Fuel and Fire in the Ancient Roman World
Towards an integrated economic understanding
Edited by Robyn Veal & Victoria Leitch
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with contributions from
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Preface

This book arises from a conference held at the British School at Rome, and the Finnish Institute in Rome, in March 2013, entitled Fuel and Fire in the Ancient Roman World. The conference represented the first real attempt to try to bridge the gap between ‘top-down’ generalized models about Roman energy consumption (itself, still a relatively new area of research), and research carried out by artefact and environmental specialists. In many ways it exceeded our expectations, although it probably raised more questions than it answered. As fuel is used in many different domestic and industrial contexts, the papers were very heterogeneous; some presenters came from a strong archaeobotanical background, which is a central area for fuel research, while others came from social, technical and economic spheres, opening up the discussion beyond archaeobotany. Some papers presented more ‘qualitative’ rather than ‘quantitative’ results but, as a new research area, this was inevitable and qualitative evaluation can provide the framework for approaching quantitative studies. Nevertheless, useful quantitative beginnings are proposed in a number of papers. Although focused on the Roman period, the research often extended beyond this chronological span, to help contextualize the results.

We gratefully acknowledge the support and assistance of the British School at Rome and the Institutum Romanum Finlandiae (Finnish Institute of Rome). In particular we thank Professor Katarina Mustakallio, then director of the IRF, for generously hosting the conference lunch on the final day. The financial support of the Oxford Roman Economy Project, through Professor Andrew Wilson, and a significant private donation from Mr Jim Ball, former Commonwealth Forests Chairman (administered through the BSR Rickman Fund) allowed speakers’ travel, accommodation and subsistence costs to be covered, as well as a contribution towards publication costs. Professor Wilson and Mr Ball both provided much appreciated moral support and intellectual input, acting as our major discussants. The McDonald Institute for Archaeological Research, through its Conversations series, also helped fund publication. Professor Graeme Barker (McDonald Institute director to September 2014), Professor Cyprian Broodbank (current director), Dr James Barrett (current deputy director) and Dr Simon Stoddart (former acting deputy director) all provided advice and guidance over time. This was much appreciated. Dora Kemp provided initial advice on manuscript preparation, and after her untimely death, Ben Plumridge took over the practical side of production. Maria Rosaria Vairo, then a Masters student of the University of Lecce, and Dana Challinor, a doctoral student at the University of Oxford, provided significant voluntary support during the conference and we thank them both profusely. Robyn Veal would also like to acknowledge the long-term financial and intellectual support of the Department of Archaeology, University of Sydney, through much of her early work on fuel. This led to the opportunity of a fellowship at the BSR, and the idea for this conference. The feedback from reviewers has greatly improved the book.

Robyn Veal & Victoria Leitch
Chapter 10

The utility of olive oil pressing waste as a fuel source in the Roman world

Erica Rowan

Olive oil, with its multitude of uses, was an enormously important product in the Roman world and consequently was produced in huge quantities. It functioned primarily as a foodstuff for consumption and cooking, and also as a fuel for lamps and a cleanser for the body. High in calories, fats and vitamins, olive oil was a crucial source of energy for the less wealthy members of Roman society (Rowan 2018a; USDA 2013). Yet the main by-product of olive oil production, olive pressing waste, commonly referred to in English as pomace, is mildly toxic and the waste water even more so (Doymaz et al. 2004, 213; Mekki et al. 2006, 1420; Ruggeri et al. 2015, 630–1). Fortunately, the chemical composition of pomace means that it can be converted into an energy efficient fuel resource. The use of pomace fuel to cook and heat within domestic properties as well as to fire kilns and bread ovens has changed little since antiquity, and it is the focus of discussion in this paper (Attom & Al-Sharif 1998, 220; Cuomo di Caprio 2007, 490; Niaounakis & Halvadakis 2006, 15; Rowan 2015a).

The Roman Imperial period (first to fourth centuries AD) and the early twenty-first century are both eras in which significantly greater olive oil production took place than in the preceding centuries (Azbar et al. 2004, 210; Doymaz et al. 2004, 214; Mattingly 1988a, 33–4; Warmock 2007, 45–57). Thus, the challenge of simultaneously removing and exploiting this resource is still pertinent. There has been a considerable quantity of contemporary research into the properties and uses of pomace (Alkhamis & Kablan 1999; Arvanitoyannis & Kassaveti 2008, 470; Attom and Al-Sharif 1998; Azbar et al. 2004, 210; Benavente & Fullana 2015; Canet et al. 2008; Doymaz et al. 2004; Karapinar & Worgan 1983; Masghouni & Hassairi 2000; Mekki et al. 2006; Niaounakis & Halvadakis 2006; Nuhoglu & Malkoc 2009; Ruggeri et al. 2015). Similarly, there has been a growing interest in the use of pomace fuel in antiquity among both archaeobotanists and the wider scholarly community (Barfod et al. 2018; Bourgeon et al. 2018; Margaritis & Jones 2008a,b; Monteix 2009, 331; Rowan 2015a; Wilson 2013, 260; Coubray et al., this volume). Large deposits of highly fragmented carbonized olive stones often signify the presence of pomace fuel waste in the archaeological record. While deposits of this type have been found throughout the Mediterranean and Middle East, few deposits from Roman sites, compared to Bronze Age and Hellenistic sites, have thus far been found (Rowan 2015a). Increased archaeobotanical sampling during excavations has begun to balance out these numbers and new evidence from Roman sites such as Utica (Tunisia) has been uncovered in recent years (Barfod et al. 2018; Bourgeon et al. 2018; Rowan 2015b, 2018b).

Research into both modern and ancient alternative fuel sources has now reached the point where it is possible to assess the consequences and benefits of increased olive oil production during the Roman period. How did the Romans deal with the large quantities of pomace generated each year and what was the potential impact of this increased production? In other words, what did it mean to have more olive pressing waste and yet more available fuel? What impact did this have on fuel-consuming activities such as ceramic production, building construction and domestic heating and cooking? In the absence of modern technology such as cabinet driers and electric fans, the Romans were limited in the number of applicable techniques regarding pomace disposal and use (Doymaz et al. 2004). Already there exists a set of scientific and historical parameters that constrain us. The following discussion will present these parameters and attempt to estimate the impact that pomace fuel use had on both rural and urban activities. Case studies will focus on building construction, olive oil production and domestic dwellings in Rome and Lepcis Magna.
The properties of pomace

Olive oil is produced by first crushing the olives and then pressing the resultant paste. Pomace, the paste that remains in the baskets after pressing, is composed of olive skin, flesh, stones (endocarps) and seeds (embryos). Pomace contains between 3.5 and 12 per cent oil and 20–30 per cent water to give it an overall moisture content of 25–55 per cent (Karapinar & Worgan 1983, 185; Mekki et al. 2006, 1419). These percentages do not change whether or not a traditional non-mechanized press (screw press, beam press, etc.) or a modern press (the application of hydraulic pressure) is used. Modern presses simply reduce pressing time because the equipment can exert more pressure on the press bed (Mattingly 1988b, 182). Thus, pomace produced in the Roman period would have contained the quantities of oil and water listed above. When the traditional press system is used, the proportion of olive oil to pomace generated during pressing does not vary to any significant degree. Every tonne of olives pressed generates 200 l (184 kg) of olive oil, 450 l of waste water, and 350–400 kg of pomace (Niaounakis 2011, 414).

This rough 2:1 ratio of pomace to oil production means that millions of kilograms of pomace are generated each pressing season. Scientists and engineers have struggled to find alternative uses for pomace as its chemical properties do not make it readily usable as an agricultural product in an untreated form (Attom & Al-Sharif 1998, 220). Pomace has a pH of 5.33, making it acidic (Hepbasli et al. 2003). The majority of the toxic chemicals are contained within the stones and when they are broken during crushing, the chemicals are released into the paste (Azbar et al. 2004, 210). According to Cato the Elder (Agr. 37.2.), pomace could be used to fertilize olive groves but, as he rightly noted, it was too acidic to fertilize cereal crops. In olive groves, the acidity has the beneficial effect of enhancing soil potassium levels while simultaneously suppressing grass growth and controlling harmful parasitic nematode populations (Boz et al. 2010, 292; García-Ruiz et al. 2012, 804). Alternatively, the pressing waste can also be fed to animals, although always mixed with other forms of fodder as pure pomace is too difficult to digest (Karapinar & Worgan 1983, 185). Consequently, pomace cannot be used as fertilizer or fodder on a large scale and even today its primary use is as a fuel (Attom & Al-Sharif 1998, 220; Jauhiainen et al. 2005, 512).

The large quantity of oil remaining in the pomace after pressing makes it an ideal fuel. Before it can be used as fuel, however, the moisture content must be reduced. Traditionally, pomace is left in the sun to dry and the water content decreases through evaporation. Although there is currently a great deal of research into the most time efficient techniques for drying pomace, in many areas of Turkey and Jordan sun-drying is still the dominant method (Doymaz et al. 2004, 214; Göğüs 2006; Vega-Gálvez 2010; Warnock 2007, 51). Once the moisture has been reduced to 5–6 per cent the pomace is ready to be used as a fuel (Akgun & Doymaz 2005, 455). It is important to note that drying pomace does not reduce the amount of oil regardless of the duration of drying or the external temperature (Doymaz et al. 2004, 216–18; Karapinar & Worgan 1983, 185). In the absence of any modern heating or drying technologies such as rotary driers, the fastest way to sun-dry pomace is to reduce the thickness of the paste by spreading it out on the ground (Doymaz et al. 2004, 216–18; Karapinar & Worgan 1983, 185). The formation of the dried pomace into usable units varies by country in the modern world. In Jordan the pomace is traditionally rolled into 8–12 cm balls, while in Turkey it is pressed into briquettes (Akgun & Doymaz 2005, 456; Warnock 2007, 48–51).

The burning properties of pomace make it suitable for both domestic and industrial purposes. Although the calorific value of pomace will vary somewhat based on the ratio of stones to pulp, Doymaz et al. (2004, 218) have determined that on average it has a calorific value of between 21.129 and 22.020 MJ/kg. While this is lower than the average calorific value of charcoal (30.77298 MJ/kg), pomace can burn with a more consistent temperature for a longer period of time than charcoal (depending on the temperature required). Ethnographic work in Thrapsano, Crete, has shown that kilns using pomace can reach up to 1000 °C. Consequently, pomace is a highly desired fuel for use in pottery kilns and in Turkey it is used in bakeries to heat the ovens. Similar to charcoal, it also burns with an odourless and smokeless fire, making it a suitable fuel for domestic cooking and heating (Brun 2003, 183). In Jordan and Israel it is used in small stoves to heat homes during the winter and in Morocco to heat baths (Ait Baddi et al. 2004; Warnock 2007, 51).

Archaeobotanical evidence in the form of carbonized olive stones from sites around the Mediterranean has demonstrated that pomace was used throughout antiquity for domestic heating and cooking (Haggis et al. 2011; Hoffman 1981, 1982; Margaritis & Jones 2008a; Sarpaki 1999; Rowan 2015a). Based on the evidence from sites in Tunisia, Cyprus and Italy, evidence for the use of pomace fuel in industrial activities includes heating the water used in olive oil production as well as fuel for pottery kilns (Haggis et al. 2011; Hoffman 1981, 1982; Margaritis & Jones 2008a; Sarpaki 1999; Rowan 2015a). During the Roman period, in addition to its
more traditional uses, pomace began to be utilized in a wider range of production activities (Rowan 2015a). There is evidence from Pompeii for its use in bread ovens (see especially Coubray et al., this volume); from La Garde (France) for heating of the baths; and from Carthage for lime production (Brun et al. 1989, 126; Ford & Miller 1976, 183–7; Monteix 2009; Monteix et al. 2012). There is also good evidence from Israel and Jordan for the late antique use of pomace fuel in glass production (Barford 2018; Fischer 1999, 896, 903).

**Quantities generated in the Roman Empire**

It must be stated that any calculations regarding the quantities of olive oil and pomace generated within the Roman Empire each year are estimates. Similarly, the quantities of olive oil generated in a particular region or even on a particular farm can never be anything more than educated guesses due to the patchiness of the archaeological record (and the variation in productivity from farm to farm). Nevertheless, in the absence of any prior syntheses and discussions of pomace fuel use within the Roman world, an examination of the estimated quantities acts as a starting point, enabling us to more precisely consider the impact of this alternative to wood fuel on Roman domestic and industrial activities.

According to Mattingly, the Roman Empire was capable of producing between roughly 543 million and 1.09 billion litres of olive oil annually. These quantities of oil equate to between 951 million and 1.91 billion kg of pomace. While small quantities of oil were no doubt produced wherever it was climatically suitable to grow olives, the main centres of production were Spain and North Africa. Mattingly has calculated that the territory of Lepcis Magna could have produced 15 million litres of oil per year, resulting in 26.25 million kg of pomace (Mattingly 1988a, 47). If the territories around Oea and Sabratha are added then the region’s total oil output may have been as much as 30 million litres, thus resulting in the generation of 52.2 million kg of pomace (Hitchner 2002, 77; Marzano 2013, 92). Similarly large quantities of oil were produced in Spain. Based on evidence from Monte Testaccio, Garnsey & Saller (1987, 58) have estimated that 55,000 Dressel 20 amphora containing 4 million litres of Baetican olive oil were imported into Rome on an annual basis. A quantity of 7 million kg of pomace would have been generated at this level of production. De Sena believes that this number is too low, as Garnsey & Saller have not taken into account the ceramic evidence from other parts of Rome and Ostia. De Sena therefore suggests that 10–12 million litres were imported from Baetica per annum during the second century AD, which would have resulted in the generation of between 17.5 million and 21 million kg of pomace (De Sena 2005, 8).

Although not an area of major olive oil production, Rome’s hinterland must also be considered. This region has been roughly defined as the areas close enough to the city in which fresh fruit, vegetables and dairy products could be imported and sold (De Sena 2005, 4; Marzano 2013, 87–8). De Sena (2005, 4) examined the archaeological evidence for farms and presses from an area of approximately 5000 sq. km around Rome, encompassing modern day Lazio and stretching 64 km upriver from Rome and 48 km along the consular roads. Marzano (2013, 89–90) has done a similar study of oil and wine presses, examining a 5500 sq. km semi-circle around the city, which includes Centumcellae, Falerii Novi, Praeneste and Antium. Unfortunately, the archaeological evidence for oil presses is scant: Marzano (2013, 89) identified only 61 oil and 84 oil or wine presses. Nevertheless, De Sena (2005, 8) has concluded that the area was densely populated with farms and he estimates that Rome’s hinterland could have produced roughly 9.7 million litres of olive oil per year. This quantity of oil would have resulted in a pomace output of approximately 17 million kg.

The production capacity of a single press varies considerably based on its size. According to Brun (1987, 279–81), presses of a similar size to those at La Garde, France, could produce 1500–2000 l of oil per year. The much larger Tripolitanian presses, based on Mattingly’s calculations, could generate 6900–13,800 l of oil per pressing season (Marzano 2013, 99; Mattingly 1988b, 185). At the minimum of 1500 l and the maximum of 13,800 l, each pressing season would result in an output of between 2625 and 24,150 kg of pomace per press. This calculation assumes only one press per site; thus far the archaeological evidence has suggested that one press was usual for the hinterland of Rome, but in the Gebel Tarhuna region to the southwest of Lepcis Magna, 67 per cent of 146 farm sites had two or more presses and 39 per cent had three or more presses up to a maximum of 17 (Ahmed 2010, 117–19; Hobson 2012, 141; Marzano 2013, 90; Oates 1953). Using Mattingly’s Tripolitanian range of press output estimates, a farm with three presses would have generated 36,225–72,450 kg of pomace per year.

**Consequences of quantity**

The generation of so much pomace each year, often within discrete areas, presented the producers with both challenges and benefits. It was a challenge because this acidic substance could not simply be left
to accumulate and decay on its own year after year without occupying and effectively sterilizing sections of land.\(^8\) It was, however, an economic opportunity as it was a product that could be sold on to potters, bakers, glass-makers and so forth. It is difficult to know whether or not the Romans regarded pomace in such dichotomous terms but it is clear that the generation of so much pomace throughout the Roman world promoted its utility as a fuel. The quantities created on an annual basis, especially in highly concentrated areas of production such as North Africa and Spain, often went beyond the needs of even a large farm and thus pomace was distributed and used more broadly.

In the more arid areas of the empire there were numerous opportunities in which to use pomace, especially in the absence of a steady supply of charcoal. Although the kilns have not yet been excavated, it is almost certain that the ARS pottery production sites in inland Tunisia used pomace to fuel the kilns (Hobson 2015; Leitch 2010, 2011; Lewit 2011, 319–20; Rowan 2015a, 2018b; Wilson 2012, 150). Since the ceramics were destined for overseas shipment, it is highly unlikely that the olive groves were planted in this inland region for the specific purpose of exploiting pomace as a fuel source. In other words, the pomace was just a beneficial by-product of olive oil production. Yet the movement of the pottery production inland indicates that the economic benefits of pomace fuel must have outweighed the high cost of transport (Lewit 2011, 320).\(^9\) The firing of the ceramic kilns solved the problem of pomace build-up while at the same time exploiting a large and steady fuel supply in an area with little natural woodland.

Similarly, the large Tunisian and Libyan cities, such as Carthage, Utica, Lepcis Magna, Sabratha and Oea, would have been able to utilize readily the large quantities of pomace being generated in their respective hinterlands (Mattingly 1995, 7–11; WMO 2014).\(^10\) The archaeological evidence from each individual site regarding pomace production and its uses is patchy due to the unevenness of the excavated areas. There has been little survey or excavation work done for the hinterlands of Carthage and Utica and there are no estimations of the number of presses or output of olive oil. The sites, however, have been extensively sampled for archaeobotanical remains (Rowan 2015b, 2018b; Stewart 1984, 257; van Zeist 1994, 325). Large quantities of carbonized olives stones have been found in Carthage and Utica in contexts associated with pottery and lime production, indicating pomace fuel use. Although dating to late antiquity, there is also evidence from Carthage for the use of pomace fuel in domestic contexts (Hoffman 1981, 1982). The areas around Lepcis Magna, Sabratha and Oea, conversely, have been well surveyed and, as stated above, hundreds of presses have been identified (Ahmed 2010; Barker 1996; Mattingly 1985, 1988a, 35–8, 1989; Oates 1953; Schörle & Leitch 2012). Unfortunately no archaeobotanical work has, as yet, been undertaken for Lepcis Magna, Sabratha and Oea. Nevertheless, combined, the existing material from all five of these sites demonstrates that wherever detailed work has been done, evidence for olive oil production and pomace use has been found.

It is therefore possible to suggest that pomace was used throughout the North African cities for a multitude of domestic and industrial functions. Pomace fuel to fire kilns and bread ovens would have been easily purchased from nearby farms. A closer examination of the domestic uses, especially if exploited by the majority of the urban population for heating and cooking, suggests that domestic activities could have made a significant and essential contribution to the reduction of the pressing waste generated in the hinterland, thereby also significantly reducing pressure on woodland resources.

New population estimates based on city size per hectare have been generated for three of the North African cities mentioned above: Lepcis Magna (90,000), Sabratha (10,850) and Carthage (300,000) (Wilson 2011, 176–84).\(^11\) Ethnographic work by Warnock (2007, 51) has shown that 0.416 kg of pomace will provide heat for a single hour when put into a portable furnace. Table 10.1 indicates pomace consumption if each individual used a small portable furnace for one or two hours every day for a year.

The time estimates simply serve as an example as pomace use could be distributed within domestic contexts in a multitude of ways. If used solely for heating, each time estimate assumes that every person would have three or six hours of heat per day during the coldest winter months (December–March) (WMO 2014). Alternatively the time estimates could relate to the time spent cooking, as the furnace or other heating implement, for example a brazier, could serve as a cooker and heater. While it is obvious that not every person would light their own individual furnace (e.g. young children), taking into account the whole population reduces the problem of houses in which multiple rooms were heated at the same time.\(^12\)

<table>
<thead>
<tr>
<th>City</th>
<th>Population</th>
<th>One hour Consumption</th>
<th>Two hours Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lepcis Magna (90,000)</td>
<td>13,665,600 kg</td>
<td>1,647,464 kg</td>
<td>45,552,000 kg</td>
</tr>
<tr>
<td>Sabratha (10,850)</td>
<td>27,331,200 kg</td>
<td>3,294,928 kg</td>
<td>91,104,000 kg</td>
</tr>
<tr>
<td>Carthage (300,000)</td>
<td>45,552,000 kg</td>
<td>5,458,320 kg</td>
<td>136,500,000 kg</td>
</tr>
</tbody>
</table>

Table 10.1. Domestic uses of pomace. Calculations are as follows: 0.416 × 365 (days) × population.\(^1\)
The utility of olive oil pressing waste as a fuel source in the Roman world

The case of Lepcis Magna

As Table 10.1 indicates, even limited domestic usage of pomace in Lepcis Magna would have halved the roughly 26.25 million kg of pomace generated each year. Additional urban usage might have included the city's large bath complexes, the Hadrianic, Eastern, Hunting and so-called Unfinished baths. Such urban usage of pomace was vital because even if half of the pomace was retained by the rural community, the majority of the rural uses of pomace (heating the water for olive oil pressing, fertilizing the olive groves and feeding livestock), required only a minimal amount of pomace.

It was the amphorae kilns associated with the rural farms around Lepcis Magna that would have consumed the majority of the leftover pressing waste (Ahmed 2010, 248–52; Mattingly 1988c). It is estimated that between 300,000 and 1 million litres of Tripolitanian olive oil was shipped to Rome each year (De Sena 2005, 8; Mattingly 1993, 153). Regardless of the exact volume, thousands of amphorae had to be produced to ship the oil. Thus, similarly to the Tunisian ARS pottery production sites, the importance of the relationship between pomace and kiln firings, in terms of both consuming and exploiting the pomace, cannot be underestimated.

In light of the significance of the kilns, it is useful to hypothesize an example of rural pomace use. Lepcis Magna had a hinterland of 3000–4000 sq. km (Mattingly 1995, 230). Unfortunately there are no estimates for the rural population and thus we will have to use a single villa/press site as an example. Based on the detailed mapping of small concentrated areas during the Kasserine and UNESCO Libyan Valleys surveys, Mattingly (2011, 81–4) has estimated that the population of a villa/press site or a major settlement was 30 people. The oileries on the Tarhuna plateau, classified as farms having five or more presses, are concentrated on the eastern side of the plateau and it has been argued that they were part of the territory of Lepcis Magna (Ahmed 2010, 116–17). Thus the rural villa used in this example will be a press site with 30 residents and five presses. The presses of the Tarhuna plateau were extremely large and Ahmed (2010, 225–32) has calculated that each one could press one tonne of olives during a single pressing session. If 350 kg of pomace were generated during each pressing, and assuming a 90-day pressing season at maximum capacity, then the five presses on the farm would produce approximately 157,500 kg of pomace each winter. If three-quarters of the pomace was shipped into Lepcis for various urban uses, 39,375 kg would remain for use by the 30 people living at the villa.

In terms of cooking and heating, the villa’s inhabitants would have had the same requirements as the urban dwellers. If each individual heated/cooked for one or two hours a day then 4555 kg or 9111 kg of pomace would be required. At a press site, an additional fuel requirement would be to heat the water during olive oil production. The traditional press method utilizes 100–120 l of water for every tonne of olives pressed (Azbar et al. 2004, 215). Following Wilson’s estimation of the energy required to heat water, where there is a heat transfer efficiency of 25 per cent, 5.6–6.72 kg of pomace would be required to heat the water needed for one pressing (Wilson 2012, 149–50). Since pressing takes place in the winter, this estimate assumes that the temperature of the water must be raised from 10 °C to 80 °C. Over a 90-day pressing season this activity would consume between 504 and 604.8 kg of pomace per press for a total of 2520–3024 kg. The other two primary rural uses, as fertilizer and fodder, are almost negligible as only a small quantity of pomace can be used on the olive trees, and when used as fodder it must be heavily mixed with other materials (Ait Baddi et al. 2004, 39; Arvanitoyannis & Kassaveti 2007, 281). In sum, during a yearly cycle, at the minimum and maximum usages for heating/cooking and water heating, between roughly 27,240 and 32,300 kg would be left over for kiln firings.

The Tarhuna plateau survey has found that pottery kilns were usually associated with or located near to properties with evidence for large-scale olive oil production (Ahmed 2010, 252). Whole carbonized olive stones were found in the one excavated kiln, which tentatively suggests the use of pressing waste as their primary fuel source. The average diameter of the 14 kilns measured was 3.65 m (Ahmed 2010, 271). Ethnographic evidence from Crete has shown that 2500 kg of pomace is needed to fire a kiln 2.5 m in diameter at 1000 °C for ten hours. Ethnographic evidence from the Ballâs Pottery Project along with papyrological evidence from Egypt suggests that approximately 500–700 amphorae could be fired within a single kiln of 4.5 m in diameter, with each firing taking three to four hours (Gallimore 2010, 171–4; Nicholson & Patterson 1989). Since the Tarhuna kilns are larger than the kiln on Crete we can estimate that 3000 kg of pomace would be required for a single ten-hour firing or 1200 kg for a four-hour firing. The remaining pomace then, if used as the exclusive fuel source, would be sufficient for 22 to 27 firings of 500 amphorae each. At the lower end of the scale of production (following Gallimore’s method), that would result in roughly 9900 amphorae, with, at the upper end, a maximum of 12,150 amphorae, assuming 10 per cent of the firings end up as wasters (Gallimore 2010, 174). Depending upon the level of domestic usage, anywhere between 69 and 82 per cent of the pomace
was available for amphorae production. All the figures, of course, are only estimates, but as Figure 10.1 shows, the quantities required for each rural activity could easily be manipulated. If additional kiln firings were required, then fewer rooms could be heated or other fuel sources such as dung could be used within the villa.

This exercise has demonstrated that, if three-quarters of the pomace was sent to Lepcis Magna, there was still enough pomace left in the rural areas to ensure sufficient fuel sources for the required domestic and industrial activities. At the same time, however, this exercise has shown the importance of Lepcis, and presumably other North African cities, as consumers, for if the cities did not use pomace then the countryside would be struggling to handle the thousands of kilograms of this toxic waste that would be left to ferment each year.

Rome’s challenge and solution

The cities and the kilns, at least in North Africa, were by far the largest consumers of pomace. Yet what if large quantities of olive oil were produced in an area where there was little pottery production? This question must be asked of Rome and its hinterland. An estimated 9.7 million litres of olive oil and thus 17 million kg of pomace were produced in Rome’s hinterland on an annual basis, yet there is no evidence for amphora kilns within this area (De Sena 2005, 8). How and where would the millions of kilograms of pomace be used?

The simple answer is that the excess pomace was used both in Rome and the countryside. Rome had the largest urban population of any city in the empire and consequently greater fuel requirements than even the largest North African cities. Heating the Imperial baths and numerous smaller local baths would have required considerable amounts of fuel, as would firing the bread ovens each day. The large and almost continuous Imperial construction projects would also have consumed significant amounts of fuel. The building of temples, baths, fora and aqueducts required the production of enormous quantities of lime and brick, both of which had to be produced in nearby kilns (DeLaine 1995, 559–60; Fontana 1995). For example, firing the 4,814,000 bessales (bricks) used in the construction of the Baths of Caracalla would have required 2166.3 tonnes of wood, and that is just one of the three types of bricks used in the baths (DeLaine 1997, 116–18, 124, 126). In terms of domestic fuel requirements, even if only half of the population of Rome required one hour of fuel for heating and cooking per day, that would mean fuel needs 5.5 times greater than the entire population of Lepcis Magna. It is interesting to note, however, that despite Rome’s high fuel requirements, there is no evidence for deforestation within the area or even the entire Italian peninsula during the Roman period (Grove & Rackham 2001, 174; Kaplan et al. 2009, 3029). The much wetter and more wooded Italian landscape, compared to North Africa, would have ensured a regular supply of charcoal and it was no doubt the primary fuel source used within the city. Veal has recently estimated Rome’s total fuel requirements, and in order to avoid deforestation one must entertain the notion that the charcoal and wood supply were supplemented by alternative sources (Veal 2017, 397–9). Pomace, a product generated locally and on a useful scale, has to be regarded as a highly plausible option.

Extremely little archaeobotanical sampling has been done within Rome and as yet there are no confirmed cases of pomace use. Consequently, pomace use within the city must, at this point, be regarded as no more than highly probable. Yet there is ample evidence from elsewhere in the empire that pomace fuel was used in the same domestic and industrial activities...
that took place within and near Rome (Rowan 2015a). At Pompeii, the discovery of thousands of carbonized fragments of olive endocarp from two bakeries indicates that pomace fuel was used to heat the bread ovens (Monteix 2009; Coubray, this volume). There is evidence for its domestic use at Herculaneum in the form of carbonized olive fragments from the Cardo V sewer (Rowan 2014). At Utica, fragmented carbonized olives stones were recovered from the bottom of multiple ceramic kilns and one large lime kiln, while from La Garde there is evidence that the villa’s baths were heated with pomace fuel (Brun et al. 1989, 126; Rowan 2018b). This widespread use of pomace needs to be taken into account and if Rome’s hinterland was producing at least moderate quantities of olive oil, it is difficult to imagine that neither the rural nor urban populations took advantage of this energy source. Despite the absence of physical material from Rome, it will be useful to examine a hypothetical division of rural and urban pomace use for Rome and its hinterland in a manner similar to that undertaken for Lepcis Magna.

The population of Rome’s hinterland has been estimated to have been approximately 250,000. This figure has been determined rather arbitrarily based on the estimated population of Roman Italy, and may in fact be too high (De Sena 2005, 6–8). Nevertheless, let us suppose that the rural population kept half of the pomace produced in the hinterland each year and therefore had 8.5 million kg to utilize for a range of activities.26 Similar to the hinterland of Lepcis, one of the rural uses would have been to heat the water used to press the olives.27 Marzano’s survey of Rome’s hinterland has shown that it was typical for a farm or villa to have only one press. She hypothesizes that each press could produce 9200 kg (10,000 l) of oil during a 90-day season (Marzano 2013, 90, 99). This quantity of oil equates to a production capacity of roughly 112 l of oil per day and the pressing of 555.5 kg of olives. At this rate, 87,300 press cycles were required to produce the estimated 9.7 million litres total production. If each cycle utilized 50–60 l of water, then heating the water would have consumed between 356,000 and 427,000 kg of pomace (Table 10.2).28

Domestic heating and cooking could easily have used up the remaining 8.1 million kg of pomace. The large population of Rome’s hinterland would have made up for the absence of fuel-consuming kilns. Domestic use also would have prevented a build-up of this toxic material, a crucial factor in an area with such a high land value. If we apply the same rural domestic heating and cooking fuel quantities of Lepcis Magna to the hinterland of Rome, then 37.96 million kg of pomace would be required to provide each individual with an hour of heat every day for one year. Not even the entire quantity of pomace generated in the hinterland (17 million kg) could have supplied Rome’s rural population with enough energy. However, these calculations assume that pomace was the only fuel in use, which, of course, is untrue. What these numbers instead suggest is that pomace accounted for a small to moderate percentage of the total fuel used by each individual.29 Yet if the rural population of Rome could easily have used all the available pomace, why would some of it be shipped into the city?

Within the city of Rome, fuel-related activities differed from those in the hinterland and consequently the ratio of fuel types was different. As stated above, fuel was required in bath buildings, bakeries, domestic residences and during building construction.30 The majority of these activities, especially bread production and domestic cooking, required far more charcoal than raw wood.31 In her model of fuel use in Pompeii, Veal (2009, 200) adopts the division of urban fuel use as 80 per cent charcoal and 20 per cent wood and the opposite for the countryside. Although charcoal has a much higher calorific content than dried wood (19 MJ/kg compared to 30 MJ/kg), its production consumes large quantities of wood (Francescato et al. 2008, 22). It can require between 4 and 7 tonnes of wood to produce one tonne of charcoal (Veal 2009, 200–1). Since pomace burns at a high and consistent temperature and with little smoke, it is often used as a charcoal alternative or supplement. In other words, pomace can be used almost anywhere charcoal is employed. Even as a small percentage of total fuel use, the exploitation of 8.1 million kg of pomace – what was effectively cheap fuel – by the city of Rome would have taken some of the pressure off the wood and charcoal industries. Moreover, although probably inexpensive, the sale of pomace would have generated some additional income.

Table 10.2. Quantities of pomace required to heat the water used for one press and then all presses in Rome’s hinterland during a single 90-day pressing season, assuming that 100–120 l of water are required to press 1 tonne of olives (after Azbar et al. 2004, 215).

<table>
<thead>
<tr>
<th></th>
<th>Quantity of oil</th>
<th>Quantity of olives</th>
<th>Quantity of hot water required</th>
<th>Quantity of pomace fuel for heating the water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily (single press)</td>
<td>111.11 l (102.2 kg)</td>
<td>555.55 kg</td>
<td>55.55–66.67 l</td>
<td>4.08–4.9 kg</td>
</tr>
<tr>
<td>Seasonally (single press)</td>
<td>10,000 l (9200 kg)</td>
<td>50,000 kg</td>
<td>5000–6000 l</td>
<td>367.2–441 kg</td>
</tr>
<tr>
<td>Seasonally (all presses)</td>
<td>9.7 million l (8.9 million kg)</td>
<td>48.5 million kg</td>
<td>4.8–5.8 million l</td>
<td>356,187–427,774 kg</td>
</tr>
</tbody>
</table>
for local farmers.\textsuperscript{32} Using 19 MJ/kg as the calorific value of oven-dry raw wood, 8.95 million kg of raw wood would have to be burnt to match the energy present in 8.1 million kg of pomace. This quantity of wood, when converted into forested area, equates to 8952.6 hectares (89.52 sq. km), assuming a low productivity value of 1 tonne/hectare (Veal 2009, 202). The exploitation of the total 17 million kg of pomace is the equivalent to burning 18,789 hectares or 187.89 sq. km of woodland each year. Near Rome, this land could have been used to produce agricultural and horticultural goods, raise livestock or produce timber for use by the city. Thus, even if the archaeobotanical material is still missing, the city’s high charcoal demands make it almost certain that pomace was exploited as a fuel source within Rome.

\textbf{Conclusions}

Unavoidably produced but intentionally exploited as a by-product of olive oil production, it is clear from the growing body of archaeobotanical evidence that pomace was an important and widely utilized fuel source within the Roman Empire. As a toxic waste it had to be removed from the land. The popularity of certain goods and activities within the empire, many of which necessitated the consumption of vast quantities of fuel, meant that there were numerous avenues for pomace use and it was surely welcomed as an inexpensive source of energy. As the above discussion has shown, it is unlikely that any region of the Roman Empire suffered the consequences of having an overabundance of unused pomace.

The objective of this chapter has not been to establish precise quantities of pomace use within the Roman Empire. Instead, the goal has been to suggest ways in which pomace could have been utilized in different geographical areas and what that would have meant for the various fuel-consuming industries. I have tried as best as possible to ensure that all ecological and archaeological parameters have been considered. The numbers are estimates and the models serve simply to suggest new ways of thinking about the exploitation and importance of various fuel resources within the Roman Empire. How important was pomace? In the arid regions of North Africa, for example, pomace exploitation may have been the only way that the thousands of amphorae required for olive oil export could have been produced. How did rural and urban pomace use differ? How much was sent to the cities and how much was retained for rural activities? Again, the 50/50 split presented here for Rome is only a suggestion. Is the exploitation of multiple fuel sources the way that the Romans avoided large-scale deforestation while at the same time maintained high rates of production, trade and construction throughout the Roman world? (Erdkamp 2016; McConnell et al. 2018). This chapter has raised more questions than it has answered, but it is hopefully only the beginning of a new area of investigation.

In summary, pomace was important. Although used in different ways and for different purposes, agricultural by-products may have been just as important as cultivated agricultural products in the ancient world. Further work will no doubt help to clarify and quantify the use of pomace within the Roman Empire. At the moment, however, it is hoped that this chapter has raised awareness of the importance of incorporating alternative fuels into our models of Roman economic activities.

\textbf{Notes}

1. 1 l of olive oil = 0.92 kg. (Marzano 2013, 99).
3. The amount of olive oil and pomace generated on an annual basis will also fluctuate based on the quality of the harvest, as olive trees vary considerably in their annual yield.
4. Mattingly (1988a, 34) estimates a total output of 500,000–1,000,000 metric tonnes of oil. When converted into litres (1 l of oil = 0.92 kg), the precise quantities are 543,478,260.89 l and 1,086,956,521.73 l.
5. Or 951,000 and 1.91 million tonnes. All estimates use the ratio of 350 kg of pomace for every 200 l of olive oil produced.
6. The accuracy of this number is debatable as he estimates that the density of presses, at least in the Ager Faliscus, was similar to the areas of peak North African production where there is one press every 2 sq. km. (Hitchner 2002; Mattingly 1988b).
7. The farm with 17 presses was quite exceptional as the next highest number of presses at a single farm was nine.
8. The specific challenge with pomace is that the high levels of phytotoxic chemicals present in the waste will kill the vegetation beneath it. Wet pomace is more harmful because it also contains some of the waste water, which is far more toxic than the paste itself. In the Aydan region of modern Turkey, piles of pomace are left to dry next to the presses in large gravel or paved outdoor areas. Moreover, pomace does not biodegrade quickly and although the stones would have been broken, they would not have been crushed or ground and consequently they would take years to fully decompose (Cayuela et al. 2007, 1985; Martin 1992, 99).
9. The oil produced on these farms was transported to the coast in skins in order to reduce shipping costs.
10. http://worldweather.wmo.int/en/home.html. There was more rainfall at Carthage and Utica than the Tripolitanian cities, but large tracts of forest would still have been scarce except near the deltas and coast, and on the mountains.
The population of Sabratha is an average of Wilson’s estimates. Calculations are as follows: 0.416 × 365(days) × population. This would occur especially in homes that had their own kitchens, as cooking and heating would then be separate activities. Although it must be kept in mind that pomace would not be the only fuel in use and fuels such as charcoal and dung would also be exploited. The ceramic evidence from Rome, primarily Monte Testaccio, and Ostia attests to the production of this large quantity of amphorae (De Sena 2005, 2).

Each tonne pressed produces 200 l of oil. The specific heat capacity of water is 4.2 kJ. At this rate it would take 420–504 kJ to raise 100–120 l of water one degree. The lower energy value of pomace of 21 MJ/kg, as calculated by Doymaz et al. 2004 has been used here. Descriptions of traditional press methods always state that hot but not boiling water is used, thus the selection of 80 °C. Ahmed (2010, 267–70) argues that the stones are evidence for pomace fuel. However, in the vast majority of cases in which archaeobotanical evidence for pomace fuel has been found, the olive stones are highly fragmented (Rowan 2015a).

Jean-Pierre Brun, pers. comm. 20 March 2014. It is highly unlikely that pomace was used on its own. Chaff is often used to start the fire. The Ballas Pottery Project found that 5–10 per cent of the vessels fired were wasters. Liquid products, such as olive oil and wine, were transported the short distance into Rome in barrels or skins and there was no need to make amphora on a large scale. Alexandria and Carthage, the two biggest cities in North Africa, had estimated populations of only 500,000 and 300,000 respectively, while the traditional population estimate for Rome during the period in question here is one million (Wilson 2010, 184–7). According to DeLaine, 2,020,000 bessales were used in the construction of the foundations and substructure while 2,794,000 were used in the central block. She has calculated that it requires 0.45 tonnes of wood to fire 1000 bessales.

The large population of Rome’s hinterland meant that rural fuel requirements would be higher than Lepcis Magna and so half, instead of only a quarter remains in the countryside. Pliny (HN 15.6) also recommends heating the press room with pomace. These calculations are identical to the Lepcis Magna calculations in that there would be a 25 per cent heat transfer and the water would have to be heated from 10 °C to 80 °C. Without more information on all types of fuel used, it is impossible to estimate precise percentages. This list is not complete and fuel was required for other activities such as metal- and glass-working. Bread is baked by first heating the oven to a high temperature. The fuel is then raked out, the loaves inserted and the metal door shut, allowing the retained heat to bake the bread. It would therefore be difficult and inefficient to use raw wood to heat the ovens. Moreover, at Pompeii and Ostia, there is no space within the relatively small bakeries to store the quantities of raw wood required. Domestic cooking, even in wealthy homes, was done using tripods or small portable braziers and ovens. Large ovens were not used and thus compact fuel sources, such as charcoal or pomace, were the more probable types of fuel that could fit beneath the tripods or in the small ovens (Veal 2012, 26–7).

32 Alternatively, wealthy landowners could have used the pomace to heat their own houses in Rome.

References


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Fuel and Fire in the Ancient Roman World

The study of fuel economics in the Roman, or indeed in any ancient world, is at a pivotal point. New research in archaeological science, the ancient economy, the ancient environment, and especially, the increasing collection of bio-archaeological datasets, are together providing a greatly enriched resource for scholars. This volume makes a first attempt to bridge the gap between ‘top-down’ generalized models about Roman energy consumption with the ‘case study’ detail of archaeological data in the Mediterranean. The papers here are the work of scholars from a variety of disciplines: from archaeobotanists and historians to archaeologists specialising in social, technical and economic fields. A more nuanced view of the organization of the social and industrial structures that underpinned the fuel economy arises. Although focused on the Roman period, some papers extend beyond this era, providing contextual relevance from the proto-historic period onwards. Much exciting interdisciplinary work is ahead of us, if we are to situate fuel economics more clearly and prominently within our understanding of Roman economics, and indeed the ancient Mediterranean economy.

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