Volume IX ● Issue 2/2018 ● Pages 147–156

INTERDISCIPLINARIA ARCHAEOLOGICA
NATURAL SCIENCES IN ARCHAEOLOGY

homepage: http://www.iansa.eu

Sustainable Fuel Practices in Roman North Africa and the Contemporary Mediterranean Basin

Erica Rowan[a*]

[a]*Royal Holloway, University of London, Egham Hill, Egham, Surrey, TW20 0EX*, *United Kingdom*

ARTICLE INFO

Article history
Received: 7th September 2018
Accepted: 31st December 2018

DOI: http://dx.doi.org/ 10.24916/iansa.2018.2.2

Key words:
olive
pomace
archaeobotany
Utica
North Africa
Roman
Tunisia
Spain
sustainability

ABSTRACT

As a readily available and renewable resource, olive pomace has been used as a fuel throughout the Mediterranean for centuries. This article will first discuss the extensive use of pomace fuel in Roman North Africa, introducing and adding the once coastal city of Utica to our growing list of sites with archaeobotanical evidence for pomace residue. The paper will then focus on the ways in which the Romans linked olive oil and pottery production. While environmental sustainability was unlikely to have been one of the Romans' conscious objectives, the use of this fuel was vital to the continued production of North African ceramics, particularly in more arid areas. Today, in the face of increasing energy demands, pomace is once again being recognized as an important and sustainable resource. More work, however, still needs to be done to improve the efficiency of pomace use. The article will conclude by highlighting the valuable lessons that can be learned from ancient practices, especially the efficient pairing of olive cultivation and pottery production.

1. Introduction

Beginning in the early Bronze Age, olive oil has been an important source of calories, fats and vitamins for those living in the Mediterranean basin (Thurmond, 2006, pp. 74–76; Salavert, 2008; Rowan, 2015, pp. 468–471; 2018). In antiquity, olive oil also served a multitude of non-dietary functions; as a fuel, a body cleanser, and a base for perfumes and cosmetics (Mattingly, 1996, p. 224). However, oil is not the only product generated by the pressing of olives. The production of olive oil results in the production of olive pressing waste, or pomace; the paste left in the baskets after the pressing is completed. This paste is made of a mixture of olive skin, flesh and broken stones. For every ton of olives pressed, roughly 200 l of olive oil and 350–400 kg of pomace are produced (Mekki *et al.*, 2006, p. 1419; Niaounakis, 2011, p. 414). When a traditional olive press is used the resulting pomace contains between 3.5–12% oil and 20–30% water (Karapmar and Worgen, 1983, p. 185; Azbar *et al.*, 2004, p. 215). Traditionally pomace is air dried, although today mechanical driers are sometimes used to speed up the process (Arjona, García and Ollero, 1999; Doymaz *et al.*, 2004; Göğüş and Maskan, 2006; Warnock, 2007, p. 51 Vega-Gálvez *et al.*, 2010). The high oil content means that once dry, pomace becomes a viable biofuel that can be used for both industrial and domestic purposes. This article will discuss the extensive use of pomace fuel in Roman North Africa before focusing on the ways in which the Romans linked olive oil and pottery production. The paper will then highlight the current state of pomace use in the Mediterranean and the valuable lessons that can be learned from ancient fuel practices.

In antiquity, pomace fuel was used for a range of activities, most notably to aid in the olive pressing process, to fire pottery, lime, and glass kilns, to heat bakery ovens and for domestic heating and cooking (Margaritis and Jones, 2008; Monteix, 2009; Rowan, 2015; Barfod *et al.*, 2018).

The burning of pomace in antiquity, especially on a large scale, means it is possible to identify and trace its use in the archaeological record. It is also possible to distinguish

*Corresponding author. E-mail: Erica.rowan@rhul.ac.uk

pomace fuel assemblages from olives burnt for ritual purposes or as table waste. In all cases, the burning, or carbonization process, turns the olive flesh and skin to ash and as a result we are often only left with burnt olives stones (endocarps) and occasionally the seeds. Usually a pomace assemblage will appear as hundreds or thousands of fragmented olive stones in a concentrated deposit (see, for example, Smith, 1998; Margaritis and Jones, 2008; Rowan, 2015). The high degree of fragmentation is the result of crushing the olives prior to the pressing stage. Many of the olive stones will not survive combustion, especially when the pomace is subject to high temperatures such as those found inside a kiln. Consequently, a high concentration suggests large-scale and/or repeat burning events and thus pomace fuel (Mason, 2007, p. 333; Warnock, 2007, p. 47). In the case of ritual or table waste, the assemblage is usually smaller and contains a greater quantity of intact stones despite lower burning temperatures increasing the chances of preservation. Reflectance measurements can also be used to confirm the use of olive pomace as a fuel and distinguish between the use of air-dried pomace and pomace that has been converted into charcoal (Braadbaart, Marinova and Sarpaki, 2016).

1.1 Current uses of pomace

Today, 97% of the world's olive oil is still made in the Mediterranean and in particular in Spain, Greece, Italy, Turkey, Morocco, and Tunisia (Christoforou and Fokaides, 2016; IOOC EU Olive Oil Figures 2018). Since 1990, EU production of olive oil has increased from 994,000 tonnes to 2.17 million tonnes or 2.36 million litres per annum (IOOC World Olive Oil Figures, 2018).[1] As olive oil output increases so too does the volume of pomace. Although the modern two- and three-phase press extraction processes make pomace output more difficult to calculate, generating 2.36 million litres of oil results in the creation of approximately 4.13–4.72 million kg of pomace. Modern press methods differ from traditional methods in that they create a more mixed and chemically toxic pulp, especially the two-phase method where all the pomace and olive waste water are mixed together. Consequently, different treatment methods must be applied to the pomace prior to its utilization as a fuel (for a good overview of the different outcomes using traditional and modern presses, see Caputo *et al.*, 2003 or Azbar *et al.*, 2004). However, since the ratio of modern continuous presses to traditional presses varies by country, for simplicity, in this article, all pressing waste with a solid component will be called pomace regardless of water content. It is beyond the scope of this article to discuss the various uses and challenges associated with olive waste water, which does not contain the flesh or stones (Niaounakis, 2011).

In the light of higher energy demands and a decreasing fossil fuel supply, in addition to the challenges associated with global warming, renewable and sustainable biomass fuels such as pomace are becoming ever more important. Unlike the combustion of fossil fuels, burning pomace will not increase levels of atmospheric carbon dioxide and therefore not contribute to rising levels of greenhouse gasses. Any CO_2 generated during combustion is offset by the continued presence of olive trees and other plant matter that photosynthesizes CO_2 (Ali Rajaeifar *et al.*, 2016, p. 87). Experiments have shown olive pomace to be a viable alternative to fossil fuels and unlike other biomass sources such as wheat or corn, the use of pomace does not act as competition for the food supply (Intini *et al.*, 2011, p. 165). Throughout the Mediterranean and the Middle East pomace is still used in traditional ways. In Jordan and Syria, olive pomace is used to heat homes and cook food, while in Turkey it is used in bakeries and olive mills (Doymaz *et al.*, 2004, p. 214; Azbar *et al.*, 2004, p. 238; Warnock, 2007, p. 47–57; Rowan, 2015, p. 466). Other small-scale uses of pomace in Spain, Italy, Greece, Croatia and Slovenia include the heating of factories, private homes, and hotels, all of which make use of local resources (M.O.R.E., 2008). While these traditional small-scale uses of pomace remain important, a greater number of factories and hotels, for example, could take advantage of this resource. Unless local demand increases, pomace will continue to be generated in quantities that far outstrip local consumption. Governments, universities and research institutions have begun to dedicate considerable resources to developing more efficient ways to exploit this clean energy resource (Demicheli and Bontoux, 1996, p. 49–53; Arvanitoyannis, 2007; Vera *et al.*, 2014; Christoforou and Fokaides, 2016; European Commission, 2017; M.O.R.E, 2018). Some of the major olive oil producing countries in the Mediterranean have started to make use of olive pomace fuel for various industrial activities and most commonly the generation of electric and thermal energy (Demicheli and Bontoux, 1996; García-Maraver *et al.*, 2012). While today's motivations are both financial and environmental, the drive to link industrial-scale, olive oil production with industrial-scale, energy generation is remarkably similar to the events that took place during the Roman period.

1.2 Olive oil production in Roman North Africa

Roman conquest of the Mediterranean began in earnest in the 3rd century BC. By the late first century BC, Rome controlled all the land around the Mediterranean Sea and, in effect, all olive oil producing regions. Although olive oil was made in many parts of the Mediterranean prior to Roman hegemony, Roman territorial expansion brought about a significant expansion of olive groves, resulting in an increase in olive oil and pomace production (Mattingly, 1988a; 1988b). This expansion is no more readily apparent than in North Africa, which underwent an "olive boom" starting roughly in the 2nd century AD, and reaching its peak in the 3rd to 5th centuries AD (Mattingly, 1988a, p. 56; 1996, pp. 235–237; Hobson, 2015a, p. 148; 2015b, p. 219). The Romans invested significant capital in the planting of olive groves and the construction of presses along the Tunisian and Libyan coasts, as well as in the Tunisian Sahel (Figure 1). An even more dedicated investment can be seen in the planting

[1] 1 litre of olive oil weighs circa 0.92 kg (Marzano, 2013, p. 99).

Figure 1. Coastal Tunisia and Libya with major sites and regions mentioned in the text (author).

of enormous olive groves and the construction of hundreds of multi-presses sites in the Tunisian High Steppe and Libyan Djebel, semi-arid regions that only receive 200–300 mm of rainfall per annum (Mattingly, 1988a, pp. 44–45; 1996, pp. 236–237; Hobson, 2015a, p. 99). The successful planting and cultivation of these olive trees resulted in the output of millions of litres of oil. The territory around the three cities of Lepcis Magna, Sabratha and Oea in modern Libya, for example, may have been producing up to 30 million litres of oil per year (Mattingly, 1988a, p. 37). If olive oil was being produced on an industrial scale, so too was pomace (Mattingly, 1988a; 1988b; Hitchner, 2002).

2. Pomace use at Utica

The site of Utica is located on the western side of the Mejerda estuary in northern Tunisia, 10 km from the coast (Hay *et al.*, 2010, p. 325). Originally a Punic settlement, the earliest structures date to the 8th century BC. After the Roman defeat of Carthage in 146 BC, Utica was made the capital of the newly founded province of Africa. Although the city lost its capital status to Carthage after the Roman civil wars of the 1st century BC, it nevertheless continued to prosper as an important port centre and many public buildings associated with large Roman cities, such as baths, basilicas and theatres

Figure 2. Area IV. The large lime kiln is visible at the top of the photo while smaller circular kiln 4022 is visible on the right-hand side. A rectangular cistern with rounded edges is located near the smaller kiln. Note the dark ash scatter near the lime kiln (photo courtesy of Andrew Wilson).

were constructed. During the imperial period it had the status of a *municipium* before achieving the higher rank of *colonia* under Hadrian. By the mid-3rd century it had become an important Christian centre. The city then declined during the Late Roman period and was captured by the Vandals in AD 439 and then the Byzantines in AD 534. Sometime between the early 5th and mid-6th centuries the alluvial fans in the estuary finally filled with sediment, cutting the city off from the coast (Delilie *et al.*, 2015, p. 304). Around AD 700, Utica was destroyed during the Arab invasion and only sparsely settled from the 9th–12th centuries (Ben Jerbania *et al.*, 2014).

Although originally a residential area, during the Roman period the south-western portion of the city was a semi-industrial zone hosting several pottery and lime kilns. From 2012 to 2014, this semi-industrial zone, labelled Area IV, was excavated by the Tunisian-British Utica Project, a joint collaboration between the Institut National de Patrimoine du la Tunisie and the University of Oxford (Fentress *et al.*, 2012; 2013; Ben Jerbania *et al.*, 2014). The Area IV excavations revealed a lime kiln and eight pottery kilns, dating from the early 1st century BC to 2nd century AD (Figure 2). The kilns were used to fire a range of coarse ware including jugs, unguentaria and chamber pots (Ben Jerbania, *et al.*, forthcoming).

Flotation samples were collected from all areas of interest including the insides of the kilns, rake-out pits, ash scatters, and floor surfaces. A minimum of 10 l was collected for each sample whenever possible, although just over 100 l was sometimes taken from ash scatters or rake-out pits (which are probably the same thing). A full description of the flotation processes, along with the complete archaeobotanical and charcoal data sets will be published in the forthcoming Utica volume. Here, the discussion will be restricted to a brief discussion of the finds of carbonized olive endocarps (Ben Jerbania *et al.*, forthcoming).

To date, 21 samples, representing 15 contexts and 188 l, or 1/3 of the total volume of Area IV material, have thus far been sorted and identified. All samples with identifiable material contained at least one carbonized olive stone fragment (Table 1). In total, there were 9 whole olive stones and 5997 fragments recovered. Charcoal was always present along with the olive stones. The only sample without any finds, and therefore the only one without any olive was 4213, a very small sample taken from a shallow cut. As Table 1 demonstrates, sample 4075.1 contained by far the greatest number of olives. In six samples olives were the only finds, and usually in small quantities. The remaining 14 samples vary significantly in their numbers of olive stone fragments, from 2 to 4776. In samples with 10 or more fragments, excluding sample 4075.1, absolute counts varied from 18 to 433, while density levels ranged from 2.4 to 50.9 fragments per litre (Figure 3).

As stated above, pomace residue assemblages typically consist of fragmented olive stones recovered in large

Table 1. Raw olive stone counts and context descriptions.

Sample	Context description	Litres	Whole	Halves	Fragments
4007	Upper fill of small kiln 4022	4	0	0	18
4007.1	Upper fill of small kiln 4022	12	0	0	166
4009.5	Ashy dump of ceramic waste near lime kiln 4003	9	0	0	7
4046	Deposit of charcoal from lime kiln 4003 rakeout pit	8	0	0	132
4058	Ashy layer in NE corner of main trench	11	0	0	52
4072.1	Bottom of small kiln 4022	15	0	0	2
4072.2	Bottom of small kiln 4022	11.5	0	0	34
4075.1	Upper fill of small kiln 4071	12	4	12	4476
4078	Lower fill of lime kiln 4003	13	0	0	3
4078.3	Lower fill of lime kiln 4003	15	0	0	1
4078.6	Lower fill of lime kiln 4003	12	0	0	1
4078.7	Lower fill of lime kiln 4003	9	0	0	1
4078.9	Lower fill of lime kiln 4003	13	0	0	1
4079.2	Bottom fill of plaster lined tank	10	0	0	42
4093	Contents of a ceramic pot	4	0	0	31
4113	Ashy pottery dump in firing pit of kiln 4159	4.5	0	0	2
4168	Lowest fill of a cistern	7.8	0	0	215
4187.5	Large ash deposit/pottery dump	9.5	1	0	22
4213	Dark grey ash deposit	0.4	0	0	0
4216.1	Possible kiln rakings from kiln 4218	5	1	0	35
4222.2	Deposit of dark grey ashy silt on top of kiln 4218	8.5	3	11	433
TOTAL		**194.2**	**9**	**23**	**5674**

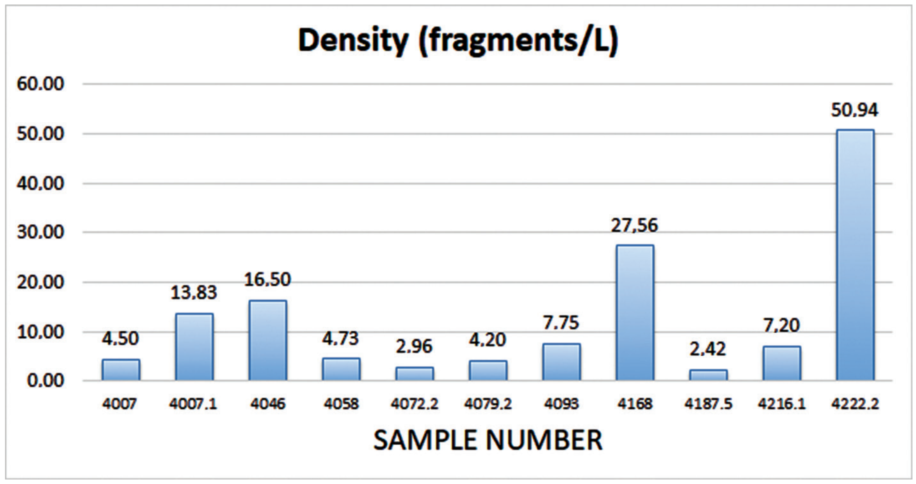

Figure 3. Density ratios for samples with 10 or more carbonized olive stone fragments. During calculations, olive stone halves were added to the total number of fragments.

quantities from concentrated deposits. The composition and characteristics of the entire Utica olive assemblage, in addition to their find spots, leaves little doubt that olive pressing waste, in conjunction with charcoal, was being used to fire the kilns. Sample 4075.1, with 4776 fragments and a density of 400 fragments per litre, was collected from inside a small kiln and therefore represents the mixture of olive pomace and charcoal that was used during the final firing. Similarly samples 4007 and 4007.1, with 18 and 166 fragments respectively, were both recovered from inside small kiln 4022 (Figure 4). Sample 4046, with 132 fragments, came from the rake-out pit of the large lime kiln. Although the majority of the remaining samples contain much lower quantities, the long period of activity in this area of the city means that some olive stone scattering is expected and the contexts with small quantities probably represent dispersed fuel. Moreover, 99.8% of the Area IV olive assemblage consisted of fragments rather than whole olives. Although post-depositional activities such as trampling can lead to fragmentation, we would still not expect the ratio of fragmented to whole olives to be so imbalanced if this was a cooking waste or ritual assemblage. Similar ratios of fragmented to whole olive stones are present in the carbonized assemblages recovered from bakeries in Pompeii and the *Cardo V* sewer in Herculaneum (Monteix, 2009; Rowan, 2015; 2017). Finally, although not discussed here in detail, the samples contained few other archaeobotanical remains and the olive stones dominate the assemblage. Thus the quantity, degree of fragmentation and concentrated nature of the deposits leaves no doubt that the Romans were using olive pressing waste to fire these kilns. Consequently, it is now possible to add Utica to the list of North African sites with secure archaeobotanical evidence for the use of this vital and renewable fuel source.

3. Pomace use in Roman North Africa

In North Africa, the huge increase in olive oil production during the Roman period altered both the regional landscape

Figure 4. Kiln 4022, which went out of use in the 2nd century AD (photo courtesy of Andrew Wilson).

and the economy. It has been noted by several scholars that there was an increase in North African pottery production following the "olive boom" (Mattingly, 1988a; Hitchner, 2002, p. 78; Mackensen, 2009, p. 38; Lewit, 2011, pp. 318–322; Hobson, 2015a, pp. 117–119, 140; Hobson 2015b, p. 219). The main products were African transport amphorae, coarse ware and African Red Slip (ARS), all designed for export and subsequently found throughout the Roman world (Bonifay, 2007; Stone, 2009; Hobson, 2015b, p. 210). In Tunisia, amphorae and coarse ware tended to be produced at sites near the coast while ARS was made and fired primarily at inland sites (Hobson, 2015, p. 105). Utica seems to be following this trend as the kilns were only producing coarse ware.

Archaeobotanical evidence indicates that coastal pottery production sites frequently used olive pomace fuel to fire the kilns (see Figure 1). At Leptiminus, pomace was a regular fuel source. Carbonized olive stones were found in or near multiple kilns whose total use life ran from the 1st and 6th centuries AD (Smith, 1998; 2001; Stirling and Ben Lazreg, 2001). Similarly at Carthage it was used for both kilns, and domestic cooking and heating over the course of several centuries (Ford and Miller, 1978, pp. 183–187; Hoffman, 1981, pp. 261–265; Stewart, 1984; Smith, 1998, pp. 193–194). Finally, pomace residue was found at a late 6th–7th century AD pottery kiln at Oudhna, the only ARS kilns to have been excavated in Tunisia (Barraud *et al.*, 1998; pp. 114–145; Lewit, 2011, p. 319; Hobson, 2015a, p. 119). The recovery of the olive stones at Utica situates this city firmly within the Roman tradition of using this agricultural by-product for pottery production.

Unfortunately, only the coastal Tunisian sites mentioned above have been sampled for archaeobotanical material. The inland olive oil farms and press sites have been extensively surveyed but not excavated (for a thorough list of surveys and associated publications, see Hobson, 2015b, pp. 212–213). There is considerable evidence to suggest that amphora production was linked to the inland olive oil processing sites in the Libyan Djebel and ARS production with inland sites in the Tunisian High Steppe (Ahmed, 2010; Lewit, 2011, pp. 319–320; Hobson, 2015b, pp. 220–221). Lewit (2011, p. 318–322) argues that co-location may have taken place for the explicit purpose of using the enormous quantities of pomace generated each year to fire the pottery kilns. Even if they were linked, as Hobson (2015a, p. 140) suggests, primarily for taxation purposes it seems doubtful that such large quantities of pottery could have been made in this dry environment without a large fuel supply. These semi-arid inland sites contained few natural fuel sources. In North Africa, therefore, there is a clear link between olive oil production, pomace production and pottery manufacturing at both coastal and inland sites.

Recent research has shown that an identical pairing of pomace with pottery was taking place in Spain, the other major olive oil producing region of the Roman Empire (Romo Salas *et al.*, 2001; Bourgeon *et al.*, 2018). At the 1st–4th century AD site of Las Delicias, located on the banks of the Genil river in the Roman province of Baetica (modern Andalusia), excavators recovered thousands of carbonized olive stone fragments from inside a kiln and in the area of the nearby olive press. Here pomace was being used both to heat the water required during pressing and to fire the Dressel 20 amphorae required to export the oil (Bourgeon *et al.*, 2018). Consequently, this practice was not restricted to North Africa and instead it seems to have been the Roman practice to intentionally pair industrial-scale, olive oil production with industrial-level, pottery production.

This highly organized and economically integrated system had several, probably unrealized, environmental benefits. Despite these high production levels and large fuel demands, there is no evidence to suggest that there was widespread deforestation in the area around Utica, or anywhere in North Africa, during the Roman period (Kaplan *et al.*, 2009; Lewit, 2011). Significant deforestation seems to have already occurred in Tunisia, particularly around Carthage, and other areas of North Africa by 300 BC, long before the increase in olive oil and pottery production (Hoffman, 1982; Kaplan *et al.*, 2009, p. 3029). The use of pomace decreased pressure on already limited woodland resources and allowed for several fuel-intensive activities such as pottery, metal, and glass production to occur simultaneously without any environmental damage (Wilson, 2002; Rowan, 2015). In addition to these manufacturing activities and regular domestic requirements, many of North Africa's larger cities, such as Carthage and Lepcis Magna, were able to support enormous bath complexes that would have required significant quantities of wood for heating (Yegül, 2010, pp. 136–144). Another advantage was that kiln firings effectively eliminated the industrial quantities of toxic and odorous pomace that would have quickly accumulated if left unexploited (Ruggeri *et al.*, 2015). While ancient authors, such as Cato (Agr. 37), suggest using some of the pomace as a pesticide for olive trees, this limited use would not have consumed the entire quantity of pomace produced on the larger olive oil producing estates.

4. Roman fuel management and modern pomace use

As the use of pomace fuel continues to expand in the modern Mediterranean, it is interesting to note that several parallels with the Roman world are already apparent. Currently, co-firing biomass fuels, such as pomace with coal, is the most cost-efficient (although not the most environmentally-friendly) way to use pomace as it does not require any changes to the existing power-plant infrastructure (Ramachandran *et al.*, 2007, p. 2005; Intini *et al.*, 2011, p. 159). Pomace residues, especially those associated with kilns or ovens in the Roman world, are almost always found in association with charcoal (Hoffman, 1982; Monteix, 2009). Thus the Romans similarly used a system of co-firing, although it was primarily for reasons of efficiency and temperature control.

One of the newer logistical, rather than technological developments that follows the Roman practice of linking presses and kilns is the habit of situating power-generating stations in areas of olive oil production. Just as ceramic manufacturing consumes large quantities of pomace, so too do power plants. *Plan de Acción Nacional de Energías Renovables (2011–2020)*, and other recent government initiatives and incentives have promoted the development and use of sustainable fuel sources in Spain (BOJA, 2010; PANER, 2010; García-Maraver *et al*., 2012; Maldonado, 2016; Menéndez *et al.*, 2018). Andalusia is the country's greatest olive oil producing region, generating 800,000 tons of oil per year. As a result of these incentives and initiatives, 12 of the 19 electric energy-generation plants in Andalusia use olive pressing waste as their primary fuel source (García-Maraver *et al*., 2012, p. 479). An olive waste-to-energy plant, outside the town of Villanueva de Algaidas in Màlaga, processes all the olive waste, including pomace and prunings and converts it into electrical energy (InfoPower, 2005). Due to economies of scale, the construction and running of such waste-to-energy plants has been shown to be financially profitable when placed in areas of high olive oil production (Caputo *et al.*, 2003). Operating on a much smaller scale, an initiative by the Provincial Deputation and the Andalusia Energy Agency is working to replace gas-oil boilers with biomass boilers to heat schools and other public buildings (M.O.R.E., 2008a). While Spain leads the way in olive pressing waste exploitation, much more can be done to utilize this resource in both the large and smaller olive oil producing countries of the Mediterranean (M.O.R.E., 2008a, pp. 35–36; Vourdoubas, 2017). In Italy, 1.2 million tons of de-oiled pomace is produced every year but very little is used in power plants (M.O.R.E., 2008b, p. 6; Intini *et al.*, 2011). Just as the Romans had pomace utilization strategies in place in areas with large olive oil outputs, so too should countries today, rather than letting it go to waste (Tawarah and Rababah, 2013, p. 146; Stamatakis, 2010).

Lebanon, for example, remains a country heavily dependent on fossil fuels. Kinab and Khoury (2015) have suggested taking a similar approach to the Andalusian practice of locating energy stations in areas with high levels of olive oil production. They propose building a treatment facility either in northern Lebanon where olive oil production is highest or in the centre of the country so that it is accessible to those in both the north and the south. The treatment facility would dry and de-oil the pomace in preparation for combustion. They argue that the 79,000 tons of pomace generated in Lebanon each year could cover the energy needs of roughly 8000 people if processed and burned correctly. Although pomace has a lower calorific value than gasoline, diesel, propane or butane, it is nevertheless equivalent to oak, another renewable resource. They argue that it would also cost considerably less for the consumer than having to buy gasoline, diesel or butane.

Olive pressing waste also remains an under-utilized resource in Tunisia which is similarly dependent on fossil fuels (Belloumi, 2009, p. 2752). Recent growth in the Tunisia olive oil industry means that it is now the 4th largest producer of olive oil in the Mediterranean. Approximately 175,000 tons of olive oil is produced annually, leading to the generation of 300,000 tons of pomace and 600,000 tons of olive waste water (Halouani, 2014; Olivea, 2017). Up to 50% of the country's olive oil is made in the south (Olivea, 2017). Despite possessing concentrated areas of olive oil production, no waste-to-energy plants have been constructed and much of the olive pressing waste, and in particular the harmful olive waste water, goes unprocessed and untreated (Stamatakis, 2010). The installation of a biomass power station in Thyna, Sfax, fuelled by olive pomace has been proposed although it is unclear if construction has or will even start (Halouani, 2014, p. 24). Olive pomace is used in the manufacture of bricks in the Cape Bon region, but that in no way exhausts Tunisia's vast pomace supply (Masghouni and Hassairi, 2000). As Tunisia continues to develop more efficient pressing and processing methods it is hoped that more resources will be dedicated to pairing olive oil and pomace production with a fuel consuming activity, as once occurred in Roman North Africa.

5. Conclusions

Olive pomace was an important and valuable resource in antiquity from the Bronze Age through to Late Antiquity (Mattingly, 1996; Smith, 1998; Margaritis and Jones, 2008; Rowan, 2015; Braadbaart, Marinova and Sarpaki, 2016; *inter alia*). Pomace was used in both domestic and commercial settings to heat the water for olive pressings, warm homes, bake bread and fire pottery and glass kilns. Depending upon the taphonomy of the assemblage, pomace fuel is readily identifiable in the archaeological record, usually in the form of a concentrated deposit of hundreds or thousands of fragmented olive endocarps. Beginning in the 2nd century AD, the Romans increased olive oil production in North Africa by investing in the planting of new olive groves and the construction of new presses. These olive groves extended even into semi-arid regions with little rainfall. The increase in olive oil enabled the growth of the pottery industry and amphorae, coarse ware and ARS began to be made in ever larger quantities. The coastal production of coarse ware, and especially amphorae, is not surprising as, in addition to olive oil, North Africa also exported large quantities of fish sauce and wine (Bonifay, 2004; Hobson, 2015b, p. 210). The reasons for the inland manufacture of ARS, a product also designed for export, is, however, more difficult to explain. The predominant theory is that the pottery kilns were located near the olive presses, so that the potters could take advantage of the enormous quantities of pomace produced during the pressing season (Lewit, 2011). Although none of the inland kiln sites have been thoroughly excavated, archaeobotanical evidence from several coastal sites, including Leptiminus, Carthage and Oudhna, indicates that olive pomace was frequently used as kiln fuel in North Africa.

The once coastal site of Utica can now also be added to the list of North African sites that utilized pomace. Recent excavations have uncovered a lime kiln and eight pottery kilns situated in a semi-industrial quarter of the city. In use during the 1st century BC–2nd century AD, these kilns similarly used a mixture of pomace and charcoal to manufacture unguentaria, chamber pots and jugs. Archaeobotanical samples taken from inside and around the kilns contained hundreds to thousands of carbonized olive stone fragments. Samples with smaller quantities represent the spread of fuel waste rather than the waste from ritual deposits or cooking fires. The pairing of olive presses and kilns can also be seen at the site of Las Delicias, located in modern day Andalusia, and undoubtedly further archaeobotanical sampling at kiln and press sites in Spain will continue to demonstrate this pattern.

Consequently, during the Roman period, it is possible to observe the increasingly organized use of pomace on an industrial scale, especially in North Africa (Ford and Miller, 1978, pp. 183–187; Hoffman, 1981, pp. 261–265; Smith, 1998; 2001; Lewit, 2011; Rowan, 2015, pp. 477–478). The Romans exploited this virtually freely-generated resource to ensure high levels of ceramic production without, consciously or unconsciously, causing harmful and long-lasting effects on the landscape. There is no evidence for deforestation in Roman North Africa, even in the already dry Tunisian High Steppe or Libyan Djebel. Moreover, it is important to note that they did not let this precious fuel source to go waste. In a world with increasing fuel demands and dwindling resources, we can learn important lessons from the highly efficient practice of pairing presses and kilns.

Today, the Mediterranean remains the world's major olive oil producing region. While pomace is still used for traditional activities, such as the firing of pottery kilns and heating homes and pressing rooms, these practices occur on a small scale. Much of the pomace generated each year is not used. Over twice as much olive oil, and therefore twice as much pomace, is generated today as was produced during the Roman Imperial period (Mattingly, 1988a). Some Mediterranean countries, and most notably Spain, have taken up the Roman practice of finding efficient ways to use up the large volumes of pomace generated in intensive, olive-oil producing regions. Numerous waste-to-energy power plants, fuelled by olive pomace, have been built in Andalusia. With an increased focus on the use of renewable and sustainable energies, especially in the EU, the greater exploitation of olive pomace seems to be a logical step forward.

Some countries, such as Lebanon and Tunisia, do not yet have systems in place to exploit their olive pressing waste, but proposals for the construction of waste-to-energy plants have been suggested (Halouani, 2014; Kinab and Khoury, 2015). The large body of extant and very recent research into olive pomace fuel use is promising and it is hoped that in the future all olive oil producing nations will become less dependent on fossil fuels and instead turn, or more importantly return, to the efficient exploitation of this sustainable source of clean energy. As a renewable fuel whose combustion has little environmental impact, especially compared to fossil fuels, it should be included in any discussion surrounding sustainability and environmental impact in the Mediterranean. Thus, there is much to be learned from the Roman pairing of agriculture and industry. As we come to realize the value in traditional biomass resources, it is clear that the past can provide us with important lessons on sustainability and resource management if only we continue to collect environmental data, study them with care, and listen to their results.

Acknowledgements

I would like to thank Oxford's Institute of Archaeology and the excavation directors, Andrew Wilson, Lisa Fentress, Imed Ben Jerbania, and Faouzi Ghozzi for inviting me to participate in the project. I would also like to thank the entire Area IV excavation team for their help with sample collection. I am grateful to the Institut National du Patrimoine in Tunisia for the excavation permits and to our project sponsor Baron Lorne Thyssen. I would also like to thank the reviewers for their insightful and helpful comments. Finally, thanks go to Anna Maria Mercuri and Assunta Florenzano for the opportunity to present these results at the 2018 CEA conference in Modena, Italy.

References

AHMED, M., 2010. *Rural Settlement and Economic Activity: Olive Oil and Amphorae Production on the Tarhuna Plateau during the Roman Period.* Unpublished thesis (PhD), University of Leicester.

ARJONA, R., GARCIA, A., OLLERO, P., 1999. The drying of alpeorujo, a waste product of the olive oil mill industry. *Journal of Food Engineering,* 41(3–4), 229–234.

ARVANITOYANNIS, I.S., KASSAVETI, A., STEFANATOS, S., 2007. Current and potential uses of thermally treated olive oil waste. *International Journal of Food Science & Technology,* 42(7), 852–867.

AZBAR, N., BAYRAM, A., FILIBELI, A., MUEZZINOGLU, A., SENGUL, F., OZER, A., 2004. A Review of Waste Management Options in Olive Oil Production. *Critical Reviews in Environmental Science and Technology,* 34(3), 209–247.

BARFOD, G.H., FREESTONE, I.C., LICHTENBERGER, A., RAJA, R., SCHWARZER, H., 2018. Geochemistry of Byzantine and Early Islamic glass from Jerash, Jordan: Typology, recycling, and provenance. *Geoarchaeology*, 2018, 1–18.

BARRAUD, D., BONIFAY, M., DRIDI, F., PICHONNEAU, J.-F., 1998. L'industrie céramique de l'Antiquité tardive. In: H. Ben Hassen and L. Maurin, eds. *Oudhna (Uthina). La redécouverte d'une ville antique de Tunisie.* Bordeaux: Ausonius, pp. 139–67.

BELLOUMI, M., 2009. Energy consumption and GDP in Tunisia: Cointegration and causality analysis. *Energy Policy,* 37(7), 2745–2753.

BEN JERBANIA, I., FENTRESS, E., GHOZZI, F., WILSON, A., CARPENTIERO, G., DHIBI, C., DUFTON, A., HAY, S., *et al.*, 2014. *Excavations at Utica by the Tunisia-British Utica Project 2014. Excavation Report.* [Viewed 16/12/2017]. Available from: https://www.researchgate.net/publication/277649792_Excavations_at_Utica_by_the_Tunisian-British_Utica_Project_2014

BEN JERBANIA, I., FENTRESS, E., GHOZZI, F., QUIINN, J., WILSON, A. eds. Forthcoming. *The INP-Oxford Excavations at Utica.* Oxford: Oxford Institute of Archaeology, University of Oxford.

BOJA, 2010. no. 2. Resolución de 22 de diciembre de 2009, de la Secretaría General de Universidades, Investigación y Tecnología, por la que se establece para la convocatoria de 2010 de los proyectos de investigación de excelencia, una línea específica de investigación sobre diversos aspectos del olivar y el aceite de olive. *Boletín Oficial de la Junta de Andalucía*. 2. Available from: https://www.juntadeandalucia.es/

boja/2010/2/19

BONIFAY, M., 2004. *Études sur la Céramique Romaine Tardive d'Afrique*. Oxford: Archaeopress.

BONIFAY, M., 2007. Ceramic production in Africa during Late Antiquity: continuity and change. In: L. Levan, E. Zanini, A.C. Sarantis, eds. *Technology in Transition: AD 300–650.* Leiden: Brill, pp. 143–158.

BOURGEON, O., PAGNOUX, C., MAUNÉ, S., VARGAS, E.G., IVORRA, S., BONHOMME, V., ATER, M., MOUKHLI, A., TERRAL, J., 2018. Olive tree varieties cultivated for the great Baetican oil trade between the 1st and the 4th centuries AD: morphometric analysis of olive stones from Las Delicias (Ecija, Province of Seville, Spain). *Vegetation History and Archaeobotany,* 27(3), 463–476.

BRAADBAART, F., MARINOVA, E., SARPAKI, A., 2016. Charred olive stones: experimental and archaeological evidence for recognizing olive processing residues used as fuel. *Vegetation History and Archaeobotany,* 25(5), 415–430.

CAPUTO, A.C., SCACCHIA, F., PELAGAGGE, P.M., 2003. Disposal of by-products in olive oil industry: waste-to-energy solutions. *Applied Thermal Engineering,* 23(2), 197–214.

CHRISTOFOROU, E., FOKAIDES, P.A., 2016. A review of olive mill solid wastes to energy utilization techniques. *Waste Management,* 49, 346–363.

DELILE, H., ABICHOU, A., GADHOUM, A., GOIRAN, J., PLEUGER, E., MONCHAMBERT, J., WILSON, A., FENTRESS, E., QUINN, J., BEN JERBANIA, I., 2015. The geoarchaeology of Utica, Tunisia: The paleogeography of the Mejerda Delta and hypotheses concerning the location of the ancient harbor. *Geoarchaeology*, 30(4), 291–306.

DEMICHELI, M., BONTOUX, L., 1996. *Survey on current activity on the valorization of by-products from the olive oil industry.* European Commission, Joint Research Centre, Institute for Prospective Technological Studies.

DOYMAZ, I., GOREL, O., AKGUN, N.A., 2004. Drying characteristics of the solid by-product of olive oil extraction*. Biosystems Engineering,* 88, 213–219.

EUROPEAN COMMISSION 2017. *Sustainable and Optimal use of Biomass for Energy in the EU beyond 2020. Final Report* [online]. [Viewed 30/8/18]. Available from: https://ec.europa.eu/energy/sites/ener/files/documents/biosustain_report_final.pdf

FENTRESS, E., GHOZZI, F., QUINN, J., WILSON, A.I. 2012. *Excavations at Utica by the Tunisian-British Utica Project 2012.* Excavation Report.

FENTRESS, E., GHOZZI, F., QUINN, J., WILSON, A.I. 2013. *Excavations at Utica by the Tunisian-British Utica Project 2013.* Excavation Report.

FORD, R.I., MILLER, N., 1978. Paleoethnobotany I. In: J.H. Humphrey, ed. *Excavations at Carthage 1976 conducted by the University of Michigan IV*. Tunis: Cérès Productions, pp. 181–187.

GARCÍA-MARAVER, A., ZAMORANO, M., RAMOS-RIDAO, A., DÍAZ, L.F. 2012. Analysis of olive grove residual biomass potential for electric and thermal energy generation in Andalusia (Spain). *Renewable and Sustainable Energy Reviews*, 16(1), 745–751.

GÖGÜS, F., MASKAN, M., 2006. Air drying characteristics of solid waste (pomace) of olive oil processing. *Journal of Food Engineering***,** 72(4), 378–382.

HALOUNAI, K. 2014. *Waste to Renewable Electricity. It is Possible in Tunisia*. [online]. Power point presentation, March 22, 2014. [Viewed 28/8/18]. Available from: http://www.oitsfax.org/files/Pr%20K%20Halouani%20-COI-Monastir%20March%2022%20%202014.pdf

HAY, S., FENTRESS, E., KALLALA, N., QUINN, J., WILSON, A., 2010. Utica. *Papers of the British School at Rome,* 78, 325–329.

HITCHNER, R.B., 2002. Olive production and the Roman economy: the case for intensive growth in the Roman Empire. In: W. Scheidel, S. von Reden, eds. *The Ancient Economy.* Edinburgh: Edinburgh University Press, pp. 71–86.

HOBSON, M.S., 2015a. *The North African Boom: Evaluating Economic Growth in the Roman Province of Africa Proconsularis (146 B.C. – A.D. 439).* JRA Supplementary Series 100, Portsmouth, Rhode Island: Journal of Roman Archaeology.

HOBSON, M.S., 2015b. The African Boom: The Origins of economic growth in Roman North Africa. In: P. Erdkamp, K. Verboven, A. Zuiderhoek, eds. *Ownership and Exploitation of Land and Natural Resources in the Roman World.* Oxford: Oxford University Press, pp. 207–233.

HOFFMAN, E.S., 1981. Palaeoethnobotany II: plant remains from Vandal and Byzantine deposits in three cisterns. In: J.H. Humphrey, ed. *Excavations at Carthage, 1977, Conducted by the University of Michigan. Vol. VI.* Ann Arbor: University of Michigan Press, pp. 259–268.

HOFFMAN, E.S., 1982. Palaeoethnobotany III: charcoal analysis from Vandal and Byzantine deposits in two cisterns. In: J.H. Humphrey, ed. *Excavations at Carthage, 1978, Conducted by the University of Michigan. Vol. VII.* Ann Arbor: University of Michigan Press, pp. 193–200.

INFOPOWER, 2005. Plantas de secado de lodos con congeneración en ciclo combinado 913,6+3,97 MWe) y generación eléctrica a partir de biomasa (9,15 MWe) en la industria olivarera andaluza. *InfoPower Plant Report.* [online]. Available from: https://www.genelek.com/wp-content/uploads/2018/06/olextra.pdf

INTERNATIONAL OLIVE OIL COUNCIL (IOOC). 2017. *World Olive Oil Figures*. [Viewed 17/12/2017]. Available from: http://www.internationaloliveoil.org/estaticos/view/131-world-olive-oil-figures

INTERNATIONAL OLIVE OIL COUNCIL (IOOC). 2017. *EU Olive Oil Figures.* [Viewed 17/12/2017]. Available from: http://www.internationaloliveoil.org/estaticos/view/131-world-olive-oil-figures

INTINI, F., KÜHTZ, S., ROSPI, G., 2011. Energy recovery of the solid waste of the olive oil industries–LCA analysis and carbon footprint assessment. *Journal of Sustainable Energy & Environment,* 2(4), 157–166.

KAPLAN, J.O., KRUMHARDT, K.M., ZIMMERMANN, N., 2009. The prehistoric and preindustrial deforestation of Europe. *Quaternary Science Reviews,* 28(27–28), 3016–3034.

KARAPMAR, M., WORGAN, J.T., 1983. Bioprotein production from the waste products of olive oil extraction. *Journal of Chemical Technology and Biotechnology,* 33, 185–188.

KINAB, E., KHOURY, G., 2015. Management of olive solid waste in Lebanon: From mill to stove. *Renewable and Sustainable Energy Reviews,* 52*,* 209–216.

LEWIT, T., 2011. Dynamics of fineware production and trade, the puzzle of supra-regional exporters. *Journal of Roman Archaeology* 24, 313–332.

MACKENSEN, M., 2009. Technology and organisation of ARS ware production-centres in Tunisia. In: J.H. Humphrey, ed. *Studies on Roman Pottery of the Provinces of Africa Proconsularis and Byzacena (Tunisia)*. JRA Supplementary Series 76. Rhode Island: Journal of Roman Archaeology, pp. 17–44.

MALDONADO, J.S., 2016. Disposiciones generales. *Boletín Oficial de la Junta de Andalucía*. 249: 77–336. [Viewed 20/8/18]. Available from: https://www.juntadeandalucia.es/boja/2016/249/BOJA16-249-00260-22930-01_00105133.pdf

MARGARITIS, E., JONES, M., 2008. 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.

MASGHOUNI, M., HASSAIRI, M., 2000. Energy applications of olive-oil industry by-products: I. The exhaust foot cake. *Biomass and Bioenergy,* 18(3), 257–262.

MASON, J.R. 2007. Experimenting the Manufacture of Nabataean Fine-ware Pottery. In: K.D. Politis, ed. *The World of the Nabataeans.* Vol. 2. Stuttgart: Franz Steiner Verlag, pp. 327–335.

MATTINGLY, D.J., 1988a. Oil for export? A comparison of Libyan, Spanish and Tunisian olive oil production in the Roman Empire. *Journal of Roman Archaeology,* 1, 33–56.

MATTINGLY, D.J., 1988b. The olive boom: Oil surpluses, wealth and power in Roman Tripolitania. *Libyan Studies,* 19, 21–42.

MATTINGLY, D.J., 1996. First fruit? The olive in the Roman world. In: G. Shipley, J. Salmon, eds. *Human Landscapes in Classical Antiquity.* London: Routledge, pp. 213–253.

MEKKI, H., ANDERSON, M., AMAR, E., SKERRATT, G.R., BENZINA, M., 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, 1419–1425.

MENÉNDEZ, J.A., FERNÁNDEZ-TRESGUERRES, L.G., VILLANUEVA, S.F., DURAN, M., MONTES-MORÁN, M.A.., ARENILLAS, A., 2018. Report on the availability of Biomass Sources in Spain: vineyards and olive groves. *Informes y documentos de trabajo.* [online]. [Viewed 21/8/18]. Available from: http://digital.csic.es/bitstream/10261/158364/1/Availability%20of%20Biomass%20Sources%20in%20Spain.pdf

MONTEIX, N., 2009. Pompéi, *Pistrina*: recherches sur les boulangeries de l'Italie romaine [2008]. *Mélanges de l'école française de Rome,* 121, 322–335.

M.O.R.E., 2008a. Report on best practices. *Market of Olive Residues for Energy. Intelligent Energy Europe.* [Viewed 23/8/18]. Available from: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/report_on_best_practices_m.o.r.e._en.pdf

M.O.R.E., 2008b. Final publishable report. *Market of Olive Residues for Energy. Intelligent Energy Europe.* [Viewed 23/8/18]. Available from: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/final_report_m.o.r.e._en.pdf

M.O.R.E., 2018. Market of Olive Residues for Energy. *Intelligent Energy Europe.* [Viewed 1/9/18] Available at: https://ec.europa.eu/energy/intelligent/projects/en/projects/more

NIAOUNAKIS, M., 2011. Olive-mill wastewater in antiquity. Environmental effects and applications. *Oxford Journal of Archaeology,* 30, 411–425.

OLIVEA, 2017. *Official Journal of the International Olive Council.* English ed. Issue 124. [Viewed 24/8/18]. Available from: http://www.internationaloliveoil.org/store/view/120-olivae-124-ingles.

PANER, 2010. Plan de Acción Nacional de Energías Renovables de España (PANER) 2011-2020. [Viewed 23/8/18]. Available from: http://www.mincotur.gob.es/energia/desarrollo/EnergiaRenovable/Paginas/paner.aspx

RAJAEIFAR, M.A., AKRAM, A., GHOBADIAN, B., RAFIEE, S., HEIJUNGS, R., TABATABAEI, M., 2016. Environmental impact assessment of olive pomace oil biodiesel production and consumption: a comparative lifecycle assessment. *Energy,* 106, 87–102.

RAMACHANDRAN, S., SINGH, S.K., LARROCHE, C., SOCCOL, C.R., PANDEY, A., 2007. Oil cakes and their biotechnological applications–A review. *Bioresource technology,* 98(10), 2000–2009.

ROMO SALAS, A., VARGAS JIMÉNEZ, J., 2001. Azanaque. Evidencias arqueológicas de un centro de producción anfórica. *Congreso Internacional Ex Baetica Amphorae,* Écija: Editorial Gráficas, pp. 405–417.

ROWAN, E., 2015. Olive oil pressing waste as a fuel source in antiquity. *American Journal of Archaeology,* 119(4), 465–82.

ROWAN, E., 2017. Bioarchaeological preservation and non-elite diet in the Bay of Naples: An analysis of the food remains from the Cardo V sewer at the Roman site of Herculaneum. *Environmental Archaeology,* 22(3), 318–336.

ROWAN, E., 2018. Olives and olive oil. In: C. Holleran and P. Erdkamp, eds. *Diet and Nutrition in the Roman World.* London: Routledge, pp. 129–139.

RUGGERI, B., BATTISTA, F., BERNARDI, M., FINO, D., MANCINI, G., 2015. The selection of pretreatment options for anaerobic digestion (AD), p. A case study in olive oil waste production. *Chemical Engineering Journal,* 259, 630–639.

SMITH, W., 1998. Fuel for thought: archaeobotanical evidence for the use of alternatives to wood fuel in Late Antique North Africa. *Journal of Mediterranean Archaeology* ,11, 191–205.

SMITH, W., 2001. Environmental sampling (1990–1994). In: L.M. Stirling, D.J. Mattingly, N. Ben Lazreg, eds. *Leptiminus (Lamta): the east baths, cemeteries, kilns, Venus mosaic, site museum and other studies.* Report no. 2. JRA Supplementary Series 41. Rhode Island: Journal of Roman Archaeology, pp. 420–441.

STAMATAKIS, G., 2010. Energy and geo-environmental applications for olive mill wastes. a review. *Hellenic J Geosci,* 45, 269–282.

STEWART, R. 1984. Carbonized Seeds. In: H.R. Hurst, S. Roskams, eds. *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: Sheffield University, Department of Prehistory and Archaeology, pp. 257.

STIRLING, L., BEN LAZREG, N., 2001. A Roman kiln complex (Site 290): preliminary results of excavations, 1995–98. In: L.M. Stirling, D.J. Mattingly, N. Ben Lazreg, eds. *Leptiminus (Lamta): the east baths, cemeteries, kilns, Venus mosaic, site museum and other studies.* Report no. 2. JRA Supplementary Series 41. Rhode Island: Journal of Roman Archaeology, pp. 220–235.

STONE, D., 2009. Supplying Rome and the empire: the distribution of stamped amphoras from Byzacena. In: J.H. Humphrey, ed. *Studies on Roman Pottery of the Provinces of Africa Proconsularis and Byzacena (Tunisia).* JRA Supplementary Series 76. Rhode Island: Journal of Roman Archaeology, pp. 127–149.

TAWARAH, K.M., RABABAH, R.A., 2013. Characterization of Some Jordanian Crude and Exhausted Olive Pomace Samples. *Green and Sustainable Chemistry* 3, 146–162.

THURMOND, D.L., 2006. *A Handbook of Food Processing in Classical Rome.* Leiden: Brill.

VEGA-GÁLVEZ, A., MIRANDA, M., DÍAZ, L.P., LOPEZ, L., RODRIGUEZ, K., DI SCALA, K., 2010. Effective moisture diffusivity determination and mathematical modelling of the drying curves of the olive-waste cake. *Bioresource Technology,* 101(19), 7265–7270.

VERA, D., JURADO, F., MARGARITIS, N.K., GRAMMELIS, P., 2014. Experimental and economic study of a gasification plant fuelled with olive industry wastes. *Energy for Sustainable Development,* 23, 247–257.

VOURDOUBAS, J., 2017. Possibilities of Energy Generation from Olive Tree Residues, by-products and Waste in Crete, Greece. *Journal of Agricultural Studies,* 5(4), 110–122.

WARNOCK, P., 2007. *Identification of Ancient Olive Oil Processing Methods Based on Olive Remains*. Oxford: Archaeopress.

WILSON, A., 2002. Urban production in the Roman world: the view from North Africa. *Papers of the British School at Rome,* 70, 231–273.

YEGÜL, F.K., 2010. *Bathing in the Roman world.* Cambridge: Cambridge University Press.