Introduction

Tel Kabri is a 34-hectare site located in the western Galilee of modern-day Israel, five kilometers east of Nahariya. During the Middle Bronze Age (ca. 1900–1600 BC), the site was the center of a major Canaanite polity, with a palace covering at least 6,000 sq.m., making it the largest Middle Bronze Age palace excavated so far in Israel [1]–[3].

During the 2013 excavations at Kabri, the remains of a palatial storage complex were uncovered, of which one room was excavated in its entirety. On the floor were the remains of approximately 40 restorable large, mostly handle-less, storage jars, as well as a few smaller vessels, all of which were found covered by a thick collapse of mudbricks from either the walls or the ceiling of the room (Figure 1). All of the fairly uniform, ca. 50-liter, storage jars were made from the most common type of ceramic fabric found at Kabri, from which the vast majority of other pottery in the palace was also made. It is probably related to Senonian marl, available locally as close as the nearby wadi. Inclusions include calcareous sand typical of the western Galilee. Before the systematic removal of the jars, samples from each were taken for organic residue analysis (ORA) and petrography; in addition, the fully articulated contents of the room were recorded using LiDAR, which collected millions of discrete three-dimensional data points and resulted in a surface plan accurate to within two mm (Figure 2).

Archaeologists have long identified wine as an important component of Bronze Age palatial economies, including social feasting [4]–[7]. Palatial wine storage rooms are known from documentary sources in both the Bronze Age Mediterranean and Mesopotamia, especially from the archives of the site of Mari [8], which are contemporary to the palace at Kabri. Their existence has also been further postulated on the basis of actual ceramic finds, including large storage jars in magazines, from Aegean palaces such as Pylos and Knossos, but none to date have been empirically confirmed by ORA. With numerous studies now verifying the efficacy and cost-effectiveness of analyzing ancient organic residues using gas chromatography in tandem with mass spectrometry (GC-MS) [9]–[12], Kabri’s largely undisturbed palatial storage complex presented the ideal situation in which to conduct a comprehensive ORA program.

Characterizing a Middle Bronze Palatial Wine Cellar from Tel Kabri, Israel

Andrew J. Koh1*, Assaf Yasur-Landau2, Eric H. Cline3

1 Departments of Classical Studies and Chemistry, Brandeis University, Waltham, Massachusetts, United States of America, 2 Department of Maritime Civilizations, The Leon H. Charney School of Marine Sciences and the Leon Recanati Institute of Maritime Studies, University of Haifa, Mount Carmel, Haifa, Israel, 3 Department of Classical and Near Eastern Languages and Civilizations, George Washington University, Washington, District of Columbia, United States of America

Abstract

Scholars have for generations recognized the importance of wine production, distribution, and consumption in relation to second millennium BC palatial complexes in the Mediterranean and Near East. However, direct archaeological evidence has rarely been offered, despite the prominence of ancient viticulture in administrative clay tablets, visual media, and various forms of documentation. Tartaric and syringic acids, along with evidence for resination, have been identified in ancient ceramics, but until now the archaeological contexts behind these sporadic discoveries had been uneven and vague, precluding definitive conclusions about the nature of ancient viticulture. The situation has now changed. During the 2013 excavation season of the Kabri Archaeological Project, a rare opportunity materialized when forty large storage vessels were found in situ in an enclosed room located to the west of the central courtyard within the Middle Bronze Age Canaanite palace. A comprehensive program of organic residue analysis has now revealed that all of the relatively uniform jars contain evidence for wine. Furthermore, the enclosed context inherent to a singular intact wine cellar presented an unprecedented opportunity for a scientifically intensive study, allowing for the detection of subtle differences in the ingredients or additives within similar wine jars of apparently the same vintage. Additives seem to have included honey, storax resin, terebinth resin, cedar oil, cyperus, juniper, and perhaps even mint, myrtle, or cinnamon, all or most of which are attested in the 18th century BC Mari texts from Mesopotamia and the 15th century BC Ebers Papyrus from Egypt. These additives suggest a sophisticated understanding of the botanical landscape and the pharmacopeic skills necessary to produce a complex beverage that balanced preservation, palatability, and psychoactivity. This new study has resulted in insights unachievable in the past, which contribute to a greater understanding not only of ancient viticulture but also of Canaanite palatial economy.

Citation: Koh AJ, Yasur-Landau A, Cline EH (2014) Characterizing a Middle Bronze Palatial Wine Cellar from Tel Kabri, Israel. PLoS ONE 9(8): e106406. doi:10.1371/journal.pone.0106406

Editor: Xiaoyan Yang, Chinese Academy of Sciences, China

Received February 24, 2014; Accepted August 3, 2014; Published August 27, 2014

Copyright: © 2014 Koh et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Funding: This work was supported by Brandeis University, University of Haifa, George Washington University, National Geographic Society, Israel Science Foundation, Institute for Aegean Prehistory, and Bronfman Philanthropies. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing Interests: The authors have declared that no competing interests exist.

* Email: akoh@brandeis.edu
Materials and Methods

All necessary permits were obtained for the described study, which complied with all relevant regulations. The Israel Antiquities Authority issued Permit G-42 to conduct excavations at Tel Kabri. No special permits were required for the present study. After the complete articulation of all jars, sherds of approximately the same size – small enough to sit flat in a 400 ml Griffin beaker – were identified near the base of each jar and immediately isolated in aluminum foil for subsequent residue extraction. The one exception was Jar 11, which had a second sample sherd taken from higher up on the body. Care was taken in documenting the entire procedure, so that precise LiDAR coordinates could be assigned to each sample sherd (Table 1). These sherds were then transported to the nearby Western Galilee Field School for non-destructive extraction using analytical grade ethanol in a process developed over the last ten years [9].

In addition to the insight gained into the efficacy of this non-destructive technique from both the current project as well as past studies [9], [13], [14], additional research is planned at Kabri to compare this technique with destructive techniques commonly used today [15]. Thus, adjacent sherds from the same vessels were collected in 2011 at Kabri with the explicit intent of comparing results from non-destructive and destructive extractions. Petrographic thin-section analysis is also being conducted by David Ben Shlomo of the Hebrew University. Our primary goal, however, is to illuminate patterns in palatial economies and social practices, some of which can only be studied through the contribution of ORA.

In all, 35 ORA samples from the storage room were ultimately extracted into filtered solution and stored in 20 ml scintillation vials; these samples came from 32 of the storage jars (with Jar 11 providing two samples), the base of a deep bowl or cup, and one soil sample to serve as a control (but which ultimately produced no organic residues). Sherds from the additional eight jars (of the 40) were collected but left untouched and unextracted as a control for future studies. The plan is to extract residues from two untested jars biannually to study the effects of sherd excavation with delayed extraction.

Less than two weeks after extraction, the 35 ORA samples were taken to the Brandeis University Department of Chemistry, concentrated to solid by rotary evaporator and redissolved in uninhibited THF to produce ~2 ml GC-MS analytes, and injected into the university’s newest GC-MS instrument – an Agilent 7890A GC with a HP-5MS column and a 5975C VL MSD Triple Axis Detector. The pulsed split injector and interface were both set to 250°C. The initial oven temperature was set to 100°C and held for two minutes before reaching 250°C at a rate of 10°C/min, at which time it was held for an additional 11 minutes, giving a total program time of 28 minutes/sample. Solvent blanks were intermittently utilized to verify that no contaminants existed from previous runs. Standard references of tartaric and syringic acids were ultimately produced (see below). The streamlined nature of the overall methodology allows for one person to take

Figure 1. Kabri wine cellar with numbered jars (looking southeast).
doi:10.1371/journal.pone.0106406.g001
numerous samples from ground to instrument to interpretation in less than a month, which is considerably faster and more efficient than the norm.

Results

All 32 tested jars and the small bowl/cup base contained tartaric acid after initial peak assignment using the National Institute of Standards and Technology mass spectral library, NIST 11 (Table 1). In order to verify this identification beyond a shadow of doubt, 5 mM standard reference samples (Figure 3) were prepared from commercially available standard compounds of both tartaric and syringic acids (Sigma-Aldrich), whose resultant spectra derived from the same GC-MS conditions were then manually cross-referenced with the ancient samples (Figure 4, 5, 6). All but three of the tested vessels also contained syringic acid, and all but three contained cinnamic acid (Table 2). Cineole also was found in almost all of the tested vessels; it is absent from only four jars and the small bowl/cup base, which can readily be attributed to a lack of preservation. In addition, significant amounts of oleanoic acid were found in 27 of the tested jars, as well as the small bowl/cup base. Methyl syringate was found in 21 of the tested jars, while 19 contained cedrol.

The fact that the ca. 3 m. x 1 m. eastern antechamber floor (Figure 7) is the lowest part of the study area but produced excellent ORA results mitigates fears of preservation being obscured by any pooling groundwater. In addition, note again that Jar 11 was tested in two locations on the jar – one near the base like all the other samples and one quite a bit higher up on the body. While this second, less optimal, location higher up on the body did not prevent the detection of both tartaric and syringic acids (Table 1), the second sample’s peak abundances were noticeably lower and at least two potentially diagnostic compounds were not detected at all (Table 2). This has obvious ramifications concerning the location of a sampled sherd on a vessel, a variable that is often ignored and even left unnoted, especially when only a few vessel sherds are extant.

Interpretation

Every sample taken from the vessels that were tested yielded positive results (Table 2). The nature and preservation of the room in conjunction with the swift and careful isolation of sampled sherds while in the field, followed by immediate extraction, likely contributed to the high rate of success and excellent data produced, which stand in contrast to uneven results in the past from objects typically excavated decades into the past and housed in uncertain conditions.

As noted, all 32 tested jars and the small bowl/cup base contained tartaric acid, and all but three also contained syringic acid. Combined with our knowledge of vessel typology and palatial economies, the presence of both tartaric and syringic acids in relative abundance as biomarkers indicates that all of these vessels originally held wine [9]-[12], [16] and that we may be confident in identifying this space as a wine storage room – that is to say, a wine cellar. On a related note, we should mention that, in addition to vineyards reestablished during the 19th century in the
viticulture-friendly Upper Galilee by Baron Edmond de Rothschild using grape varieties imported from Bordeaux, we know from a papyrus in the Zenon Archive from Ptolemaic Egypt dating to 257 BC (p.lond.7.1948) that the ancient Bethanath estate located just 15 km to the southeast (modern B’ina outside Karmiel in the Beit HaKerem Valley) produced wine from 80,000 vines, which was purportedly indistinguishable from the celebrated wines of Chios [17]. Salvage excavations in 2001 at the adjacent tell of Nahf led excavators to conclude that the area was an important center for viticulture certainly in the Hellenistic period and perhaps as far back as the Early Bronze Age IB period (ca. 3100 BC), judging by the finds [18]. Supported by the locally-sourced clay of the Kabri wine jars, this makes Karmiel a good candidate for the location of Kabri’s ancient vineyards. If grape DNA can be isolated at Kabri in future seasons, it is possible that more closely related cultivars that are presently feral in the region [19] or surviving in European vineyards after export in antiquity [20] could be identified or even cloned.

The lack of syringic acid in three of the tested jars opens up the possibility that those three held white wine, rather than red wine, but it is difficult to say with certainty without further evidence, such as distinguishing markings on the jars. It is possible that the syringic acid did not survive or was undetectable in these three jars during the present study.

| ARCHEM # | Jar # | X.Y,Z LiDAR Coordinates (m)* | Tartaric Acid Absolute Abundance† | Tartaric Acid Relative Abundance (%)$ | Syringic Acid Absolute Abundance† | Syringic Acid Relative Abundance (%)$ |
|----------|-------|------------------------------|----------------------------------|--------------------------------------|----------------------------------|--------------------------------------|
| 4324     | 1     | 65.391, 27.563, 51.131       | 3343756                          | 57.79                                | 202525                           | 3.5                                  |
| 4296     | 2     | 67.219, 27.688, 50.978       | 3004788                          | 37.50                                | 239754                           | 2.99                                 |
| 4295     | 3     | 67.953, 28.188, 50.961       | 13622358                         | 62.24                                | 196340                           | 0.9                                  |
| 4294     | 4     | 68.469, 28.375, 51.018       | 7457540                          | 55.61                                | 135975                           | 1.01                                 |
| 4323     | 5     | 66.297, 27.750, 51.082       | 2029624                          | 35.25                                | 75666                            | 1.31                                 |
| 4312     | 6     | 65.578, 28.563, 51.041       | 145271                           | 0.96                                 | N/A                              | N/A                                  |
| 4304     | 7     | 65.656, 29.813, 50.930       | 404307                           | 32.63                                | 227830                           | 18.39                                |
| 4307     | 8     | 64.953, 29.500, 50.945       | 805717                           | 18.39                                | N/A                              | N/A                                  |
| 4321     | 9     | 67.766, 29.313, 51.004       | 10324787                         | 100                                  | 199528                           | 1.93                                 |
| 4291     | 11    | 68.719, 29.250, 50.983       | 11985301                         | 43.35                                | 143509                           | 0.52                                 |
| 4322     | 11    | 69.078, 29.313, 50.976       | 23144172                         | 85.03                                | 795193                           | 2.92                                 |
| 4313     | 12    | 70.000, 29.875, 51.087       | 228412                           | 100                                  | 3086                            | 1.35                                 |
| 4316     | 13    | 70.688, 29.500, 51.091       | 1792475                          | 9.02                                 | N/A                              | N/A                                  |
| 4305     | 15    | 70.156, 30.750, 50.980       | 2294968                          | 4.24                                 | 15457123                         | 28.56                                |
| 4300     | 16    | 69.578, 31.063, 50.980       | 391777                           | 11.63                                | 775446                           | 23.02                                |
| 4299     | 17    | 70.297, 31.813, 51.143       | 1303896                          | 27.86                                | 403613                           | 8.63                                 |
| 4311     | 18    | 69.453, 32.375, 51.087       | 1708411                          | 29.51                                | 327871                           | 5.66                                 |
| 4303     | 19    | 68.859, 32.125, 51.100       | 564888                           | 3.77                                 | 7281238                          | 48.66                                |
| 4302     | 20    | 69.641, 33.188, 51.242       | 473817                           | 5.28                                 | 298093                           | 3.32                                 |
| 4297     | 22    | 67.828, 32.313, 51.111       | 546275                           | 3.78                                 | 4539456                          | 31.38                                |
| 4306     | 23    | 67.219, 31.375, 50.981       | 774848                           | 25.74                                | 251112                           | 8.34                                 |
| 4308     | 24    | 65.891, 31.875, 51.202       | 875524                           | 32.06                                | 382734                           | 14.02                                |
| 4310     | 25    | 66.688, 30.563, 50.870       | 756151                           | 33.36                                | 461805                           | 20.37                                |
| 4298     | 26    | 67.047, 29.563, 50.848       | 1188437                          | 7.24                                 | 385049                           | 2.35                                 |
| 4292     | 27    | 68.984, 28.563, 51.021       | 7053156                          | 24.04                                | 509446                           | 1.74                                 |
| 4314     | 28    | 69.891, 30.438, 50.960       | 1862927                          | 21.13                                | 1399240                          | 15.26                                |
| 4320     | 29    | 67.625, 30.025, 50.870       | 4008053                          | 18.79                                | 711355                           | 3.33                                 |
| 4301     | 31    | 67.500, 32.438, 50.993       | 1310401                          | 1.67                                 | 635407                           | 0.81                                 |
| 4317     | 33    | 66.672, 34.375, 50.949       | 5026543                          | 100                                  | 445482                           | 8.86                                 |
| 4325     | 34    | 65.719, 34.250, 50.792       | 5402354                          | 19.9                                 | 199423                           | 0.73                                 |
| 4319     | 35    | 68.109, 35.313, 50.828       | 491234                           | 67.1                                 | 538802                           | 73.59                                |
| 4318     | 36    | 69.703, 30.188, 50.919       | 7921530                          | 24.49                                | 7415574                          | 22.93                                |
| 4315     | 37    | 69.500, 30.313, 50.909       | 995859                           | 16.33                                | 2792653                          | 44.32                                |
| 4289     | Base  | 64.992, 27.375, 51.057       | 3548407                          | 11.47                                | 137261                           | 0.44                                 |

*213400 and 768200 meters were removed from X and Y coordinates respectively for brevity.

Peak area determined by integration in chromatograms.

Percentage relative to maximum peak in a given chromatogram.

doi:10.1371/journal.pone.0106406.t001
In addition, all but three of the tested jars contained cinnamic acid. While it can be notoriously difficult to match extant compounds to their original sources from antiquity, and there are alternatives for each suggested here, it is possible to present likely sources based on 1) concentrations of compounds inherently found in commodities; 2) ethnobotanical knowledge of the natural distribution of ancient commodities; and 3) surviving documentary accounts of commodities acquisition and utilization. As new internal and external evidence is produced, these interpretations can be duly updated. In the case of cinnamic acid, it occurs foremost in the storax resin of *Liquidambar orientalis*, or Oriental Storax or Sweetgum, at 150,000 ppm if one discounts its New World kin, *L. styracifula*, at 230,000 ppm. Cinnamic acid also occurs in *Styrax officinalis*, or Styrax or Snowbell, whose benzoe resin is chemically similar and presumably explains historical descriptions of “storax” that more closely resemble it than the resin from *Liquidambar*. One possible clue as to its source at Kabri is the occurrence of oleanic acid in *Liquidambar* and *Pistacia*, but not *Styrax* [21]. Due to its prevalence in the Kabri wine jars, it is probable that this aromatic resin was the primary preservative added at nearby wine production centers in the Upper Galilee region, still renowned for viticulture to this day, before transport to the palace.

Cineole also was found in all but four of the tested jars. Isolating the source(s) of cineole can be difficult, but likely candidates include cyperus roots (*Cyperus rotundus*), mint (*Mentha*), juniper berries (*Juniper communis* or *phoenicea*) well known today for the connection to gin, and cinnamon bark (*Cinnamomum*) [22]. It is notable that all of these potential candidates were also ingredients of Egyptian kyphi, whose herbal additives have been postulated to

Figure 3. 5 mM standard reference samples. A. Total-ion chromatogram of tartaric acid standard, B. Total-ion chromatogram of syringic acid standard.

doi:10.1371/journal.pone.0106406.g003
originate from the Levant [10]. In addition, caryophyllene was found in six of these jars as well, which supports the presence of cedar oil (Cedrus libani), mint, juniper berries, and cinnamon bark as additives.

Methyl syringate, which was found in 21 of the tested jars, occurs in good quantity in honey [23]. It would not be at all surprising if honey had been added to this wine, for it fits well with the textual evidence from both the 18th century BC Mari tablets [8] and Egyptian kyphi recipes [24] from the 15th century BC onwards. Presuming that this physical evidence at Kabri is indicative of local apiculture, it would push back direct evidence in the southern Levant by at least seven centuries before the apiary at Tel Rehov [25]. Nineteen of the tested jars contained cedrol, which likely originated from the nearby stands of C. libani (Cedar of Lebanon) and its cedar oil [26] or, less likely, from juniper, where it only occurs in small quantities (2000 ppm). The oleanoic acid that was found in 27 of the tested jars, as well as the small bowl/cup base, could have come from terebinth (Pistacia palaestina or terebinthus) resin, a local antimicrobial additive [26] long associated with ancient wines [11]. This interpretation is supported by the detection of moronic and masticadienoic acids in five of the tested jars, in addition to the small bowl/cup base. However, despite robust quantities of oleanoic acid in the other 22 tested jars, the lack of these two additional terpenes – moronic and masticadienoic acid – in these jars leaves open the possibility that their oleanoic acid derives from a different source, such as the aforementioned storax resin or cyperus.

Overall, the five tested jars with the best represented organic residues – judging by the definition and number of individual GC peaks – occurred in two general areas of the storage room: in the eastern antechamber near the northern entrance, exemplified by intact Jar 35 (Figure 4) and towards the south central part of the room between Jars 26 and 36 (Figure 7, Table 2). This latter group was found near a feature/platform abutting the southern wall and perhaps not coincidentally surrounding an installation enconced in the ground in front of the feature/platform and found under Jar 26. These conditions combined with jars producing simpler and noticeably consistent chromatograms on the cellar’s east periphery (Figure 5, 6) suggest that wines may have been brought into the cellar from the southeast, triaged near the east wall, treated at the central installation, and stored in the northern antechambers before consumption, although this awaits final verification after the entire building is published. Jars 15–20 with their simpler and consistent chromatograms represent a line of well-preserved vessels that might have originally leaned against one another and the east wall of the wine cellar awaiting treatment at the central installation. Like Jar 11, Jar 15 received slightly special attention from us. In the latter’s case, two subsamples from the jar’s master sample were injected as bookends into the Brandeis GC-MS approximately twelve hours apart with samples from other jars intervening with the usual blanks interspersed throughout. In the end, these two subsamples produced nearly indistinguishable chromatograms (Figure 6).

Discussion

Tartaric acid and syringic acid have been identified in earlier production and funerary deposits [10], [12], but the archaeological contexts behind these sporadic discoveries had been limited, precluding definitive conclusions about the nature of ancient viticulture, especially as it pertains to consumption. The storage jars that we found in the closed and sealed archaeological context within the well-studied palace at Kabri are unlikely to have held anything but liquids, considering their narrow necks, and the ORA conducted on 32 of the 40 (as mentioned above, sherd from the additional eight jars were collected but left untouched and unextracted as a control for future studies) has now allowed us to confidently identify them as belonging to the oldest and largest palatial wine cellar that has been chemically confirmed from the
ancient Near East. Moreover, the controlled context containing numerous similar wine jars of presumably the same vintage presented an unprecedented opportunity for a scientifically intensive study of its organic residue remains, allowing for the detection of subtle differences in the quality and quantity of ingredients or additives within the various wine jars, though the possibility that the jars were used and reused over the course of their lifetime must also be considered.

Overall, the ORA indicates that the Kabri palatial wine cellar included resinated red wine, and possibly resinated white wine, with many of the jars containing herbal additives in fairly consistent ratios to both tartaric and syringic acids (Table 3). These ingredients, of which only trace compounds like oleanolic acid are now extant, may have included those mentioned above, such as honey, storax resin, terebinth resin, cyperus, cedar oil, juniper, and perhaps even mint, myrtle (*Myrtus communis*) [26], or cinnamon. Many of these ingredients, like the honey discussed above, are attested as additives to wine in the 18th century BC Mari texts from Mesopotamia and in Egyptian kyphi recipes published for at least two millennia starting by the 15th century BC.

The Mari texts generally record types of wine and additives; for instance, one mentions “One jar of strong wine, one jar of sweet wine, and eight jars of wine of second quality shipped together with three types of herbal aromatics: one kirippum-jar of oil of Cyprus, one kirippum-jar of oil of myrtle, and one kirippum-jar of oil of juniper” [8]. The kyphi texts are a bit more involved. For instance, after recounting the methodical brewing process of kyphi documented by the Egyptian priest Manetho in the 3rd century BC, the 1st century Greek historian Plutarch remarks that kyphi was used as a potion to cleanse internal organs [27]. Besides the obvious antimicrobial properties of many of these additives [28], some like cedar oil were likely known centuries before the Middle Bronze Age to possess astringent, diuretic, sedative, and stimulant properties.

---

**Figure 5. Total-ion chromatograms of Jars 16–20.** A. Total-ion chromatogram from Jar 16 (ARCHEM 4300), B. Total-ion chromatogram from Jar 17 (ARCHEM 4299), C. Total-ion chromatogram from Jar 18 (ARCHEM 4311), D. Total-ion chromatogram from Jar 19 (ARCHEM 4303), E. Total-ion chromatogram from Jar 20 (ARCHEM 4302).

doi:10.1371/journal.pone.0106406.g005
properties as well [29]. The complex recipe of the Kabri wine thus may provide concrete evidence for the sophistication of Canaanite viticulture.

Furthermore, the large total volume of the stored wine – up to 2,000 liters – and the context of this storeroom, next to a ceremonial room within the palace in which banquets might have been held, may contribute to a greater understanding of Canaanite court ceremony and economy. Although 2,000 liters – or the equivalent of 3,000 modern bottles of wine – may seem like a lot, it is not enough for wide-spread distribution and should probably be seen as directly related to consumption within the palace rather than to either production or distribution [30]; in other words, we may have here the private reserve of the ruler and his household. When considered with issues of long-term preservation in antiquity and the overall consistency of both the wine and containers, it seems likely that the wine cellar held a single vintage, which was habitually replenished in a given year.

Future Work

In looking to the future, we note that there is a southeastern entrance (or exit) to this room. This connects the excavated storage room with another, as yet largely unexcavated, room that is located directly to the south, in which the remains of at least six additional large storage jars have already been found. These were excavated and removed at the end of the 2013 season, since they would not have survived the winter. There is also what appears to be yet another opening, this one leading off to the northwest of our storage room, which may lead to additional rooms in this storage complex, but investigation of these additional areas will have to wait until the next excavation season, in 2015.
| Jar # | Cinnamic acid | Cineole | Methyl Syringate | Caryophyllene | Oleanolic Acid | Masticadienoic Acid | Caryophyllene | Myristyl acetate |
|-------|---------------|---------|------------------|---------------|----------------|---------------------|---------------|----------------|
| 1     |               |         |                  |               |                |                     |               |                |
| 2     |               |         |                  |               |                |                     |               |                |
| 3     |               |         |                  |               |                |                     |               |                |
| 4     |               |         |                  |               |                |                     |               |                |
| 5     |               |         |                  |               |                |                     |               |                |
| 6     |               |         |                  |               |                |                     |               |                |
| 7     |               |         |                  |               |                |                     |               |                |
| 8     |               |         |                  |               |                |                     |               |                |
| 9     |               |         |                  |               |                |                     |               |                |
| 10    |               |         |                  |               |                |                     |               |                |
| 11    |               |         |                  |               |                |                     |               |                |
| 12    |               |         |                  |               |                |                     |               |                |
| 13    |               |         |                  |               |                |                     |               |                |
| 14    |               |         |                  |               |                |                     |               |                |
| 15    |               |         |                  |               |                |                     |               |                |
| 16    |               |         |                  |               |                |                     |               |                |
| 17    |               |         |                  |               |                |                     |               |                |
| 18    |               |         |                  |               |                |                     |               |                |
| 19    |               |         |                  |               |                |                     |               |                |
| 20    |               |         |                  |               |                |                     |               |                |
| 21    |               |         |                  |               |                |                     |               |                |
| 22    |               |         |                  |               |                |                     |               |                |
| 23    |               |         |                  |               |                |                     |               |                |
| 24    |               |         |                  |               |                |                     |               |                |
| 25    |               |         |                  |               |                |                     |               |                |
| 26    |               |         |                  |               |                |                     |               |                |
| 27    |               |         |                  |               |                |                     |               |                |
| 28    |               |         |                  |               |                |                     |               |                |
| 29    |               |         |                  |               |                |                     |               |                |
| 30    |               |         |                  |               |                |                     |               |                |
| 31    |               |         |                  |               |                |                     |               |                |
| 32    |               |         |                  |               |                |                     |               |                |
| 33    |               |         |                  |               |                |                     |               |                |
| 34    |               |         |                  |               |                |                     |               |                |
| 35    |               |         |                  |               |                |                     |               |                |
| 36    |               |         |                  |               |                |                     |               |                |
| 37    |               |         |                  |               |                |                     |               |                |
| 38    |               |         |                  |               |                |                     |               |                |

Table 2: Chemical occurrence of additive compounds.
Figure 7. Plan of Kabri wine cellar.
doi:10.1371/journal.pone.0106406.g007
Table 3. Additives data from wine cellar jars.

| ARCHEM # | Jar # | Compounds of Interest | Possible Additive Source(s) | Absolute Abundance* | Relative Abundance (%) | Ratio to Tartaric Acid | Ratio to Syringic Acid |
|----------|-------|-----------------------|-----------------------------|---------------------|------------------------|------------------------|------------------------|
| 4324     | 1     | cinnamic acid         | storax resin                | 1494759             | 25.83                  | 0.4470                 | 7.3806                 |
| 4296     | 2     | cinnamic acid         | storax resin                | 1276725             | 15.93                  | 0.4249                 | 5.3251                 |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 228932         | 2.86                   | 0.0762                 | 0.9549                 |
|          |       | methyl syringate      | honey                       | 158663              | 1.98                   | 0.0528                 | 0.6618                 |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 1614423       | 20.15                  | 0.5373                 | 6.7337                 |
|          |       | cedrol                | cedar oil                   | 2043677             | 25.50                  | 0.6601                 | 8.5241                 |
| 4295     | 3     | cinnamic acid         | storax resin                | 5288827             | 24.17                  | 0.3882                 | 26.9371                |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 97827           | 0.45                   | 0.0072                 | 0.4983                 |
|          |       | methyl syringate      | honey                       | 135629              | 0.62                   | 0.0100                 | 0.6908                 |
|          |       | moronic acid          | pistacia resin              | 4781078             | 21.85                  | 0.3510                 | 24.3510                |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 143789         | 0.66                   | 0.0106                 | 0.7323                 |
|          |       | masticadienoic acid   | pistacia resin              | 196814              | 0.90                   | 0.0144                 | 1.0024                 |
| 4293     | 4     | moronic acid          | pistacia resin              | 2566950             | 19.14                  | 0.3442                 | 18.8781                |
|          |       | masticadienoic acid   | pistacia resin              | 157914              | 1.18                   | 0.0212                 | 1.1613                 |
| 4323     | 5     | N/A                   | N/A                         | N/A                 | N/A                    | N/A                    | N/A                    |
| 4312     | 6     | cinnamic acid         | storax resin                | 41939               | 0.28                   | 0.2887                 | N/A                    |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 4251964       | 28.07                  | 29.2692                | N/A                    |
|          |       | methyl syringate      | honey                       | 539556              | 3.56                   | 3.7141                 | N/A                    |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 4528939       | 29.90                  | 31.1758                | N/A                    |
|          |       | cedrol                | cedar oil                   | 366042              | 2.42                   | 2.5197                 | N/A                    |
| 4304     | 7     | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 26747          | 2.14                   | 0.0662                 | 0.1174                 |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 1239199       | 100                    | 3.0650                 | 5.4391                 |
|          |       | cedrol                | cedar oil                   | 121888              | 9.84                   | 0.3015                 | 0.5350                 |
| 4307     | 8     | cinnamic acid         | storax resin                | 4379377             | 100                    | 5.4354                 | N/A                    |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 19364          | 0.44                   | 0.0240                 | N/A                    |
|          |       | methyl syringate      | honey                       | 208538              | 4.76                   | 0.2588                 | N/A                    |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 390542        | 8.92                   | 0.4847                 | N/A                    |
| 4321     | 9     | cinnamic acid         | storax resin                | 2442191             | 23.65                  | 0.2365                 | 12.2398                |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 573568       | 5.56                   | 0.0556                 | 2.8746                 |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 1018503      | 9.86                   | 0.0986                 | 5.1046                 |
|          |       | cedrol                | cedar oil                   | 196248              | 1.90                   | 0.0190                 | 0.9836                 |
| 4291     | 11    | cinnamic acid         | storax resin                | 245035              | 0.89                   | 0.0204                 | 1.7075                 |
|          |       | moronic acid          | pistacia resin              | 4975001             | 18.00                  | 0.4151                 | 34.6668                |
|          |       | masticadienoic acid   | pistacia resin              | 470967              | 1.70                   | 0.0393                 | 3.2818                 |
| 4322     | 11    | cinnamic acid         | storax resin                | 2021760             | 7.43                   | 0.0874                 | 2.5425                 |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 96850          | 0.36                   | 0.0042                 | 0.1218                 |
|          |       | methyl syringate      | honey                       | 105724              | 0.39                   | 0.0046                 | 0.1330                 |
|          |       | moronic acid          | pistacia resin              | 9005507             | 33.08                  | 0.3891                 | 11.3249                |
|          |       | masticadienoic acid   | pistacia resin              | 791283              | 2.91                   | 0.0342                 | 0.9951                 |
| 4313     | 12    | cinnamic acid         | storax resin                | 7282                | 3.19                   | 0.0319                 | 2.3597                 |
|          |       | cineole               | cyperus, mint, juniper berries, or cinnamon bark | 34235         | 14.99                  | 0.1499                 | 11.0936                |
| 4316     | 13    | cinnamic acid         | storax resin                | 19864640            | 100                    | 11.0822                | N/A                    |
| ARCHEM # | Jar # | Compounds of Interest | Possible Additive Source(s) | Absolute Abundance* | Relative Abundance (%) | Ratio to Tartaric Acid | Ratio to Syringic Acid |
|----------|-------|-----------------------|----------------------------|---------------------|------------------------|-----------------------|------------------------|
| 4305     | 15    | cinnamic acid         | storax resin               | 28785576            | 53.19                  | 12.5429               | 1.8623                 |
|          |       | cinnamic acid         | storax resin               | 28785576            | 53.19                  | 12.5429               | 1.8623                 |
|          |       | cinnamic acid         | storax resin               | 28785576            | 53.19                  | 12.5429               | 1.8623                 |
| 4306     | 16    | cinnamic acid         | storax resin               | 555136              | 16.48                  | 1.4170                | 0.7159                 |
|          |       | cinnamic acid         | storax resin               | 555136              | 16.48                  | 1.4170                | 0.7159                 |
|          |       | cinnamic acid         | storax resin               | 555136              | 16.48                  | 1.4170                | 0.7159                 |
| 4299     | 17    | cinnamic acid         | storax resin               | 1162478             | 24.84                  | 0.8915                | 7.8802                 |
|          |       | cinnamic acid         | storax resin               | 1162478             | 24.84                  | 0.8915                | 7.8802                 |
|          |       | cinnamic acid         | storax resin               | 1162478             | 24.84                  | 0.8915                | 7.8802                 |
| 4311     | 18    | cinnamic acid         | storax resin               | 577577              | 9.98                   | 0.3381                | 1.7616                 |
|          |       | cinnamic acid         | storax resin               | 577577              | 9.98                   | 0.3381                | 1.7616                 |
|          |       | cinnamic acid         | storax resin               | 577577              | 9.98                   | 0.3381                | 1.7616                 |
| 4302     | 20    | cinnamic acid         | storax resin               | 8975654             | 100                    | 18.9433               | 30.1102                |
|          |       | cinnamic acid         | storax resin               | 8975654             | 100                    | 18.9433               | 30.1102                |
|          |       | cinnamic acid         | storax resin               | 8975654             | 100                    | 18.9433               | 30.1102                |
| 4297     | 22    | cinnamic acid         | storax resin               | 14466863            | 100                    | 26.4827               | 3.1869                 |
|          |       | cinnamic acid         | storax resin               | 14466863            | 100                    | 26.4827               | 3.1869                 |
|          |       | cinnamic acid         | storax resin               | 14466863            | 100                    | 26.4827               | 3.1869                 |
**Table 3.** Cont.

| ARCHEM # | Jar # | Compounds of Interest | Possible Additive Source(s) | Absolute Abundance* | Relative Abundance (%) | Ratio to Tartaric Acid $\dagger$ | Ratio to Syringic Acid $\dagger$ |
|----------|-------|-----------------------|----------------------------|---------------------|------------------------|---------------------------------|-------------------------------|
| 4306     | 23    | cinnamic acid         | storax resin               | 583336             | 19.38                  | 0.7528                         | 2.3230                         |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 1616217         | 53.68                  | 2.0859                         | 6.4362                         |
|          |       | methyl syringate       | honey                      | 160411              | 5.33                   | 0.2070                         | 0.6388                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 2465266       | 81.88                  | 3.1816                         | 9.8174                         |
|          |       | cedrol                 | cedar oil                  | 1467052             | 48.73                  | 1.8933                         | 5.8422                         |
| 4308     | 24    | cinnamic acid         | storax resin               | 88711               | 3.25                   | 0.1013                         | 0.2318                         |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 2416827        | 88.51                  | 2.7604                         | 6.3146                         |
|          |       | methyl syringate       | honey                      | 212555              | 7.78                   | 0.2428                         | 0.5554                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 2090629       | 76.56                  | 2.3879                         | 5.4624                         |
| 4310     | 25    | cinnamic acid         | storax resin               | 8059                | 0.36                   | 0.0107                         | 0.0044                         |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 215071        | 9.49                   | 0.2844                         | 0.1183                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 2266978       | 100                    | 2.9880                         | 1.2471                         |
|          |       | cedrol                 | cedar oil                  | 1281799             | 56.54                  | 1.6952                         | 0.7051                         |
| 4298     | 26    | cinnamic acid         | storax resin               | 16405292            | 100                    | 13.8041                        | 42.6057                        |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 1974529        | 12.04                  | 1.6615                         | 5.1280                         |
|          |       | methyl syringate       | honey                      | 741031              | 4.52                   | 0.6235                         | 1.9245                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 3827611       | 23.33                  | 3.2207                         | 9.9406                         |
|          |       | cedrol                 | cedar oil                  | 254127              | 15.53                  | 0.2138                         | 0.6600                         |
| 4292     | 27    | cinnamic acid         | storax resin               | 243079             | 0.83                   | 0.0345                         | 0.4771                         |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 64891         | 0.22                   | 0.0092                         | 0.1274                         |
|          |       | methyl syringate       | honey                      | 104826              | 0.36                   | 0.0149                         | 0.2058                         |
|          |       | moronic acid          | pistacia resin             | 5290463             | 18.03                  | 0.7501                         | 10.3847                        |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 105802        | 0.36                   | 0.0150                         | 0.2077                         |
|          |       | masticadienoic acid   | pistacia resin             | 389893             | 1.33                   | 0.0553                         | 0.7653                         |
| 4314     | 28    | cinnamic acid         | storax resin               | 1701520             | 19.30                  | 2.1184                         | 2.8204                         |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 3946414        | 44.76                  | 2.1184                         | 2.8204                         |
|          |       | methyl syringate       | honey                      | 1578962             | 17.91                  | 0.8476                         | 1.1284                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 7184739       | 81.48                  | 3.8567                         | 5.1347                         |
|          |       | cedrol                 | cedar oil                  | 4705967             | 53.37                  | 2.5261                         | 3.3632                         |
| 4320     | 29    | cinnamic acid         | storax resin               | 894407             | 4.19                   | 0.2232                         | 1.2573                         |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 105494        | 0.49                   | 0.0263                         | 0.1483                         |
|          |       | caryophyllene          | cedar oil, mint, juniper berries, or cinnamon bark | 234542        | 1.10                   | 0.0585                         | 0.3297                         |
|          |       | methyl syringate       | honey                      | 200929              | 0.94                   | 0.0501                         | 0.2825                         |
|          |       | moronic acid          | pistacia resin             | 5538087             | 25.96                  | 1.3817                         | 7.7853                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 145885        | 0.68                   | 0.0364                         | 0.2051                         |
|          |       | masticadienoic acid   | pistacia resin             | 465817             | 2.18                   | 0.1162                         | 0.6548                         |
| 4301     | 31    | cinnamic acid         | storax resin               | 78383225            | 100                    | 59.8162                        | 123.3591                       |
|          |       | cineole                | cyperus, mint, juniper berries, or cinnamon bark | 3412391        | 4.35                   | 2.6041                         | 5.3704                         |
|          |       | oleanoic acid         | cyperus, pistacia resin, storax resin | 5089707       | 6.49                   | 3.8841                         | 8.0102                         |
|          |       | cedrol                 | cedar oil                  | 3385811             | 4.32                   | 2.5838                         | 5.3286                         |
| 4317     | 33    | cinnamic acid         | storax resin               | 2209658             | 43.96                  | 0.4396                         | 4.9602                         |
Table 3. Cont.

| ARCHEM # | Jar # | Compounds of Interest | Possible Additive Source(s) | Absolute Abundance* | Relative Abundance (%)† | Ratio to Tartaric Acid‡ | Ratio to Syringic Acid‡ |
|----------|-------|-----------------------|----------------------------|---------------------|-------------------------|------------------------|------------------------|
| cineole  |       | cyperus, mint, juniper berries, or cinnamon bark | 280319                  | 5.58                | 0.0558                  | 0.6292                 |
| Caryophyllene |      | cedar oil, mint, juniper berries, or cinnamon bark | 107570                  | 2.14                | 0.0214                  | 0.2415                 |
| Oleoic acid |      | cyperus, pistacia resin, storax resin | 560737                  | 11.16               | 0.1116                  | 1.2587                 |
| Cedrol   |       | cedar oil              | 41459                    | 0.82                | 0.0082                  | 0.0931                 |
| 4325     | 34    | Cinnamic acid         | storax resin             | 537645              | 1.98                    | 0.0959                 | 2.6960                 |
| methyl syringate |      | honey                  | 35184                    | 0.13                | 0.0065                  | 0.1764                 |
| Moronic acid |      | pistacia resin        | 3838164                 | 14.14               | 0.7105                  | 19.2463                |
| Oleoic acid |      | cyperus, pistacia resin, storax resin | 59010                | 0.22                | 0.0109                  | 0.2999                 |
| Mastichadenoic acid |   | pistacia resin         | 303105                  | 1.12                | 0.0561                  | 1.5199                 |
| 4319     | 35    | Cinnamic acid         | storax resin             | 246579              | 33.68                   | 0.5020                 | 0.4576                 |
| Cineole  |       | cyperus, mint, juniper berries, or cinnamon bark | 295643              | 40.38               | 0.6018                  | 0.5487                 |
| Caryophyllene |      | cedar oil, mint, juniper berries, or cinnamon bark | 46537               | 6.36                | 0.0947                  | 0.0864                 |
| Oleoic acid |      | cyperus, pistacia resin, storax resin | 150258              | 20.52               | 0.3059                  | 0.2789                 |
| 4318     | 36    | Cinnamic acid         | storax resin             | 2605220             | 8.05                    | 0.3289                 | 0.3513                 |
| Cineole  |       | cyperus, mint, juniper berries, or cinnamon bark | 3147852             | 9.73                | 0.3974                  | 0.4245                 |
| Caryophyllene |      | cedar oil, mint, juniper berries, or cinnamon bark | 888008             | 2.75                | 0.1121                  | 0.1197                 |
| Methyl syringate |      | honey                 | 240911                  | 0.74                | 0.0304                  | 0.0325                 |
| Moronic acid |      | pistacia resin        | 8034511                 | 24.84               | 1.0143                  | 1.0835                 |
| Oleoic acid |      | cyperus, pistacia resin, storax resin | 238757             | 0.74                | 0.0301                  | 0.0322                 |
| Masticadenoic acid |   | pistacia resin        | 338245                  | 1.05                | 0.0427                  | 0.0456                 |
| 4315     | 37    | Cinnamic acid         | storax resin             | 1296918             | 21.27                   | 1.3023                 | 0.4644                 |
| Cineole  |       | cyperus, mint, juniper berries, or cinnamon bark | 391683             | 6.42                | 0.3933                  | 0.1403                 |
| Oleoic acid |      | cyperus, pistacia resin, storax resin | 2582576             | 42.35               | 2.5933                  | 0.9248                 |
| Cedrol   |       | cedar oil              | 1654328                 | 27.13               | 1.6612                  | 0.5924                 |
| 4289     | Base  | Cinnamic acid         | storax resin             | 6555436             | 21.19                   | 1.8474                 | 47.7589                |
| Caryophyllene |      | cedar oil, mint, juniper berries, or cinnamon bark | 1308486           | 42.3                | 0.3688                  | 9.5328                 |
| Methyl syringate |      | honey                 | 228195                  | 0.74                | 0.0643                  | 1.6625                 |
| Moronic acid |      | pistacia resin        | 10566264                | 34.15               | 2.9777                  | 76.9794                |
| Oleoic acid |      | cyperus, pistacia resin, storax resin | 207828             | 0.67                | 0.0586                  | 1.5141                 |
| Masticadenoic acid |   | pistacia resin        | 333968                  | 1.08                | 0.0941                  | 2.4331                 |

*Peak area determined by integration in chromatograms.
†Percentage relative to maximum peak in a given chromatogram.
‡Ratio of compound of interest’s absolute abundance to organic acid’s absolute abundance.

doi:10.1371/journal.pone.0106406.t003

Acknowledgments

We gratefully acknowledge the volunteers and especially the senior staff of the Kabri Archaeological Project – N. Goshen, I. Samet, and A. Ratzlaff – for facilitating the study of the wine cellar. We are grateful as well to A. Koloski-Ostrow, C. Thomas, B. Snider, I. Epstein, C. Wade, I. Krauss, A. Crandall for facilitating access to the Brandeis University Department of Chemistry GC-MS laboratory and B. Foley of the Woods Hole Oceanographic Institution for helpful comments on ancient viticulture.

Author Contributions

Conceived and designed the experiments: AJK AY-L EHC. Performed the experiments: AJK. Analyzed the data: AJK. Contributed reagents/materials/analysis tools: AJK. Wrote the paper: AJK EHC AY-L.
References

1. Yasur-Landau A, Cline EH, Pierce GA (2008) Middle Bronze Age settlement patterns in the Western Galilee, Israel. J. Field Archaeol. 33: 59–83.
2. Cline EH, Yasur-Landau A, Goshen N (2011) New fragments of Aegean-style painted plaster from Tel Kabri, Israel. Am. J. Archaeol. 115: 245–261.
3. Yasur-Landau A, Cline EH, Goshen N, Marom N, Samet I (2012) An MB II orthostat building at Tel Kabri, Israel. B. Am. Sch. Oriental Re. 367: 1–29.
4. Palmer R (1994) Wine in the Mycenaean palace economy. Liége: Université de Liége.
5. Hamilakis Y (1996) Wine, oil and the dialectics of power in Bronze Age Crete: a review of the evidence. Oxf. J. Archaeol. 15: 1–32.
6. Wright JC (2004) The Mycenaean feast. Princeton: The American School of Classical Studies at Athens.
7. Brogan TM, Koh AJ (2008) Feasting at Mochlos? New evidence for wine production, storage and consumption from a Bronze Age harbor town on Crete. In: Hitchcock LA, Laffineur R, Crowley J, editors. Dai: the Aegean feast. Liége: Université de Liége.
8. Chambon G (2009) Les archives du vin à Mari. Paris: Société pour l’étude du Proche-Orient ancien.
9. Koh AJ, Betancourt PP (2010) Wine and olive oil from an Early Minoan I hilltop fort. Medit. Archaeol. Archaeometry 19: 13–23.
10. McGovern PE, Mirozaian A, Hall GR (2009) Ancient Egyptian herbal wines. PNAS 106: 7361–7366.
11. Stern B, Heron C, Tellefsen T, Serpico M (2008) New investigations into the Uluburun resin cargo. J. Archaeol. Sci 35: 2180–2203.
12. Barnard H, Dooley AN, Areshian G, Gasparyan B, Faull KF (2011) Chemical evidence for wine production around 4000 BCE in the Late Chalcolithic Near Eastern highlands. J. Archaeol. Sci. 38: 977–984.
13. Gerhardt KO, Searles S, Biers WR (1990) Corinthian Figure Vases: Non-destructive extraction and gas chromatography-mass spectrometry. In: Biers WR, McGovern PE, editors. Organic contents of ancient vessels: materials analysis and archaeological investigation. Philadelphia: MASCA Research Papers in Science and Archaeology 7.
14. Biers WR, Gerhardt KO, Braniff RA (1994) Lost scents: investigations of Corinthian “plastic” vases by gas chromatography-mass spectrometry. Philadelphia: MASCA Research Papers in Science and Archaeology 11.
15. Beeston RF, Palaimu J, Beck C, Stout EC (2006) Appendix M: organic residue analysis of pottery sherds from Chrysokamino. In: Betancourt PP. The Chrysokamino metallurgy workshop and its territory. Princeton: Hesperia Suppl. 36.
16. Guichard-Jane MR, Born-Gomez M, Andres-Lacueva C, Jauregui O, Lamuela-Raventos RM (2004) Liquid chromatography with mass spectrometry in tandem mode applied for the identification of wine markers in residues from ancient Egyptian vessels. Anal. Chem. 76: 1672–1677.
17. Skat TC (1974) Greek papyri in the British Museum, Volume VII, The Zenon Archive. London: British Museum.
18. Smithline H (2008) Results of three small excavations in Nahfi, Upper Galilee. ‘Atiqot 59: 87–101.
19. Klein BY, Ben-Yair C, Bar-Gal GK, Greenblatt CL (2008) Microsatellite genotyping of cultivars of the Holy Land grapevines, Vitis vinifera ssp. sativa (Vitaceae). Bot. J. Linn. Soc. 156: 513–521.
20. McGovern PE, Lalley BP, Rovira N, Mirozaian A, Gallahan M, et al. (2013) Beginning of viticulture in France. PNAS 110: 10147–10152.
21. Modugno FR, Ribecheini E, Perla Colombini M (2006) Aromatic resin characterization by gas chromatography-mass spectrometry: Raw and archaeological materials. J. Chromatogr. A. 1134: 298–304.
22. Namdar D, Gilboa A, Neumann R, Finkelstein I, Weiner S (2013) Cinnamaldehyde in early Iron Age Phoenician flasks raises the possibility of Levantine trade with South East Asia. Medit. Archaeol. Archaeometry 13: 1–19.
23. Tuberoso CI, Bifulco E, Jerkovic I, Caboni P, Caharas P, et al. (2009) Methyl syringate: a chemical marker of Asphodelus microcarpus Salzm. et Viv. (monofloral honey). J. Agric. Food Chem. 57: 3895–3900.
24. Manniche L (2006) An Ancient Egyptian Herbal. Austin: University of Texas Press.
25. Nazar A, Panitz-Cohen N (2007) It is the land of honey: Beekeeping at Tel Rehov. Near East. Archaeol. 70.4: 202–219.
26. Liphshitz N (2002) The Paleobotanical Remains. In: Tel Kabri: the 1986–1993 excavation seasons. Tel Aviv: Tel Aviv University.
27. Plutarch (c. 100) Moralia, 384B.
28. Bouchra C, Mohamed A, Mina IH, Hmamouchi M (2003) Antifungal activity of essential oils from several medicinal plants against four postharvest citrus pathogens. Phytopathol. Mediterr. 42: 251–256.
29. Prabuseenivasan S, Jayakumar M, Ignacimuthu S (2006) In vitro antibacterial activity of some plant essential oils. BMC Compl. Alternative Med. 6: 39.
30. Palaima TG (2004) Sacrificial feasting in the Linear B documents. Hesperia 73: 217–246.