavations at Carthage: The British Mission.* Vol. 1, pt. 1, *The Avenue du President Habib Bourguiba, Salammbo: The Site and Finds Other than Pottery*, edited by H.R. Hurst and S. Roskams, 325. Sheffield: Sheffield University, Department of Prehistory and Archaeology.

van Zeist, W., and S. Bottema. 1983. "Palaeobotanical Studies of Carthage: A Comparison Between Microscopic and Macroscopic Plant Remains." *Centre de Documentation Archéologique de la Conservation de Carthage Bulletin* 5:18–22.

Veal, R. 2009. "The Wood Fuel Supply to Pompeii Third Century BC to AD 79: An Environmental, Historical and Economic Study Based on Charcoal Analysis." Ph.D. diss., University of Sydney.

———. 2012. "From Context to Economy: Charcoal as an Archaeological Interpretative Tool. A Case Study from Pompeii (3rd c. B.C.–A.D. 79)." In *More Than Just Numbers? The Role of Science in Roman Archaeology,* edited by I. Schrüfer-Kolb, 19–52. *JRA* Suppl. 91. Portsmouth, R.I.: Journal of Roman Archaeology.

Warnock, P. 2007. *Identification of Ancient Olive Oil Processing Methods Based on Olive Remains. BAR-IS* 1635. Oxford: Archaeopress.

Wikander, O. 2008. "Sources of Energy and Exploitation of Power." In *The Oxford Handbook of Engineering and Technology in the Classical World*, edited by J.P. Oleson, 136–57. Oxford: Oxford University Press.

Wilson, A.I. 2012. "Raw Materials and Energy." In *The Cambridge Companion to the Roman Economy*, edited by W. Scheidel, 133–55. Cambridge: Cambridge University Press.

———. 2013. "The Mediterranean Environment in Ancient History: Perspectives and Prospects." In *Ancient Mediterranean Environment Between Science and History*, edited by W.V. Harris, 259–76. Columbia Studies in the Classical Tradition 39. Leiden: Brill.