www.maajournal.com

Mediterranean Archaeology and Archaeometry
Vol. 22, No 1, (2022), pp. 45-65
Open Access. Online & Print.

DOI: 10.5281/zenodo.5906722

CRACKING THE HISTORY OF THE OLIVE: DIFFERENTIATING OLIVE OIL AND OTHER MEDITERRANEAN PLANT OILS THROUGH ORGANIC RESIDUE ANALYSIS

Zuzana Chovanec

State University of New York at Albany, USA
(zuzana.chovanec@gmail.com)

Received: 18/12/2021
Accepted: 12/01/2022

ABSTRACT

The possibility of differentiating olive oil from other plant oils in archaeological residues based on fatty acid profiles is assessed using gas chromatography/mass spectrometry (GC/MS) and statistical analysis. First, an artificial aging experiment was undertaken in order to model chemical alterations of fatty acids present in Cypriot olive oil. Fatty acid ratios were identified that may be used for differentiating olive oil from other oils, which were then applied to a reference database of 14 additional plants known in Cyprus. These results were then applied to a dataset of 68 ancient pottery samples from Bronze Age Cyprus. The outcome indicated that if a pottery vessel contained only olive oil, it may be distinguishable from other organic residues. Larger implications of documenting the role of the olive in historical investigations of Mediterranean foodways are also discussed.

KEYWORDS: olive oil, Mediterranean, Cyprus, organic residue analysis

1. INTRODUCTION

The aim of this paper is to apply residue analysis as it pertains to lipids to a category of subsistence products that played a significant role in Mediterranean history. It has long been argued that oil-bearing plants have been valued for subsistence, industrial and ritual functions (Renfrew 1973:194). Without a doubt, the olive figured prominently in the Mediterranean basin, both past and present (Frankel 1999; Hadjisavvas 2009, 1996, 1992). While in common use, it is likely that olive oil was not the only plant oil used in antiquity. In an era in which residue studies are increasingly being incorporated into archaeological research, presumptive identifications of organic products no longer are sufficient. The presence of olive oil has been noted in some publications that do not provide corroborating chemical evidence, over-interpret chemical results, or relegate to a footnote or appendix the fact that a plant or degenerated oil was identified (e.g., Dabney et al. 2004: 202; Evans in Merrillees 2003[1989]). While in some contexts the presence of a plant oil likely was olive oil on the basis of other lines of evidence (e.g., Koh and Betancourt's [2010: 18-19] identification of olive oil in storage jars at Kephali in Eastern Crete based on the presence of strong peaks of oleic acid; see also Mayyas 2018: 71), some identifications are based on one or two chemical compounds that are widely distributed. Such statements had been made for the presence of wine and beer (Guash-Jané et al. 2006; Sherratt 1987); however, as Mariti (1984: 70) highlights in relation to differences in the production of Cypriot wine, the archaeological and cultural context is key to the interpretation of chemical data.

That being said, basing the identification of a plant oil based on a single lipid is typically not sufficient because lipids are not biomarkers in isolation (see discussion about biomarkers below; also Mayyas 2018: 69); rather it is the range and proportion of different lipids in relation to one another that make them indicative of an ancient residue's source. In other instances, an incomplete understanding of how presumed biomarkers may transform into others under specific conditions may result in misrepresentations of the past if over-interpreted. A case in point is Linares et al.'s (2019) chemical identification of vanillin in three mortuary vessels at Megiddo, which was interpreted as evidence for an early Bronze Age long distance trade in vanilla, a plant indigenous to the Americas and Southeast Asia. Vanillin, though a biomarker in vanilla, is also found in myrtle berry (Aleksic and Knezevic 2014: 245) and aniseed (Chovanec 2013: 163), as well as a derivative of lignin (Wang et al. 2018). In the end, one must acknowledge that plant oils are comprised of many chemical constituents, a number of which may not preserve in the archaeological record.

The danger of interpretative presumptions have been discussed at length by Wiley (1988, 1985) and others (Feinman 1997; Lyman and O'Brien 2001; Stahl 1993) who highlight the disservice that historical analogies do for the examination of the past. With a broad set of historical documents from which to draw, archaeologists investigating the prehistoric Mediterranean may be tempted to draw synchronic parallels. Such interpretations inevitably become factoids in the literature. This is evident in Cypriot archaeology in Merrillees' (2003[1962]) suggestion that the Base Ring juglets served as specialized containers for opium, as well as the erroneous designation of the Late Bronze Age White Slip bowls as containers for the production, storage, and consumption of milk. The misnomer "milk bowl" was initially coined by Gjerstad in reference to its "milky-white" surface treatment, rather the kind of substance it may have held (Åström 1972: 441; Beck et al. 2004: 13).

The growing number of organic residue studies in archaeology may represent a step towards deconstructing such interpretative inconsistencies. Some such studies have shown that assumptions of a specific product were misplaced, in view of chemical evidence. The aforementioned chemical analysis of the Cypriot White Slip bowls indicated their use for various mixtures containing cooked meat, vegetables and other subsistence products (Beck et al. 2004). A second example is Guash-Jané et al.'s (2006: 98-9) determination that the sacred Egyptian drink, *shedeh*, consisted of a wine made of red grapes rather than pomegranates, as previously suggested. In other cases, substances and production processes are corroborated, such as in Solazzo and Erhardt's (2007) identification of marine mammal oil in Arctic coastal areas. In both the Egyptian and the Arctic examples, sufficient contextual information, whether archaeological or historical, pointed to potential sources of the residue. However, where there is extensive documentation for the production and consumption of a particular product, it is crucial to frame such discussions in historical context, such as Brogan and Koh's (2008) identification of wine production at Mochlos. Investigating the use and proliferation of the olive in the Mediterranean basin raises similar issues.

This paper discusses analytical research aimed at evaluating whether olive oil can be differentiated from other plant oils based on fatty acids. Using reference materials from the island of Cyprus as a case study, three research components are discussed: 1) an artificial aging study on olive oil in order to model patterns of decomposition and determine fatty acid ratios that may be used to identify olive oil in archaeological contexts; 2) comparing the fatty acid profiles

and ratios of olive oil with other plants that are indigenous to the island of Cyprus and would have been known during the Bronze Age; and 3) application of these results to a dataset of archaeological samples that underwent lipid extraction and analysis in order to assess the utility of the proposed ratios. Implications for understanding the history of the olive in the Mediterranean and methods for demonstrating this in archaeological chemical analysis are also discussed.

2. BACKGROUND

2.1. The Olive in the Mediterranean

The olive (*Olea europaea* L.) and its oil have become archetypal symbols of the Mediterranean as an experiential construct centred on sight, taste, and aroma (Knapp and Blake 2005: 6-7) (see Fig. 1). The olive is a member of the so-called dietary triad of the Mediterranean, which also includes grapes and grains (Hamilakis 1999: 44; Renfrew 1972: 280). The culinary aspect of the olive is well-documented in both the archaeological and historical record. On the island of Crete, the cultivation of olive trees is documented by archaeobotanical remains (i.e., pollen, carbonized pits), equipment for the production of olive oil (e.g., stone beds for pressing, tubs for separating and collecting oil), as well as quantities of oil being recorded in Linear B tablets suggesting that surpluses were being exported (Boardman et al. 1976: 188; Riley 2002: 65-7). A similar set of material indicates olive oil production in the Southern Levant from the Late Bronze Age onward (Frankel 1999; Giammellaro 1996: 56; Wolff 1991), though Hadjisavvas (1992: 75) and Margaritis (2013: 747-8) indicates evidence for oil extraction in Palestine, Crete, and the Cyclades occurred as early as the Chalcolithic. In Cyprus, the exploitation of the olive in its wild form is documented as carbonized archaeobotanical remains from as early as the Aceramic Neolithic (Barker 2005: 55-6; Hadjisavvas 1996: 129-35; Knapp 2013: 17-8, 180, 196, 216-7, 289, 296, 365-6, 377-9). The question of whether the nature of this exploitation was the collection of wild fruits or the result of orchard husbandry cannot easily be determined by the morphology of carbonized olive pits in the absence of large samples (Hanson 2003: 450; see Newton et al. 2006 for discussion of Egyptian samples). Further, as discussed by Hamilakis (1996: 2-3) the stage at which the olive is pressed and method of pressing further may further reduce archaeobotanical preservation. Cultivation and the large scale production of olive oil, by proxy, is generally indicated by processing facilities and large deposits of pits (Hansen 2003: 450), but also through potmarks on storage vessels (Smith 2012). This aspect complicates the documentation of the domestication of the olive and production of oil in the Early Bronze Age, both in Cyprus and elsewhere in the Mediterranean because of the gap that this difference leaves in the physical evidence of the domestication process (Merlin 1984: 196; Riley 2002: 65; Steel 2004: 60, 158-61).

Figure 1. Harvesting olives in Akamas (1991, courtesy of Stuart Swiny, left), extra virgin Cypriot olive oil (2020, courtesy of Stuart Swiny, centre), and an olive tree on the road to Tamassos (2009, taken by the author, right).

Hamilakis (1999: 43) further underscores that the exploitation of olives as a domesticate requires a substantial investment of capital, time and labor in that the trees take several years to become established and produce fruit biennially, which further requires processing. As Katz (2012: 126-7) details, raw olives contain the bitter and toxic compound, oleuropein, which must be leached out through fermentation or brining prior to consumption. This process takes at least a few months when the skin of the olive is cracked and up

to a year when cured whole. The agricultural and processing timelines may be corroborated by what was seen as the curious export of Cypriot oil to known oil-producing regions in Syria and Crete (Hadjisavvas 1996: 130).

It is clear later in history that the olive and its oil became a staple in the Mediterranean and beyond. In the case of Cypriot oil, Strabo writing in the 1st century (14.6.5 in Hadjisavvas 1996: 135) holds it in the highest esteem, stating that "Cyprus is second to none of the islands: it is rich in wine and oil, produces grain in abundance and possesses extensive copper mines…". Olives imported from Syria were also noted culinary items in Neo-Assyrian banquets (Joannes 1996: 35). Classical Greek agriculture revolved around the production of olives and grapes. The resulting olive oil was used for culinary, cosmetic and hygienic purposes. There were also different grades of oil: extra virgin oil from green olives, oil from the first cold pressing of black olives, and ordinary oil. It was such an important product that Greek colonies imported the oil if sufficient amounts could not be produced locally (Amouretti 1996: 80-6). The same was true of Romans living outside of the Mediterranean. Their insistence on olive oil and wine introduced these products to other cuisines (Corbier 1996: 131). Olive oil also figured prominently in aromatic Arabic cuisine (Rosenberger 1996: 212-3). From the 12th and 13th centuries onward the olive tree was cultivated on a vast scale, attaining its position as the emblem of Mediterranean cuisine by the beginning of the 17th century (Cortonesi 1996: 271; Flandrin 1996b: 417).

Hadjisavvas (1996: 129) states that "[the] ability of the olive to fulfill numerous and diverse needs made it the single most important agricultural product in antiquity". There is no question of the esteem held by the olive tree and the oil of its fruit in the history of the Mediterranean. The question that remains is when and where the olive became the primary source of oil. Diverse sources and uses of plant oils are well documented in Egypt, where olive trees were not grown and any olive oil used was imported. Olive, sesame, linseed and sweet ben nut oils were used in cooking, for light, cosmetics, perfumes, ointments, and in mummification (Bresciani 1996: 39; 1992: 18, 24; Quirke and Spender 1992: 18, 24; Reeves and Wilkinson 1996: 30). Hamilakis (in Steel 2004: 112, 175), Karageorghis (2002:11, 13, 25; 1996: 62) and Bendeall (2014: 142) argue that olive oil was used in the production of perfumed oils that were utilized in rituals and exchanged as prestigious gifts among dignitaries. Likewise, Koh et al. (2021: 111) suggest olive oil may have served as a fixative. However, olive oil is not necessarily required for the production of perfumed oils. The main production method described in administrative tablets from Mycenaean Pylos is enfleurage, which is "an absorption process whereby flowers were spread on greased plates, the flowers being frequently removed so that more and more perfume could be absorbed by the grease or fat" (Matthews 1973: 46). In pharaonic Egypt, banquet guests customarily wore solid cones made of animal fat and scented oils (Flandrin 1996a: 19; Quirke and Spencer 1992: 18, 24; Shelmederine 1985: 16, 128). While the use of the greased plate is a modern technique, ancient adaptations would have consisted of steeping flowers in cold oil (i.e., olive, almond, or sesame) or through hot steeping, or maceration (Shelmederine 1985: 13). If olive oil was used for this purpose, it would have required priming with the addition of astringent substances because, as Theophrastus (de Odor, 55 in Shelmederine 1985: 14; Koh and Birney 2017: 25) indicates, it does not retain fragrances well (Shelmederine 1985: 13-4).

This demonstrates that the Mediterranean has had a long history of the extraction and exploitation of plant oils. However, the prehistoric Bronze Age in particular may reveal how the use of the olive transitioned from the exploitation of a largely wild fruit to the highly valued commodity of protohistoric and historic times. Due to the limited nature of archaeological and botanical remains in addressing earlier stages of olive exploitation, the application of residue analysis and the ability to differentiate between different types of plant oils has the potential to answer this question.

2.2. *Organic Residue Analysis and Lipids*

A central concept in organic residue analysis (ORA) is the biomarker, which refers to one or more chemical constituents that have a limited distribution in the plant or animal world and, therefore, indicate the presence of a particular species (Evershed 2008: 897). Earlier residue studies, which often identified a generic plant oil focused on the identification of lipids, which represent a class of organic molecules that are comprised of fatty acids, waxes, and steroids (Barnard et al. 2007: 41; Evershed 2000: 204-7; Lambert 1997: 164-6). They are common constituents in fats and essential oils of plants, animals and other organisms and are frequently targeted in archaeological residue studies. There are two general categories of fatty acids: 1) saturated fatty acids that are long-chain carboxylic acids with 12 to 24 carbons in single bonds; and 2) unsaturated fatty acids with one or more double bonds (Barnard et al. 2007: 44-5; Lambert 1997: 164-6; Newman 1998: 49).

Unlike biomarkers, lipids have a wide distribution in both plants and animals (Eerkens 2005: 89; Malainey 2007: 77; Mayyas 2013: 197). Due to their lack

of specificity, some analysts have focused on other classes of biochemicals, such as alkaloids, flavonoids, and essential oils (Barnard et al. 2007: 41-2; Derham 2004: 187-90; Rafferty 2007: 179; Tushingham et al. 2012). However, the long-known benefit of lipids is that they are hydrophobic and, therefore, preserve in archaeological contexts readily (Barnard et al. 2007: 41-2; Heron and Evershed 1993: 268; Kimp et al. 2004: 1503). Thus, some residue analysts have tried to identify patterns in the distribution of lipids that may aid in distinguishing lipid sources, such as differentiating between types of plants (fruits, nut, leafy vegetables, ruminants, non-ruminants, fish) using ratios and statistical analysis (Barnard et al. 2007: 44-5; Eerkens 2007: 90-1; Krueger at al. 2018: 215; Malainey 2011: 207-210; Parras et al. 2020: 130). Another approach is to model the chemical degradation process to better understand the distribution of lipids in archaeological contexts (Chovanec et al. 2012; Malainey et al. 1999; Regert et al. 2001, 1998). Both approaches were taken in this study.

3. METHODOLOGY

The experiment began with the characterization of a sample of Cypriot olive oil using an extraction method adapted from Stauffer's (2006) protocol for the analysis of vegetal oils. For reasons discussed above, fatty acids were targeted and subsequently derivatized, converting them in fatty acid methyl esters (FAMEs) (Barnard et al. 2007: 47-9; Kitson et al. 1993: 5-6; Pollard and Heron 2008: 65).

3.1. Extraction and Instrumentation

All analytical work was performed using equipment in the Forensics Laboratory in the Chemistry Department at the University at Albany, the staff of which provided training and research assistance and was consulted in the development of analytical procedures.

All glassware and equipment used in the analysis were cleaned and sterilized prior to each use. Four to five drops of olive oil were extracted with a 1:1 mixture of dichloromethane:methanol (2:1, v/v) and methanol:hydrochloric acid (100:1, v/v) in a reflux apparatus for one hour at a temperature of 70°C. The condenser was then removed and the mixture heated at a lower temperature for approximately 15 to 20 minutes, after which the mixture was removed from the heating block. Two ml of hexanes were added and the mixture was stirred for one minute and allowed to settle into visible layers. The top layer was carefully collected and analysed by GC/MS.

A Hewlett Packard 6890 gas chromatograph was used in tandem with a 5972 selective mass detector, which was equipped with 1ml auto-injector. A sample volume of 1µL was injected. An HP-5 capillary column that measured 30 m in length, 250 µm in diameter with 5% phenylmethylsiloxane, and a film thickness of 0.25 µm was used. For quality control purposes, blanks of acetone were run prior to each extracted sample to ensure detected constituents were inherent in the sample. The analytical method included an initial temperature of 75°C held for two minutes and ramped up to 280°C at 15°C per minute and held for 30 minutes for a total method runtime of 45.67 minutes. There was a splitless interface to the quadrupole mass selective detector with a two minute solvent delay and a mass range from 50 to 500.

This analytical program was developed in consultation with staff in the Forensic Lab in the Department of Chemistry at the University at Albany. All of the results discussed here were analysed using these parameters. Some of the archaeological samples discussed were also analysed using two other protocols (see Chovanec 2013, 2016 for analytical procedures and details about research questions). Appropriate precautions were taken in the analysis of all samples to ensure that chemical results are inherent to the sample, rather than due to contamination. In the case of the archaeological samples, it should be noted that all results are based on the analysis of residues absorbed into the ceramic matrix, samples of which were obtained by either pulverizing small sherds or by scraping interiors of vessels (see Chovanec 2013, 2016 and Chovanec et al. 2015 for additional details).

Using this method, six fatty acid methyl esters were identified which comprised 99.63% of the total lipid content (see Table 1).

The artificial aging experiments began with the preparation of two aliquots of olive oil that were sealed in glass flasks. The first was placed in a laboratory oven set at 70°C and the second was placed under an ultraviolet lamp (250 nm). The samples were removed after one week, one month, and three months, underwent lipid extraction, and analysed using the method noted above. A similar procedure was undertaken in an artificial aging study on opium residues (see Chovanec et al. 2012).

3.2. Aging Experiment Results

A total of 13 fatty acids and isomers were detected in significant amounts during the course of the experiment (see Table 1 for details). By far, oleic acid occurs in the greatest abundance (up to 68.3% of lipid content), followed by palmitic acid (up to 47.3% of the total lipid content) with smaller quantities of stearic acid and linoleic acid (up to 12.8% and 11.1%, respectively). The remaining compounds occurred in trace amounts. These proportions correspond to those reported by Kiritsakis and Markakis (1967 in Riley 2002: 64) for Cretan olive oil. Riley (2002: 68) further notes slight variations in the fatty acid profiles of olive oils

deriving from Greece and South Africa. One such variation in Cretan olive oil that is also reflected in the Cypriot sample is the lack of alpha-linolenic acid (C18:3). Stauffer (2006: 1024) reported a similar range and proportion of FAMEs in his analysis, as well as an absence of C18:3.

Table 1 Relative Proportions of fatty acids throughout aging experiment

FAME	Name	Initial	Heat 1 Week	Heat 1 Month	Heat 3 Months	UV 1 Week	UV 1 Month	UV 3 Months
C8:0	Caprylic	0	0.9107	0	0.4899	0	3.8400	3.8400
C9:0	Pelargonic	0	1.9875	0	0.9301	0	5.5890	5.5890
C14:0	Myristic	0	0	0	0.4057	0	0	0
C14:1	Myristoleic	0.8060	0	0	0	0	0	0
C16:0	Palmitic	19.9840	29.6896	20.5966	27.3809	21.5608	47.3260	47.3260
C16:1	Palmitoleic	0.7470	09.7800	0	0.4686	1.1797	0	0
C17:0	Margaric	0	0	0	0.5102	0	0	0
C18:0	Stearic	4.3440	6.2412	4.4248	2.8777	5.7153	12.8230	12.8230
C18:1	Oleic	68.3030	59.7798	66.9891	46.3672	61.5144	30.4240	30.2420
C18:2	Linoleic	5.8160	0	7.9894	1.6726	10.0298	0	0
C19:0	Nonadeca-noic	0	0	0	14.8732	0	0	0
C20:0	Arachidic	0	0.4133	0	-0.2221	0	0	0
C21:0	Heneicosa-noic	0	0	0	4.2460	0	0	0

3.3. Fatty Acid Ratios

A key aim of lipid analysis research is to develop methods of analysis that may allow for the lipid profiles of different plant and animal products to be distinguished. One method is to determine which ratios of fatty acids tend to occur in different products. Marchbanks (1989 in Malainey et al. 1996: 95) argued that the following ratio of unsaturated fatty acids could be used to distinguish products such as uncooked plants, fish, and land mammals: %S = (C12:0 + C14:0)/(C12:0 + C14:0 + C18:2 + C18:3). Skibo (1992 in Malainey et al. 1999: 96), noting the limited occurrence of C12:0 and C14:0 in modern foods, proposed that two ratios, C18:0/C16:0 and C18:1/C16:0, could be used to associate uncooked foods with cooking pots residues that consisted of only one type of food. Loy (1994 in Malainey 2011: 208) proposed a Saturation Index, 1-((C18:1 + C18:2)/C12:0 + C14:0 + C16:0 + C18:0)). The application of these ratios to archaeological residues may be problematic in that they do not account for changes to the ratios due to different rates of decomposition. Saturated, unsaturated, and polyunsaturated fatty acids decompose at different rates and should be considered in the analysis of archaeological residues. An increasing number of studies incorporate chemical degradation experiments to address this shortcoming (Chovanec et al. 2012; Malainey 2007; Regert et al. 2001, 1998).

Some general trends in the behavior of fatty acids in aged olive oil can be observed in Fig. 2 and Fig. 3. First, the degradation process appears to be more complex in the UV irradiated sample than the heated sample. This observation is corroborated by Riley's (2002: 70) observation that "photo-oxidation contributes to the formation of free radicals needed to set auto-oxidative processes in motion". Moreover, there appears to be an inverse relationship in the abundances of palmitic acid (C16:0) and oleic acid (C18:1), as well as stearic acid (C18:0) and linoleic acid (C18:2).

3.4. Statistical Analysis1

One issue that arose during the aging experiment is that neither Marchbank's nor Loy's ratios could be applied because the full range of required lipids were not identified, such as lauric acid (C12:0). Moreover, the approach taken here was based on monitoring alterations inherent in the olive oil itself in order to determine which ratios would be applicable to ancient examples of olive oil. This means that the ratios proposed by Marchbanks and Loy would not be appropriate. To better address the problem, Malainey's (2011: 207) approach was followed in calculating relative proportions for each FAME detected in respect to the total lipid content of the sample.

[1] All statistical analyses were performed in R.

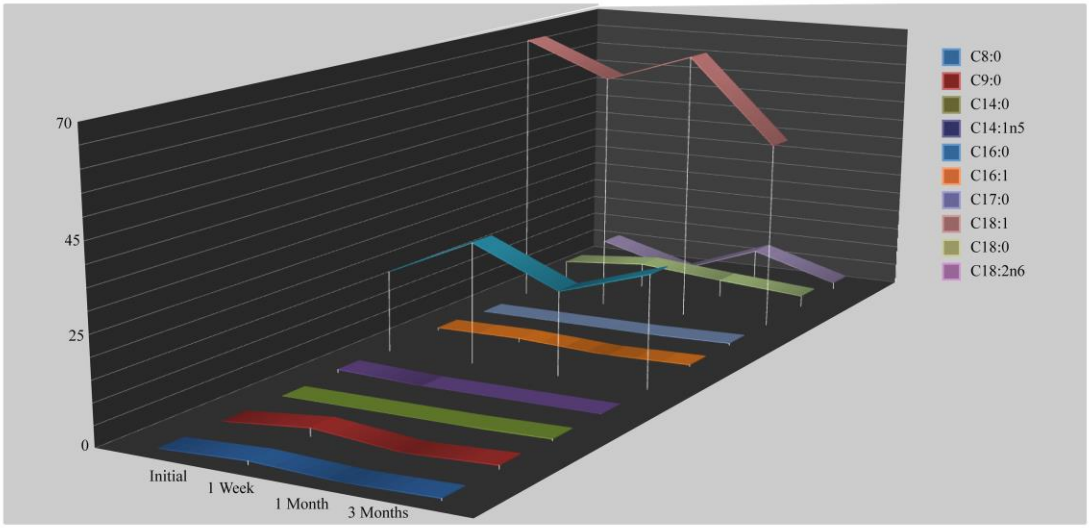

Figure 2 Alterations of heated olive oil

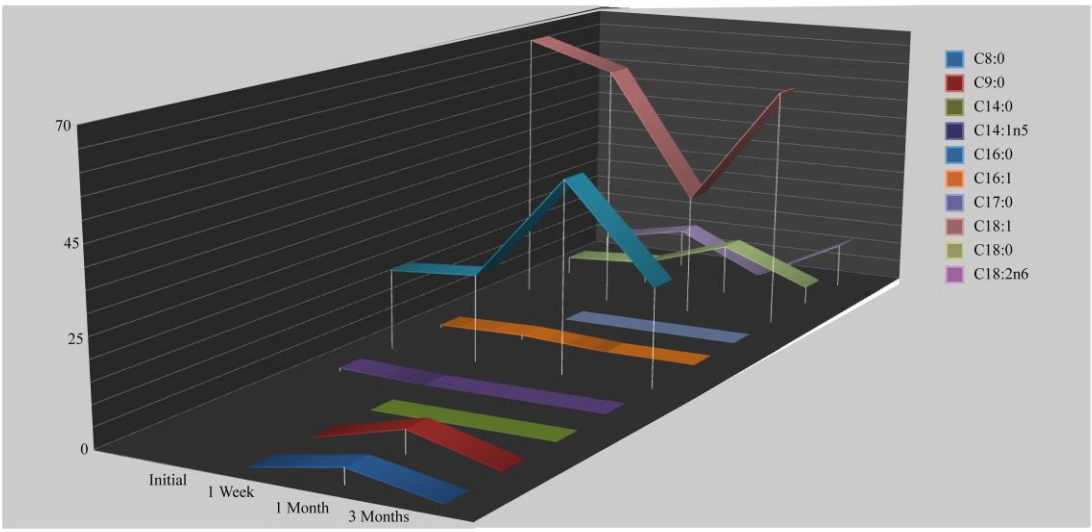

Figure 3 Alterations of UV irradiated olive oil

One of the goals of this study was to identify fatty acid ratios that could be used to differentiate olive oil from other plant oils. Koirala and Rosentreter (2009) suggested that the following sets of ratios should be used over others because these pairs are the most abundant and structurally similar and therefore will have similar rates of degradation: C16:0-C18:0, C16:1-C18:1, C18:2-C18:0.

The problem, as stated above, is that all fatty acids were not present in all stages of the experiment, which prevents applying ratios that were observed under different conditions. To better understand the relationship between the fatty acids that were identified in the olive oil aging study, a Pearson's r correlation was performed (the correlation matrix and significant probability values are provided in Table 2 and Table 3). Five ratios of medium-chain (C12-C18) fatty acids were shown to be correlated. An additional eight ratios involved dibasic fatty acids (see Table 4).

To determine whether the ratios identified during the aging experiment were specific to only olive oil, the same procedure was applied to a sample of fourteen plants that would have been available on the island during prehistoric times. Eight of these, bay leaf, carob, fig leaf, heliotrope, myrtle, both pink and white varieties of rock rose, and thyme, were obtained from the island of Cyprus. The remaining six – panther mushroom, hyssop, opium, poppy seed, red wine, and wormwood – were samples that were commercially available for research purposes[2].

[2] It should be noted that the sources of some of the reference samples and method of preparation for transport may have affected the total lipid content detected. While these botanical reference samples did undergo chemical characterization, they were not subjected to the aging experiment described here.

Table 2 Pearson correlation data values

	C8:0	C9:0	C14:0	C14:1	C16:0	C16:1	C17:0
C8:0							
C9:0	0.9897519						
C14:0	-0.0661338	-0.03480296					
C14:1	-0.2430524	-0.27128352	-0.1666667				
C16:0	0.9694546	0.97901631	0.0530403	-0.3772669			
C16:1	-0.3199758	-0.25228755	-0.0027514	0.2407184	-0.3165184		
C17:0	-0.0661338	-0.03480296	1	-0.1666667	0.0530403	-0.0027514	
C18:0	0.9012915	0.87507625	-0.4535288	-0.1957657	0.8213749	-0.1823207	-0.4535288
C18:1	-0.9166066	-0.89434882	-0.2619944	0.3576217	-0.9360482	0.3791404	-0.2619944
C18:2	-0.7212946	-0.79799944	-0.3050241	0.1105571	-0.7553773	-0.0464872	-0.3050241
C19:0	-0.0661338	-0.03480296	1	-0.1666667	0.0530403	-0.0027514	1
C20:0	-0.1210343	-0.07835502	-0.5350261	-0.1697786	-0.011396	-0.0800892	-0.5350261
C21:0	-0.0661338	-0.03480296	1	-0.1666667	0.0530403	-0.0027514	1

	C18:0	C18:1	C18:2	C19:0	C20:0	C21:0
C8:0						
C9:0						
C14:0						
C14:1						
C16:0						
C16:1						
C17:0						
C18:0						
C18:1	-0.7146384					
C18:2	-0.4758506	0.6441944				
C19:0	-0.4535288	-0.2619944	-0.3050241			
C20:0	0.0407032	0.2689122	0.1932147	-0.5350261		
C21:0	-0.4535288	-0.2619944	-0.3050241	1	-0.5350261	

Table 3 Significant probabilities for fatty acid correlation data

	1	7	8	18	22	23
i	C8:0	C8:0	C9:0	C14:0	C8:0	C9:0
j	C9:0	C16:0	C16:0	C17:0	C18:0	C18:0
cor	0.98975192	0.96945458	0.97901631	1	0.90129152	0.87507625
p	0.00002031	0.00030809	0.00012113	0.00000000	0.00557159	0.00989384
	26	29	30	33	36	37
i	C16:0	C18:0	C9:0	C16:0	C18:0	C8:0
j	C18:0	C18:1	C18:1	C18:1	C18:1	C18:2
cor	0.821374935	-0.91660662	-0.89434882	-0.93604816	-0.714638382	-0.72129460
p	0.023465700	0.003686375	0.006578179	0.00191886	0.071138490	0.067327400
	38	41	48	52	73	77
i	C9:0	C16:0	C14:0	C17:0	C17:0	C19:0
j	C18:2	C18:2	C17:0	C19:0	C21:0	C21:0
cor	-0.797999444	-0.75537727	1	1	1	1
p	0.031487930	0.049576240	0.00000000	0.00000000	0.000000000	0.0000000

The complete set of reference samples, which included the initial test of olive oil and the 14 plants mentioned above, again were tested for correlation using a Pearson's test (see Table 5). The purpose of this test was to determine potential fatty acid ratio pairs. Only those with significant probabilities are noted.

A total of five ratios, which were previously noted in the olive oil aging study, were identified (see Table 5). The major result of the comparison between the ratios identified in the aging of the olive oil with those of the reference samples is that different sets of fatty acids were found to be correlated. It should be noted that the breadth of the data is reduced due to the constituents involved in the comparison. An important observation in the comparison is the absence of ratios involving palmitoleic acid (C16:1), which makes a comparison between unsaturated pairs impossible. This is important because it has previously been suggested that saturates should be paired with saturates (e.g., C16:0-C18:0), and unsaturates with unsaturates (e.g. C16:1-C18:1) due to their similar degradation curves. Based on the results of this study, this proposition may not be tenable.

Table 4 Correlated fatty acid ratios in olive oil during course of aging experiment

Ratio	Initial	Heat 1 Week	Heat 1 Month	Heat 3 Months	UV 1 Week	UV 1 Month	UV 3 Months	μ	Σ
C8-C9		0.96210619		0.98281040		0.95667220		0.96719627	0.01379250
C8-C16		0.64919438		0.64907800		0.64898060		0.64908432	0.00010700
C8-C18		0.85729090		0.91974970		0.84007580		0.87237215	0.04192330
C8-C18:2				0.9565237				0.95652366	
C9-C16		0.67476375		0.66043050		0.67837300		0.67118909	0.00949030
C9-C18		0.89105642		0.93583640		0.87812290		0.90167191	0.03028580
C9-C18:1		0.58507973		0.59315270		0.74243070		0.64022101	0.08860810
C9-C18:2				0.97325350				0.97325349	
C14-C17				0.99575310				0.99575309	
C16-C18	1.27684579	1.32054578	1.28173590	1.41700960	1.25312828	1.29445450	1.32889840	1.31037402	0.05368510
C16-C18:1	0.77986398	0.86708827	0.78755870	0.89813030	0.80842996	1.09442840	0.83230800	0.86682966	0.10895730
C16-C18:2	1.23166849		1.18378790	1.47366520	1.15170547		1.15810340	1.23987610	0.13447250
C18-C18:1	0.61077382	0.65661356	0.61444690	0.63382090	0.64512945	0.84547460	0.62631430	0.66179623	0.08259260

Table 5 Reference sample fatty acid ratios

Ratio	Amanita	Bay Leaf	Fig Leaf	Heliotrope	Hyssop	Myrtle	Olive Oil	Opium
C8-C18:1	0.502361065		0.521804602					
C9-C18:2			0.939709225					0.833961128
C10-C18:2			1.065198049					0.833961128
C10-C20:4			1.133540058					
C14-C17		0.935285243						
C14:1-C18								0.893655681
C16-C18:1			0.762524154					0.779863984
C18-C18:1	0.513731377		0.587875226					0.610773824

Ratio	Pink Rock-rose	Poppy Seed	Thyme	White Rock-rose	Wine	Wormwood	μ	σ
C8-C18:1				0.848756741	0.536761875		0.587545834	0.146568129
C9-C18:2	0.6116047	0.509239569		0.724336494		0.536128932	0.671635785	0.16582872
C10-C18:2	0.6116047	0.787391014		0.724336494		0.536128932	0.727580618	0.18986665
C10-C20:4		3.407422347					2.270481202	1.607877586
C14-C17							0.935285243	
C14:1-C18							0.893655681	
C16-C18:1				1.246981576			0.929789905	0.274832831
C18-C18:1							0.570793476	0.050726214

To examine how these results match up with residues from Cypriot pottery, a sherd of modern pottery (see Fig. 4) made using traditional techniques from the village of Kornos, was treated with Cypriot olive oil. The surface of the sherd was abraded to remove the exterior that may have been handled. The olive oil was permitted to permeate the surface of the sherd for four days. The sherd was then pulverized and underwent lipid extraction and analysis using the parameters indicated above. An untreated sherd of the same vessel was similarly analysed for quality control purposes.

The results of the analysis indicated four medium chain fatty acids with proportions well within the ranges observed during the course of the olive oil aging experiment (see Table 6). A key observation is that myristoleic acid (C14:1) and palmitoleic acid (C16:1) were not detected. The absence of the former may be related to the compound's volatility, its tendency to degrade, or inherent issues in the extraction process. It should be noted that the latter does persist in the aging experiment, particularly in the heated sample. This might be explained by the fact that the sherd treated with oil was stored in a loosely covered container made of clear glass, whereas the olive oil samples that underwent aging experiments were sealed tightly. Moreover, the fact that C16:1 disappears after one month of UV irradiation might suggest that the compound is more susceptible to photo-oxidation (Riley 2002: 70). These observations have bearing on conclusions pertaining to the fatty acid ratios that could be used in identifying plant oils.

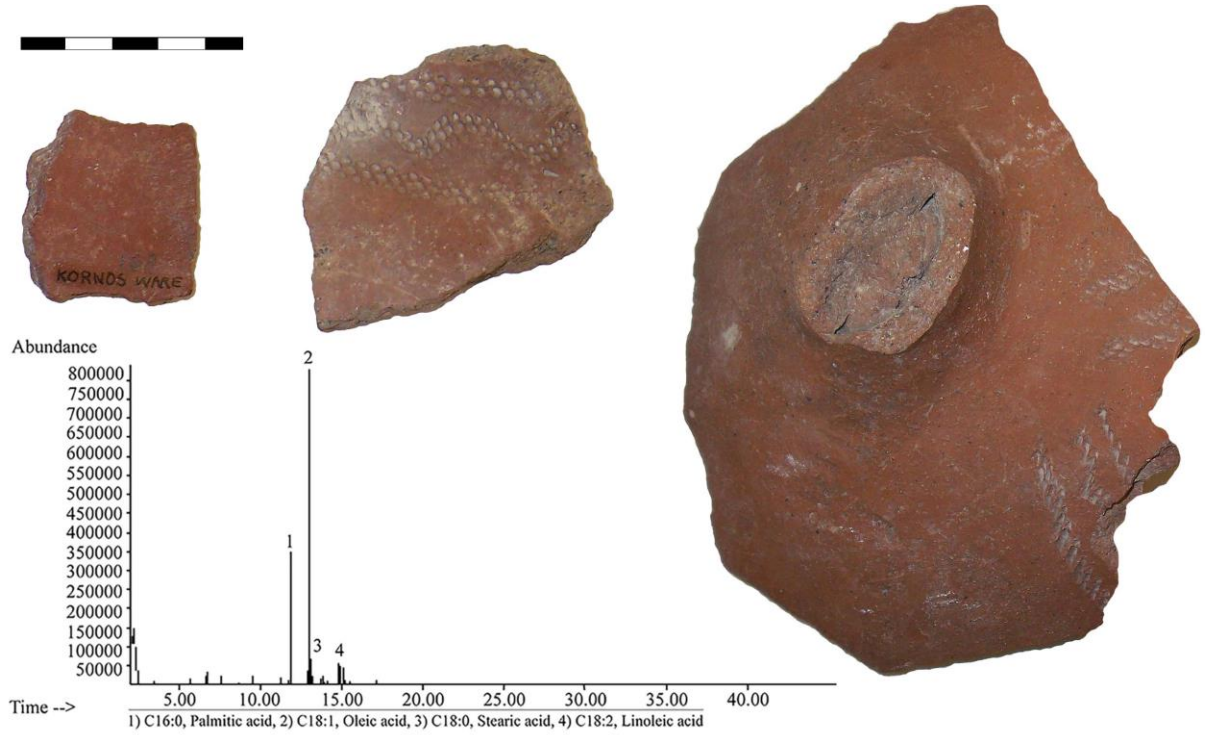

Figure 4 Modern Kornos ware from the Barlow Collection (courtesy of Stuart Swiny, University at Albany) and chromatogram of small sherd pictured treated with Cypriot olive oil.

Table 6 Comparison of relative proportions of olive oil-treated sherd with that of aged olive oil from experiment

FAME	On Sherd	Olive Oil	Heat 1 week	Heat 1 month	Heat 3 months	UV 1 week	UV 1 month	UV 3 months	μ	σ
C16:0	22.4296	19.984	29.6896	20.5966	27.3809	21.5608	47.3260	24.2400	27.25340	9.5525
C18:0	4.7965	4.344	6.2412	4.4248	2.8777	5.7153	12.8230	4.2804	5.8152	3.2757
C18:1	67.699	68.303	59.7798	66.9891	46.3672	61.5144	30.4240	59.7766	56.1649	13.4028
C18:2	5.0749	5.8160	0	7.9894	1.6726	10.0298	0	11.1369	7.3289	3.75881

4. APPLICATION TO ARCHAEOLOGICAL DATASET

In order to evaluate these results, ratios were calculated for fatty acids identified in a dataset of archaeological samples that underwent the lipid extraction and analysis as described above for olive oil reference samples and the analysis of the Kornos Ware sherd above. The dataset formed the basis of Chovanec's 2013 unpublish dissertation and consisted of samples of ceramic bottles, bowls, and other containers from both stratified and unstratified contexts dating to the Bronze Age in Cyprus. Within the larger research project, the lipid analysis program was applied to 68 of 110 pottery samples (see Table 8 and Chovanec 2013 for full analytical details).

4.1. Identification of Olive Oil Based on Fatty Acid Ratios

Of the sixty-eight samples that underwent lipid analysis, twelve returned results for further evaluation. These samples were obtained from stratified specimens from the Bronze Age sites of Sotira *Kaminoudhia*, Politiko *Troullia*, and Episkopi *Bamboula*, as well as unstratified specimens from the Belcher and Barlow Collections at the University at Albany. The vessels predominantly consisted of smaller open and closed shapes (e.g., bottles, juglets, bowls) of finer wares, though several coarse ware vessels (e.g., storage jars) were also included. The vast majority were sherds, but largely complete vessels were also included (see Chovanec 2018, 2016 for additional examples and Chovanec 2013 for full details). As was done for the reference samples discussed above, relative proportions of fatty acid distributions were calculated, normalized and resulting ratios determined. Eight of these had fatty acid pairs that were determined to be significant during the experimental study and five had ratio values within ranges observed in the aging study. These data are summarized in Table 7. Red values are significant but outside of the range of olive oil and bold values are within that range.

Table 7 Comparison of reference and archaeological ratios

Archaeological Samples								
Ratio	EB74	P27	P148	BC18	PT20	BR2	PT21	PT22
C8:0-C9:0	1.004108934				0.909984086			
C8:0-C16:0	0.609359289				0.852973938			
C8:0-C18:0	0.647127368							
C8:0-C18:1	1.007223954							
C9:0-C16:0	0.606865718			0.903927305	0.937350391			
C9:0-C18:0	0.644479245			0.931784229				
C9:0-C18:1	1.003102273							
C16:0-C18:0	1.061979983	1.129779081	1.069585411	1.03081766				
C16:0-C18:1	1.652922952					**0.902387626**	**0.923477031**	**0.868646113**
C16:0-C18:2						**1.205347004**	0.751816681	
C18:0-C18:1	1.556453961							
Product:	Mixture	Olive Oil	Other	Mixture?	Other	**Olive Oil**	**Mixture?**	**Olive Oil**

Aged Olive Oil								
Ratio	Initial	Heat 1 week	Heat 1 month	Heat 3 months	UV 1 week	UV 1 month	UV 3 months	Average
C8:0-C9:0		0.9621062		0.983		0.95667222		0.967196273
C8:0-C16:0		0.6491944		0.649		0.648980593		0.649084322
C8:0-C18:0		0.8572909		0.92		0.840075824		0.872372153
C8:0-C18:1								
C9:0-C16:0		0.6747637		0.66		0.678372989		0.671189087
C9:0-C18:0		0.8910564		0.936		0.878122941		0.901671915
C9:0-C18:1		0.5850797		0.593		0.742430655		0.640221012
C16:0-C18:0	1.276845787	1.3205458	1.281735891	1.417	1.253128278	1.29445446	1.328898388	1.310374024
C16:0-C18:1	0.779863984	0.8670883	0.787558698	0.898	0.808429961	1.094428386	0.832308043	0.86682966
C16:0-C18:2	1.231668491		1.183787914	1.474	1.15170547		1.158103383	1.239786095
C18:0-C18:1	0.610773824	0.6566136	0.614446942	0.634	0.645129453	0.845474614	0.626314284	0.661796225

Botanical Reference Samples					
Ratio	Amanita	Carob	Olive Oil	White Rock-rose	Wine
C8:0-C9:0					
C8:0-C16:0					
C8:0-C18:0					
C8:0-C18:1	0.502361065	0.521804602		0.848756741	0.536761875
C9:0-C16:0					
C9:0-C18:0					
C9:0-C18:1					
C16:0-C18:0					
C16:0-C18:1		0.762524154	0.779863984	1.246981576	
C16:0-C18:2					
C18:0-C18:1	0.513731377	0.587875226	0.610773824		

In three samples, the Base Ring juglets from Episkopi *Bamboula* (EB74, EB02 VII Lot 2 053, Fige. 5, right) and the Barlow Collection (BR2) and a Drab Polished juglet from Sotira *Kaminoudhia* (P148, Area A, Unit 18, Lot 14, FN 2, Fig. 6, right), relevant fatty acid ratios were present, but the ratio values were not within the ranges for any reference samples. The sample from Episkopi *Bamboula*, in particular, seems to suggest a complex mixture to which the concept of differentiation by fatty acid ratios cannot be applied.

Two samples, a Middle Bronze Age White Painted III-V Stringhole jug from the Belcher Collection (BC18, Fig. 5, left) and a Red Polished footed container from Politiko *Troullia* (PT21, W.012.120.111.2, Fig. 7, centre), indicated the presence of one ratio with values in the range of olive oil (C9:0-C18:0 and C16:0-C18:1, respectively). However, other ratios were identified with ratios outside of the observed range, which makes it unlikely that the substance contained in the vessel consisted *only* of olive oil.

Figure 5 Sampled White Painted III-IV Stringhole Jug from the Belcher Collection, University at Albany (courtesy of Stuart Swiny) (left) and shoulder of Base Ring I Jug from Late Bronze Age tomb at Episkopi Bamboula (courtesy of Gisela Wahlberg; photo taken by author).

Figure 6 Archaeological Samples from Sotira Kaminoudhia: Brown Polish bottle (P27) from Tomb 4 (left) and Drab Polished bottle (P148) from Area A (right) (courtesy of Stuart Swiny)

The remaining three samples, a Red Polished juglet (PT20, W.012.120.70, Fig. 7, left) and Black Polished juglet from Politiko *Troullia* (PT22, V.010.53.12, Fig. 7, right), as well as a Brown Polished bottle from Sotira *Kaminoudhia* (P27, Fig. 6, left), had only ratios within the olive oil range represented. It must be acknowledged that PT22 and P27 only had one fatty acid pair. Thus, the evidence is limited but consistent with an olive oil identification. PT20, on the other hand, had two fatty acid ratios with values well within the range observed for olive oil. No other biomarkers indicating the presence of ingredients other than olive oil were detected. Thus, an olive oil identification is feasible.

Figure 7 Archaeological Samples from Politiko Troullia: Red Polished juglet (PT20 from Area W) (left), Red Polished footed vessel (PT21 from Area W) (centre), and body of a Black Polished juglet (PT22, from Area V) (right). (Courtesy of Steve Falconer and Patricia Fall; photos taken by author).

These results serve to corroborate the set of significant fatty acid ratios identified during the course of this study. It should be noted that this dataset was collected in context of a larger research program centred on the documentation of subsistence and prestigious organic products through chemical analysis, in which questions concerning olive oil in prehistoric Cyprus comprised one component. As such, there is not an explicit assumption that the dataset to which the proposed fatty acid ratios are applied should contain only olive oil. Rather, what was illustrated in this application is the range of fatty acids recovered from organic residues that absorbed into the ceramic matrix of pottery vessels typical of the Bronze Age in Cyprus. To better assess the applicability of the ratio data presented here, a study should be conducted that targets vessels from an archaeological context documenting the production or storage of olive oil. In addition, the other 14 reference samples should also undergo artificial aging experiments for comparative purposes.

Table 8 Archaeological Sample Dataset from Chovanec (2013)

Source[3]	Stratified	Sample No.	Ware[4]	Shape	Section	Sample Type	Decoration
EP	EB02.VIII.2	EB74	BR I		Shoulder	Sherd	Relief
EP	EB04.XII.J28W-2	EB75	BR I		Body	Sherd	
EP	EB02.VIII.2AE	EB76	BR I	Juglet	Base	Sherd	
EP	EB02.VIII.2AE	EB77	BR I	Juglet	Neck	Sherd	
EP	EB02.VIII.2	EB78	BR I		Base	Sherd	
EP	EB02.VIII.2E	EB79	BR I		Base	Sherd	Relief
EP	EB02.VIII.2E	EB80	BR I		Body	Sherd	Relief
EP	EB04.XII.I28W-4	EB81	BR I		Base	Sherd	
SK	Area B, Unit 13.10, Lot 71	SK1	RP M	Bowl	Rim	Sherd	None
SK	Area B, Unit 13.24 Lot 79	SK2	RP	Bowl	Base	Sherd	None
SK	Area B, Unit 12b, FN 15	SK3	C	Tray	Body	Sherd	None
SK	Area A, Unit 27, Lot 3, P185	SK4	C	Storage jar	Body	Sherd	None
SK	Tomb 4, P27	SK5	Br P	Bottle	Body	Sherd	Lime-filled incisions
SK	Area A, Unit 44, P169	SK6	DPBC	Juglet	Body	Sherd	Punctate
SK	Tomb 19, P105	SK7	Br P	Bottle	Body	Sherd	Lime-filled incisions
SK	Area A, Unit 5, P74	SK8	RPBT	Bottle	Body	Sherd	Lime-filled incisions

[3] EP = Episkopi *Bamboula*; SK = Sotira *Kaminoudhia*, AM = Alambra *Mouttes*, MA = Marki *Alonia*; PT = Politiko *Troullia*; UA BC = University at Albany Belcher Collection; UA BR = University at Albany Barlow Collection

[4] BR I = Base Ring I; BR II = Base Ring II; RP M = Red Polished Mottled; RP = Red Polished; C = Coarse; Br P = Brown Polish; DPBC = Drab Polished Blue Core; RPBT = Red Polished Black-Topped; RP = Red Polished; RP B = Red Polished B; BP = Black Polished; WP = White Painted; RP IV = Red Polished IV; RS/BS = Red Slip/Black Slip

SK	Area A, Unit 18, Lot 14, FN 2, P148	SK9	DPBC	Juglet	Body	Sherd	Stringhole
SK	Tomb 4, P29	SK10	Br P	Bottle	Body	Sherd	Incised
SK	Area B, Unit 13.34, Lot 77, 1	SK11	RP	Bowl	Body	Sherd	None
SK	Area A, Unit 7, G17C, 3	SK12	Br P	Bottle	Body	Sherd	None
AM	Building IV, Room 8	F82-P95	RP B	Juglet		Scraping	None
AM	Building IV, Room 13	F92-P4	RP B	Juglet		Scraping	None
MA	CXII-8, E-1, 15	P15122	BP	Closed	Body	Sherd	Lime-filled incisions
MA	CXXII-5, E-1, S7	P16171	RPBT	Closed	Body	Sherd	Lime-filled incisions
PT	W.006.78.42.1	PT1	RP		Spout	Scraping; Sherd	Lime-filled incisions
PT	S.011.42.8	PT2	RP	Jug	Neck/Shoulder	Scraping; Sherd	Punctate
PT	Q.004.39.6	PT4	RP		Spout	Scraping	
PT	Q.009.49.49	PT8	RP	Bowl	Spout	Scraping; Sherd	None
PT	S.011.76.110	PT9	RP	Bowl	High Spout	Scraping	Relief
PT	Q.009.49.30	PT10	RP	Bottle		Scraping; Sherd	None
PT	T.007.44.49	PT11	RP	Closed	Body	Scraping; Sherd	Lime-filled incisions
PT	Z.0.18.1	PT13	RP		Spout	Scraping; Sherd	Relief
PT	U.002.13.1	PT14	RP		Spout	Scraping; Sherd	Lime-filled incisions
PT	W.012.120.69	PT19	RP		Spout	Scraping; Sherd	Lime-filled incisions
PT	W.012.120.70	PT20	RP	Juglet	Base	Scraping; Sherd	Lime-filled incisions
PT	W.012.120.111.2	PT21	RP	Footed Closed	Base	Scraping; Sherd	Lime-filled incisions
PT	V.010.53.12	PT22	BP	Juglet	Body	Scraping; Sherd	Lime-filled incisions
PT	D.010.64.2	PT26	WP	Closed	Body	Scraping	Painted
PT	G.003.16.1.4	PT27	RP	Cup	Body	Scraping	None
PT	D.010.64.2	PT29	WP	Closed	Neck	Scraping	Painted, Stringhole
PT	U.006.17.1	PT31	RPBT	Bowl	Body	Scraping; Sherd	None
PT	P.004.36.1	PT32	WP	Bowl	Rim	Scraping	Painted
PT	U.006.30.1	PT33	RP	Cup	Base	Scraping; Sherd	None
PT	U.006.30.2	PT34	RP	Bowl	Body	Scraping	Lime-filled incisions
PT	P.004.54.4	PT37	RP	Closed	Body	Scraping; Sherd	Lime-filled incisions
PT	P.004.40.1.7	PT39	RPBT	Bowl	Body	Scraping	None
PT	P.004.40.1.7	PT41	RPBT	Bowl	Body	Sherd	None
PT	P.004.41.2	PT42	RP IV	Jug	Base	Scraping; Sherd	None
PT	W.018.190.1	PT43	RS/BS	Bowl	Body	Scraping; Sherd	Incised
PT	O.008.77.2	PT49	WP	Closed	Base	Scraping; Sherd	Painted
PT	O.009.85.1	PT50	BP	Askos	Body	Scraping; Sherd	None
PT	P.003.87	PT51	RP	Amphoriskos	Shoulder	Scraping; Sherd	Lime-filled incisions
PT	O.009.98.1	PT54	RP	Juglet	Neck	Scraping; Sherd	None

PT	U.034.232.1	PT55	RP		Spout	Scraping; Sherd	None
PT	U.010.173.1	PT57	RPBT	Bowl	Body	Scraping; Sherd	Lime-filled incisions
PT	O.011.103.47	PT60	C	Cooking pot	Body	Sherd	None
PT	R.007.76.3.2	PT63	RPBT	Bowl	Body	Sherd	Lime-filled incisions
PT	R.007.76.3.3	PT64	RPBT	Bowl	Body	Sherd	Lime-filled incisions
PT	R.014.61.3	PT65	C	Cooking pot	Base	Sherd	None
PT	R.015.101.3	PT66	RP	Juglet	Rim	Sherd	Lime-filled incisions
PT	R.022.108.6	PT68	BP	Juglet	Base	Sherd	Lime-filled incisions
PT	Y.024.156.4	PT72	RP	Closed	Base	Sherd	Lime-filled incisions
PT	O.018.219.1	PT73A	C	Storage jar	Body	Sherd	None
UA BC	N	BC5	RP	Gourd juglet	Base	Drilling	Lime-filled incisions
UA BC	N	BC11	BP	Flask	Base	Scraping	Lime-filled incisions
UA BC	N	BC18	WP	Juglet	Body	Scraping	Stringhole, Painted
UA BC	N	BC20	WP	Juglet	Base	Drilling	Painted
UA BR	130.DK.1	BR2	BR II	Juglet	Body	Sherd	Painted

5. DISCUSSION

The implications of this study, though not definitive, are instructive for better understanding ancient Mediterranean foodways, the role that the olive and its products played therein, and the assessment of scientific data that corroborate resulting ideas. The term foodways is apt in explicating the historic relationship of the olive in the Mediterranean. It is a concept that "…includes all activities, rules, and meanings that surround the production, harvesting, processing, cooking, serving, and consumption of food" (Peres 2017: 421). Inherent in this idea is the element of choice: "we eat food, yet we do not eat every food available" (Peres 2017: 421). The element of choice is made even more significant when we consider the history of agriculture in the Mediterranean relies also on our understanding of transported landscapes, wherein subsistence and other important plants and animals were brought to new destinations at some distance over land and sea. The long history of the olive in the Mediterranean and in the human imagination then necessitates a certain level of deconstruction. As such, the kind of targeted chemical analysis as discussed here is crucial to assessing the differences in such a plant, both in its physical and chemical nature, but also its social and cultural roles.

The olive tree, its fruit, and the oil it produces is emblematic of the Mediterranean diet, culture, and larger aesthetic (Knapp and Blake 2005: 6-7; Hamilakis 1999: 44). But knowing when, where, and in what capacity it assumed this role has implications for our understanding of the foodways of the region, and for the interpretation of archaeological remains. The production and consumption of food and drink is a highly formalized and personalized practice that is informed by the most specific and intimate of cultural sensibilities (Fuller 2005: 761). The types of foods being consumed by a cultural group may serve as a major indicator of ethnic membership (Hamilakis and Sherratt 2012: 189-190; Mintz and Du Bois 2002: 105, 107-9). In some cases, the range of culturally important foods and the rules governing their production and consumption may serve as more direct proxies of cultural affinity than technological or stylistic characteristics of material culture (Fuller 2005: 761).

Like other cultural practices, consumption traditions or foodways changed over time as different traditions came into contact with one another, colonized new landscapes with different animal and plant species, and engaged in various social and economic transactions. In antiquity, the modern concept of a "cuisine" would have been more directly associated with agro-economic availability, making the larger question of foodways a more local matter (Mintz and Du Bois 2002: 110; Twiss 2012: 357-9). Some products have long histories in local, regional and global contexts.

The results of the study discussed here illustrate some key differences in how the olive may have been utilized in Bronze Age Cyprus. At Sotira *Kaminoudhia*, an Early Bronze Age settlement along the south coast of the island, archaeological samples obtained from both mortuary and settlement contexts. It is noteworthy that Tomb 4 was a disturbed tomb of presumably one individual with fragmentary funerary objects, including several bottles and flasks which are comparable to those found in the settlement (Swiny and Herscher 2003: 103, 108-10). Other ORA analyses suggested that the bottle contained a medicinal substance that likely was comprised of a series of aromatic plants in a plant oil (see Chovanec 2013: 292). The results presented here may suggest that the oil in the

medicinal mixture may have been olive oil[5]. The Late Bronze Age tombs at Episkopi *Bamboula* contained similar kinds of complex mixtures, but without an olive oil base (Chovanec 2013: 287). By the Late Bronze Age, the settlement at Episkopi *Bamboula* was engaged in large scale production and transport of a variety products, including olive oil (see Smith 2012 and Pratt 2014).

Comparing the chemical evidence with the archaeobotanical data provides further insight. The Drab Polished juglet from Sotira *Kaminoudhia* was found in Unit 18 of Area A which consisted of households dating to the Early Bronze Age (Swiny 2003: 27). The presence of olive pits and carbonized wood in the archaeobotanical remains in this Unit indicates that the olive was utilized for both subsistence and likely construction purposes, but the extent of cultivation is not known (Hansen 2003: 449-452).

The assemblage from Politiko *Troullia,* a Middle Bronze Age settlement in the foothills of the Troodos Mountains, provides further socioeconomic perspective, in light of the chemical evidence from this study. The ceramic containers discussed above derived from Areas V and W, which correspond to the southeastern section of an open courtyard that likely served multiple functions, including as a workspace (Falconer et al. 2017). The olive was one of the dominant species in the archaeobotanical remains, with the broader assemblage highlighting orchard products as a significant resource (Falconer et al. 2013: 106, 111). Orchards, which would have included olive trees, likely were cultivated along the hillsides surrounding the settlement. As such, the evidence seems to point to the cultivation of olives and processing of olive oil at the household level (Falconer et al. 2013: 112; Margaritis 2013: 752-3; Warnock 2007), which has broader implications for the social role of food production and consumption within a community (Twiss 2007: 57).

6. CONCLUSIONS

The aim of this study was to assess the possibility of differentiating olive oil from other plant oils in archaeological residues based on fatty acid profiles. This was accomplished by modelling the chemical alterations that olive oil underwent during the course of an artificial aging experiment and identifying concomitant fatty acid pairs that could be used for the identification of olive oil residues through statistical analysis. The resulting fatty acid ratios were then compared to the set of ratios identified by the same means in a sample of 15 reference plants and products that would have been known in Cyprus during the Bronze Age. This comparison indicated that different sets of ratio pairs and associated ratio values were concurrent, which suggested that olive oil should be distinguishable from other products. In order to test this proposition, the experimental fatty acid ratios were applied to an existing dataset consisting of mass spectral information for a range of pottery vessels that date to the Cypriot Bronze Age and underwent lipid analysis. The outcome suggests that if a vessel contained only olive oil, it should be distinguishable from other organic residues.

There are several issues in this study that should be considered. First is the condition of the botanical reference samples that were submitted for analysis. The fact that some of the plant samples were obtained from commercial sources, were dried before transport, or were prepared using modern processes may have bearing on the total lipid content detected. One example is that of the poppy seeds. Merlin (1984: 89) states that the nutritious oil of opium poppy seeds constitute up to 45 percent of the total weight of the seed. This is not reflected in the analysis of the poppy seeds in this study, but it did show linoleic acid as the predominant fatty acid which Luthera et al. (1989 in Kapoor 1997: 97) showed to predominate in all stages of seed development.

Second is the comparison of the olive oil aging data with reference samples that had not undergone artificial degradation. While opium did undergo such a study, the focus was on identifying decomposition pathways of opium alkaloids, rather than lipids (Chovanec et al. 2012). A final issue is that the sample of plants and products is rather limited. Future work should address these problems.

The results of the study should not be taken as definitive evidence, but rather should be viewed as an approach for the potential documentation of a well-known commodity in the ancient Mediterranean. Additional study is necessary to corroborate these findings, but the evidence presented in this paper suggests that olive oil may be identified in archaeological residues as a single product. Due to the prominent role of the olive in the Mediterranean, being able to definitively demonstrate the presence of olive oil in the archaeological record would have far reaching implications in not only documenting the social and economic history of a highly valued commodity, but also in addressing larger issues of archaeological interpretation.

[5] The complete analysis will appear in the second volume of the Sotira *Kaminoudhia* excavation report, in preparation.

ACKNOWLEDGEMENTS

This research was funded in part by the following sources: National Science Foundation (grants awarded to Dr. Sean Rafferty, 0822493, and Dr. Steven Falconer, 10310527), the Institute of Cypriot Studies at the University at Albany, Sigma-Xi Scientific Research Society, American Schools of Oriental Research, and the Cyprus American Archaeological Research Institute. Special thanks to the Department of Antiquities in Cyprus for permission to export samples, Dr. Gisela Walberg for permission to analyse material from Episkopi Bamboula, Dr. Stuart Swiny for his permission to analyse samples from Sotira *Kaminoudhia* and the Barlow and Belcher Collections at the University at Albany, Dr. Steven Falconer and Dr. Patricia Fall for permission to analyse material from Politiko *Troullia* and for their research assistance, Mr. Colin Henck, Dr. David Burz and the Chemistry Department at the University at Albany, Dr. Walter Crist for his editorial comments, and Dr. Justin Lowry for his advice on the statistical analysis.

REFERENCES

Aleksic, V. and P. Knezevic (2014) Antimicrobial and antioxidative activity of extracts and essential oils of *Myrtus communis* L. *Microbiological Research* Vol. 169, pp. 240-254. https://doi.org/10.1016/j.micres.2013.10.003.

Amouretti, M.-C. (1996) Urban and Rural Diets in Greece In *Food: A Culinary History* J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 79-89.

Åström, P. (1972) *The Late Cypriote Bronze Age architecture and pottery. The Swedish Cyprus Expedition.* Vol. IV. Part IC. Lund, Sweden, The Swedish Cyprus Expedition.

Barker, G. (2005) Agriculture, Pastoralism, and Mediterranean Landscape in Prehistory. In *The Archaeology of Mediterranean Prehistory*. E. Blake and A.B. Knapp (eds). Malden, Blackwell Publishing, Ltd., pp. 46-76.

Barnard H., A.N. Dooley, and K.F. Faull (2007) An Introduction to Archaeological Lipid Analysis by Combined Gas Chromatography Mass Spectrometry (GC/MS) In *Theory and Practice in Archaeological Residue Analysis*, H. Barnard and J.W. Eerkens (eds). Oxford. BAR International Series 1650, Archaeopress.

Beck, C. W., E. C. Stout, K. M. Wovkulich, V. Karageorghis, and E. Aloupi (2004) The Uses of Cypriote White-Slip Ware Inferred from Organic Residue Analysis. *Egypt and The Levant: International Journal for Egyptian Archaeology and Related Disciplines* Vol. XIV, pp.13-43.

Bendall, L. M. (2014) Gifts to the Goddess: Pylian Perfumed Olive Oil Abroad? In *KE-RA-ME-JA: Studies Presented to Cynthia W. Shelmerdine*, D. Nakassis, J. Gulizio, and S. James (eds). Philadelphia, INSTAP Academic Press, pp. 141-162.

Boardman, J., K. K. Kenyon, E.J. Moynahan and J.D. Evans (1976) The Olive in the Mediterranean: Its Culture and Use. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* Vol. 275, No. 936, pp. 187-196.

Brogan, T. M. and A. J. Koh (2008) Feasting at Mochlos? New Evidence for Wine Production, Storage, and Consumption from a Bronze Age Harbor Town on Crete. In *Proceedings of DAIS. University of Melbourne, Centre of Classics and Archeology*. Université de Liège and University of Texas Press, pp. 27-39.

Bresciani, E. (1996) Food Culture in Ancient Egypt. In *Food: A Culinary History*, J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 38-45.

Brun, J.-P. (2000) The Production of Perfumes in Antiquity: The Cases of Delos and Paestum. A*merican Journal of Archaeology,* Vol. 104, No. 2, pp. 277-308. DOI: 10.2307/507452.

Carl, P. and B. G. Peterson (2013) PerformanceAnalytics: Econometric tools for performance and risk analysis (R package), November 13. http://r-forge.r-project.org/projects/returnanalytics/.

Chovanec, Z. (2016) Making Sense of Ancient Scents: Documenting the Use of Perfumed Substances in Ancient Cyprus. In *Ancient Cyprus Today: Museum Collections and New Research Approaches to the Archaeology of Cyprus*, Studies in Mediterranean Archaeology and Literature, Pocket Book 184, G. Bourogiannis and C. Mühlenbock (eds). Uppsala: Åström, pp. 207-217.

Chovanec, Z. (2013) Products of Social Distinction: Organic Residue Analysis of Specialized Products in Bronze Age Cyprus. PhD. Unpublish PhD Thesis. Albany, State University of New York at Albany.

Chovanec, Z., S. M. Rafferty, and S. Swiny (2012) Opium for the Masses: An Experimental Archaeological Approach in Determining the Antiquity of the Opium Poppy. *Journal of Ethnoarchaeology*. Vol. 4, No. 1, pp. 5-35. https://doi.org/10.1179/eth.2012.4.1.5.

Corbier, M. (1996) The Broad Bean and the Moray: Social Hierarchies and Food in Rome. In Food: A Culinary History J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 128-140.

Cortonesi, A. (1996) Self-Sufficiency and the Market: Rural and Urban Diet in the Middle Ages. In *Food: A Culinary History* J. Flandrin and M. Montanari (eds). New York, Columbia University Press, Pp. 268-274.

Dabney, M. K., P. Halstead, and P. Thomas (2004) Mycenaean Feasting on Tsoungiza at Ancient Nemea. *Hesperia*, Vol. 73, No. 2, pp. 197-215.

Derham, B. (2005) Archaeological and Ethnographic Toxins in Museum Collections. In *Impact of the Environment on Human Migration in Eurasia*. NATO Science Series: IV: Earth and Environmental Sciences, pp. 185-197.

Evershed, R. P. (2000) Biomolecular Analysis by Organic Mass Spectrometry. In *Modern Analytical Methods in Art and Archaeology*, Vol. 155. E. Ciliberto, G. Spoto (eds). Toronto, John Whiley and Sons, Inc., pp. 117-239.

Evershed, R. P.- (2008) Organic Residue Analysis in Archaeology: The Archaeological Biomarker Revolution. *Archaeometry* Vol. 50, No. 6, pp. 895-924. https://doi.org/10.1111/j.1475-4754.2008.00446.x.

Falconer, S. E. and P. L. Fall (with contributions by I. Berelov, Z. Chovanec, W. Crist, J. Czarzasty, J. Klinge (2017) Archaeological and landscape studies at Politiko-Troullia, Cyprus. *Report of the Department of Antiquities, Cyprus, 2011-12*, pp. 255-276.

Falconer, S. E. and P. L. Fall (2013) Household and community behavior at Bronze Age Politko-*Troullia*, Cyprus. *Journal of Field Archaeology* Vol. 38, No. 2, pp. 101-119. DOI 10.1179/0093469013Z.00000000041.

Feinman, G. M. (1997) Thoughts on new approaches to combining the archaeological and historical records. *Journal of Archaeological Method and Theory* Vol. 4, No. 3-4, pp. 367-77.

Flandrin, J.-L. (1996a) Introduction: The Humanization of Eating Behaviors. In *Food: A Culinary History* J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 13-20.

Flandrin, J.-L. (1996b) Dietary Choices and Culinary Technique, 1500-1800. In *Food: A Culinary History* J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 403-417.

Fox, J. and S. Weisberg (2013) Car: Companion to Applied Regression (R package), accessed October 14, https://r-forge.r-project.org/projects/car/.

Frankel, R. (1999) *Wine and Oil Production in Antiquity in Israel and Other Mediterranean Countries.* JSOT/ASOR Monograph Series 10. Sheffield, Sheffield Academic Press.

Fuller, D. Q. (2005) Ceramics, seeds and culinary changes in prehistoric India. *Antiquity* Vol. 79, No. 306, pp. 761-777.

Giammellaro, A. S. (1996) The Phoenicians and Carthaginians: The Early Mediterranean Diet. In *Food: A Culinary History* J. Flandrin and M. Montanari, (eds). New York, Columbia University Press, pp. 55-65.

Guash-Jané, M. R., C. Andrés-Lacueva, O. Jáuregui, R. M. Lamuela-Raventós (2006) The origin of the ancient Egyptian drink Shedeh revealed using LC/MS/MS, *Journal of Archaeological Science* Vol. 33, pp. 98-101. https://doi.org/10.1016/j.jas.2005.06.013.

Hadjisavvas, S. (1992) Olive Oil Processing in Cyprus: From the Bronze Age to the Byzantine Period. Studies in Mediterranean Archaeology, Vol. XCIX, Nicosia.

Hadjisavvas, S. (1996) The economy of the olive. In *The Development of the Cypriot Economy: From the Prehistoric Period to the Present Day*, Karageorghis, V. and D. Michaelides (eds). Nicosia: University of Cyprus and the Bank of Cyprus, pp. 127-137.

Hadjisavvas, S. (2009) Wine for the Elite, Olive for the Masses: Some Aspects of Early Agricultural Technology in Cyprus in *Exploring the Longee Duree*. *Essays in Honor of Lawrence E. Stager.* J. David Schloen (eds). Winona Lake, Eisenbrauns.

Hamilakis, Y. (1996) Wine, oil and the dialectics of power in Bronze Age Crete: A Review of the Evidence. *Oxford Journal of Archaeology* Vol. 15, No. 1, pp. 1-32. https://doi.org/10.1111/j.1468-0092.1996.tb00071.x.

Hamilakis, Y. (1999) Food Technologies/Technologies of the Body: The Social Context of Wine and Oil Production and Consumption in Bronze Age Crete. W*orld Archaeology*, Food Technology in Its Social Context: Production, Processing, and Storage, Vol. 31, No. 1, pp. 38-54.

Hamilakis, Y. and S, Sherratt (2012) Feasting and the consuming body in Bronze Age Crete and Early Iron Age Cyprus. *British School at Athens Studies*, Vol. 20, pp. 187-207.

Hansen, J. (2003) The Botanical Remains. In *Sotira Kaminoudhia: An Early Bronze Age Site in Cyprus*, Swiny, Rapp, and Herscher (eds). Boston, American Schools of Oriental Research, pp. 449-453.

Harrell, Jr., F. E. (2013) Hmisc: Harrell Miscellaneous (R package), October 29, https://github.com/harrelfe/Hmisc.

Heron, C. and R. P. Evershed (1993) The Analysis of Organic Residues and the Study of Pottery Use. In *Archaeological Method and Theory*. Vol 5. M. B. Schiffer. Tuscon, University of Arizona Press, p. 247-284.

Joannes, F. (1996) The Social Function of Banquets in the Earliest Civilizations. In *Food: A Culinary History* J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 32-37.

Kapoor, L.D. (1995) *Opium poppy: botany, chemistry, and pharmacology*. Binghampton, The Haworth Press, Inc.

Karageorghis, V. (1996) Some aspects of the maritime trade of Cyprus during the Late Bronze Age. In *The Development of the Cypriot Economy: From the Prehistoric Period to the Present Day*, Karageorghis, V. and D. Michaelides (eds). Nicosia, University of Cyprus and the Bank of Cyprus, pp. 61-70.

Karageorghis, V. (2002) *Early Cyprus: Crossroads of the Mediterranean*. Los Angeles, The J. Paul Getty Museum.

Katz, S. E. (2012) *The Art of Fermentation: An In-Depth Exploration of Essential Concepts and Processes from Around the World*. White River Junction, Chelsea Green Publishing.

Kimpe, K., C. Drybooms, E. Schrevens, P.A. Jacobs, R. Degeest, and M. Waelkens (2004) Assessing the relationship between form and use of different kinds of pottery from the archaeological site Sagalassos (southwest Turkey) with lipid analysis. *Journal of Archaeological Science* Vol. 31, pp. 1503-1510. https://doi.org/10.1016/j.jas.2004.03.012.

Kitson, F. G., B. S. Larsen, C. N. McEwen (1996) *Gas Chromatography and Mass Spectrometry*. San Diego, Academic Press.

Knapp, A. B. (2013) *The Archaeology of Cyprus: From Earliest Prehistory through the Bronze Age*. Cambridge, Cambridge University Press.

Knapp, A. B. and E. Blake (2005) Prehistory in the Mediterranean: The Connecting and Corrupting Sea. In *The Archaeology of Mediterranean Prehistory*, E. Blake and A.B. Knapp (eds). Malden, Blackwell Publishing, Ltd., pp. 1-23.

Koh, A. J., A. M. Berlin, and S. C. Herbert (2021) Phoenician Cedar Oil from Amphoriskoi at Tel Kedesh. *Bulletin of ASOR* Vol. 385, pp. 99-117.

Koh, A. J. and K. J. Birney (2017) Organic compounds and cultural continuity: the Penn Museum late Minoan IIIC stirrup jar from Tourloti, *Mediterranean Archaeology and Archaeometry*, Vol. 17, No. 2, pp. 19-33. DOI: 10.5281/zenodo.581717

Koh, A. J. and P. Betancourt (2010) Wine and Olive Oil From an Early Minoan I Hilltop Fort. *Mediterranean Archaeology and Archaeometry* Vol. 10, No. 2, pp. 15-23.

Koirala, B. and J. Rosentreter (2009) Examination of prehistoric artifacts via fatty acid methyl ester (FAME) techniques using modern environmental stewardship. *Journal of Archaeological Science* Vol. 36, pp. 1229-1242. https://doi.org/10.1016/j.jas.2009.01.012.

Krueger, M., U. Wicenciak, Z. Kowarska, P. Niedzielski, L. Kozak, M. Kruger, K. Jakubowski, J. Proch, M. Mleczek, A. Waśkiewicz (2018) First results of organic residue analysis on ceramic vessels (Jiyeh and Chhîm, Lebanon) by High Performance Liquid Chromatography with Tandem Mass Spectrometry. *Mediterranean Archaeology and Archaeometry*, Vol. 18, No. 1, pp. 209-220. DOI: 10-.5281/zenodo.1165358

Lambert, J. B. (1997) *Traces of the Past: Unraveling the Secrets of Archaeology Through Chemistry*. Reading, Perceus Books.

Linares, V., M. J. Adams, M. S. Cradic, I. Finkelstein, O. Lipschits, M. A.S. Martin, R. Neumann, P. W. Stockhammer, and Y. Gadot (2019) First evidence for vanillin in the old world: Its use as mortuary offering in Middle Bronze Age Canaan. *Journal of Archaeological Science Reports* Vol. 25, pp. 77-84. https://doi.org/10.1016/j.jasrep.2019.03.034.

Lyman, R. L. and M. J. O'Brien (2001) The Direct Historical Approach, Analogical Reasoning, and Theory in Americanist Archaeology. *Journal of Archaeological Method and Theory* Vol. 8, No. 4, pp. 303-342.

Malainey, M. E. (2007) Fatty Acid Analysis of Archaeological Residues: Procedures and Possibilities. In Theory and Practice in Archaeological Residue Analysis. H. Barnard and J.W. Eerkens (eds). Oxford: BAR International Series 1650, Archaeopress, pp. 77-89.

Malainey, M. E. (2011) *A Consumer's Guide to Archaeological Science: Analytical Techniques*. New York, Springer.

Malainey, M. E., R. Przybylski, and B.L. Sherriff (1999) The Effects of Thermal and Oxidative Degradation on the Fatty Acid Composition of Food Plants and Animals of Western Canada: Implications for the Identification of Archaeological Vessel Residues. *Journal of Archaeological Science* Vol. 26, pp. 95-103. https://doi.org/10.1006/jasc.1998.0306.

Margaritis, E. (2013) Distinguishing exploitation, domestication, cultivation and production: the olive in the third millennium Aegean. *Antiquity* Vol. 87, No. 337, pp. 746-757. http://antiquity.ac.ak/ant/087/ant080746.htm.

Mariti, G. (1984) *Wines of Cyprus: Vine planting to harvesting. Wine making to marketing*. Athens , Nicolas Books.

Matthews, L. G. (1973) *The Antiques of Perfume*. London, G. Bell & Sons.

Mayyas, A. S. (2018) Organic residue analysis in ancient pottery sherds from sites in Jordan. *Mediterranean Archaeology and Archaeometry*, Vol. 18, No. 1, pp. 61-75. DOI: 10.5281/zenodo.1069524

Mayyas, A.S., D. Khaled, T. Hoffman, U. Thorenz, I. Bany Yaseen, E-K. Mohammed. (2013) Organic residues preserved in archaeological ceramics from the Early Bronze Age site of Khirbet al-Batrawy in North-Central Jordan. *Mediterranean Archaeology and Archaeometry, Vol. 13, No. 2, pp. 189-206.*

McGovern, P. E. (2003) *Ancient Wine: The Search for the Origins of Viniculture*. Princeton, Princeton University Press.

McGovern, P. E. (2009) *Uncorking the Past: The Quest for Wine, Beer, and other Alcoholic Beverages*. Berkeley, University of California Press.

Merlin, M. D. (1984) *On the Trail of the Ancient Opium Poppy: Natural and Early Cultural History of Papaver somniferum*. East Brunswick, Associated University Presses.

Merrillees, R. S. (2003[1962]) Opium Trade in the Bronze Age Levant. In *On Opium, Pots, People, and Places: Selected Papers. An Honorary Volume for Robert S. Merrillees*. Sävedalen, Paul Åström, pp. 2-8.

Mintz, S. W. and C. M. Du Bois (2002) The Anthropology of Food and Eating. *Annual Review of Anthropology*, Vol. 31, pp. 99-199. doi: 10.1146/annurev.anthro.32.032702.131011.

Newman, R. (1998) Technical Report: Organic Residues from Egyptian Blue Anhydrite Duck Flasks and Other Anhydrite Vessels. *Metropolitan Museum Journal* Vol. 33, pp. 49-55.

Newton, C., J.-F, Terral and S. Ivorra (2006) The Egyptian olive (Olea europaea subsp. Europaea) in later first millennium B.C.: origins and history using morphometric analysis of olive stones). *Antiquity* Vol. 80, No. 308, pp. 405-414.

Oksanen, J. (2008) vegan: an introduction to ordination (R package), accessed November 1. http://vegan.r-forge.r-project.org/.

Parras, D.J., A. Sánchez, Á. Luque, M. A. Lechuga, and C. Raueda (2020) The diet of Romans during 2nd Punic War in their Camp Cerro de Las Albahacas (Santo Tomé, Spain) from organic residue analysis in ceramic vessels by GC-MS, HPLC-APCI and GC-C-IRMS Methods. *Mediterranean Archaeology and Archaeometry*, Vol. 20, No. 1, pp. 127-143.

Pollard, A. M., and C. Heron (2008) *Archaeological Chemistry*, 2nd Ed. Cambridge: The Royal Society of Chemistry.

Pratt, C. E. (2014) *Critical Commodities: Tracing Greek Trade in Oil and Wine from the Late Bronze Age to the Archaic Period*. Doctoral Thesis: Los Angeles, University of California.

Quirke, S. and J. Spencer, eds. (1992) *The British Museum Book of Ancient Egypt*. New York, Thames and Hudson, Ltd.

Rafferty, S. M. (2007) The Archaeology of Alkaloids. In *Theory and Practice in Archaeological Residue Analysis*. H. Barnard and J.W. Eerkens (eds). Oxford: BAR International Series 1650, Archaeopress, pp. 179-188.

Reeves, N. and R. H. Wilkinson (1996) *The Complete Valley of the Kings: Tombs and Treasures of Egypt's Greatest Pyramids*. London, Thames and Hudson, Ltd.

Regert, M., H. A. Bland, S. N. Dudd, P. F. van Bergen, and R. P. Evershed (1998) Free and Bound Fatty Acid Oxidation Products in Archaeological Ceramic Vessels. *Proceedings: Biological Sciences*, Vol. 265, No. 1409, pp. 2027-2032.

Regert, M., S. Colinart, L. Degrand, and O. Decavalls (2001) Chemical Alteration and Use of Beeswax Through Time: Accelerated Ageing Tests and Analysis of Archaeological Samples from Various Environmental Contexts. *Archaeometry* Vol. 43, No. 4, pp. 549-569. https://doi.org/10.1111/1475-4754.00036.

Renfrew, C. (1972) *The emergence of civilization: the Cyclades and the Aegean in the third millennium B.C.* London, Methuen.

Renfrew, J. M. (1973) *Palaeoethnobotany: The prehistoric food plants of the Near East and Europe*. New York, Columbia University Press.

Riley, R.F. (2002) Olive Oil Production on Bronze Age Crete: Nutritional Properties, Processing Methods and Storage of Minoan Olive Oil. *Oxford Journal of Archaeology* Vol. 21, No. 1, pp. 63-75. https://doi.org/10.1111/1468-0092.00149.

Rosenberger, B. (1996) Arab Cuisine and Its Contribution to European Culture. In *Food: A Culinary History* J. Flandrin and M. Montanari (eds). New York, Columbia University Press, pp. 207-223.

Shelmerdine, C. W. (1985) *The Perfume Industry of Mycenaean Pylos. Studies in Mediterranean Archaeology*, Pocketbook 34. Göteborg, Paul Åströms.

Sherratt, A. (1987) Cups that Cheered: The Introduction of Alcohol to Prehistoric Europe. In *Economy and Society in Prehistoric Europe: Changing Perspectives*, A. Sherratt. Princeton (ed). Princeton University Press, pp. 376-402.

Smith, J. A. (2012) Seals, Scripts, and Politics at Late Bronze Age Kourion. *American Journal of Archaeology* Vol. 116, No. 1, pp. 39-103.

Solazzo, C. and E. Erhardt (2007) Analysis of Lipid Residues in Archaeological Artifacts: Marine Mammal Oil and Cooking Practices in the Arctic. In *Theory and Practice in Archaeological Residue Analysis*. H. Barnard and J.W. Eerkens (eds). Oxford: BAR International Series 1650. Archaeopress, pp. 161-178.

Stahl, A. B. (1993) Concepts of Time and Approaches to Analogical Reasoning in Historical Perspective. *American Antiquity* Vol. 58, No. 2, pp. 235-260.

Stauffer, E. (2006) A Review of the Analysis of Vegetable Oil Residues from Fire Debris Samples: Analytical Scheme, Interpretation of the Results, and Future Needs. *Journal of Forensic Science*, Vol. 51, No. 5, pp. 1016-1032. https://doi.org/10.1111/j.1556-4029.2006.00220.x.

Steel, L. (2004) *Cyprus Before History: From the Earliest Settlers to the End of the Bronze Age*. London, Duckworth & Co., Ltd.

Swiny, S. (2003) The Settlement. In *Sotira Kaminoudhia: An Early Bronze Age Site in Cyprus*. S. Swiny, G. Rapp, and E. Herscher (eds). Cyprus American Archaeological Research Institute Monograph 4. Boston, American Schools of Oriental Research, pp. 9-102.

Swiny, S. and E. Herscher (2003) The Cemetery. In *Sotira Kaminoudhia: An Early Bronze Age Site in Cyprus*. S. Swiny, G. Rapp, and E. Herscher (eds). Cyprus American Archaeological Research Institute Monograph 4. Boston, American Schools of Oriental Research, Pp. 103-144.

Tushingham, S., D. Ardura, J. W. Eerkens, M. Palazoglu, S. Shahbaz, and O. Fiehn (2012) Hunter-gather tobacco-smoking: earliest evidence from the Pacific Northwest Coast of North America. *Journal of Archaeological Science* Vol. 40, No. 2, pp. 1397-1407. https://doi.org/10.1016/j.jas.2012.09.019.

Twiss, K. (2012) The Archaeology of Food and Social Diversity. *Journal of Archaeological Research* Vol. 20, pp. 357-395. DOI 10.1007/s10814-012-9058-5.

Twiss, K. (2007) Home Is Where The Hearth Is: Food and Identity in the Neolithic Levant. In *The Archaeology of Food and Identity*, K.C. Twiss (ed). Center for Archaeological Investigations, Carbondale, Southern Illinois University, pp. 50-68.

Wang, Y., S. Sun, F. Li, X. Cao, and R. Sun (2018) Production of vanillin from lignin: The relationship between β-O-4 linkages and vanillin yield. *Industrial Crops and Products* Vol. 116, pp. 116-121. https://doi.org/10.1016/j.indcrop.2018.02.043.

Warnock, P. (2007) Identification of Ancient Olive Oil Processing Methods Based on Olive Remains. *BAR International Series* 1635. Oxford, B.A.R.

Wolff, S. R. (1991) Archaeology in Israel. *American Journal of Archaeology* Vol. 95, No. 3, pp. 489-538.

Wylie, A. (1985) The Reaction Against Analogy. In *Advances in Archaeological Method and Theory*, Vol. 8. M.B. Schiffer (ed). New York, Academic Press, pp. 136-153.

Wylie, A. (1988)'Simple' Analogy and the Role of Relevance Assumptions: Implications of Archaeological Practice. *International Studies in the Philosophy of Science* Vol. 2, No. 2, pp. 134-150.