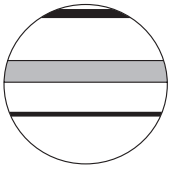

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Intentional, dual purpose of ancient wine presses as cisterns for runoff water harvesting in drylands

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Abstract

Rock-quarried wine presses were prevalent across the Mediterranean Basin throughout ancient times and particularly during the Late Roman and Byzantine ages. Archeological surveys have uncovered many presses across Israel. Overall, a ratio of ~5 m^{-1} has been recorded between treading floor area (in m^2) and volume of collecting vat (in m^3). A recent survey of two presses located at the transition zone between the semi-arid northern Negev, Judean Lowlands, and Southern Hebron Hills of Israel revealed a considerably smaller ratio between the treading floor and collecting vat. In addition, extensive rock exposures were located around the treading floors of the two presses. A 3D laser scanning revealed that the surrounding rock exposure formed a drainage network which flows to the treading floor. Moreover, indications for light modifications of the surrounding rock exposure were recorded for the two presses. In one of the presses, this modification was indicated by remnants of ancient plaster, which were found filling several gaps in the surrounding rock exposure. It is suggested that the purpose of the plaster was for allowing hydrological connectivity between the upslope and downslope edges of these gaps. In the second press, this modification included the chiseling of adjacent bedrock, for the purpose of, it is suggested, channeling runoff water to the treading floor. The findings suggest the intentional collection of raindrops falling on the surrounding rock exposure, together with those falling on the treading floor, which were drained as runoff into the collecting vat. The collected runoff could be used for domestic consumption in this dryland region, augmenting the provision of water for the local populations during the agricultural off-season.

Keywords

ancient agriculture, byzantine archeology, dryland inhabitation, human adaptation, source:sink ratio, viticulture

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Introduction

During the Byzantine age (4th to 7th century AD), the wine industry was a dominant economic sector in the eastern Mediterranean Basin (Avrutis, 2015), where Palestine filled a role as an important wine producer (Dray, 2015; Hadas, 2007b; Kingsley, 2003). Particularly, the northern Negev region, Judean Lowlands, and Southern Hebron Hills are abundant with archeological remains of vineyards and wine presses dated to the Byzantine age (Hadashot Arkheologiot – Excavations and Surveys in Israel, n.d.; Haiman, 2012; Mayerson, 1985; Figure 1). Since the mid-20th century, dozens of wine presses have been excavated by the Israel Antiquities Authority across this semi-arid region.

Wine production was conducted in designated presses. The local populations judiciously utilized the prevailing physical conditions of the northern Negev, Judean Lowlands, and Southern Hebron Hills for the installation of these presses. Despite many exceptions, it can be generally stated that wine presses along the Mediterranean coast were entirely or partially constructed above the ground surface, while those in the hilly or mountainous inlands were entirely quarried in the bedrock. Another difference is that while most of the presses on the coast have a relatively complex structure, a comparatively large portion of the inland presses have a simpler structure. An additional difference is the paving of treading floors and collecting vats with stone tablets that seal non-rocky surfaces and are therefore more characteristic of the shoreline presses (Hadashot Arkheologiot – Excavations and Surveys in Israel, n.d.).

Obviously, measures of the wine presses, including the treading floor, filtration basin, and collecting vat, are highly heterogeneous and primarily determined by the rock exposure dimensions (Aviam, 2004). Yet, a kind of generalization can be made, stating an overall common ratio between the treading floor (source area, in m^2) and collecting vat (sink volume, in m^3) (i.e. source:sink ratio, in m^{-1}). Among the 186 Late Roman and Byzantine wine presses found across present-day Israel, the mean area of treading floor is 12.4 m^2 and the mean volume of collecting vat is 2.4 m^3, yielding a mean source:sink ratio of 5.2 m^{-1} (Kingsley, 1999, 2002). A similar ratio of 5.5 ± 0.4 m^{-1} was also reported for 22 wine presses across the northern Negev, Judean Lowlands, Southern Hebron Hills, and Beer Sheba Valley (Hadashot Arkheologiot – Excavations and Surveys in Israel, n.d.). An additional ~40 wine presses have been surveyed across

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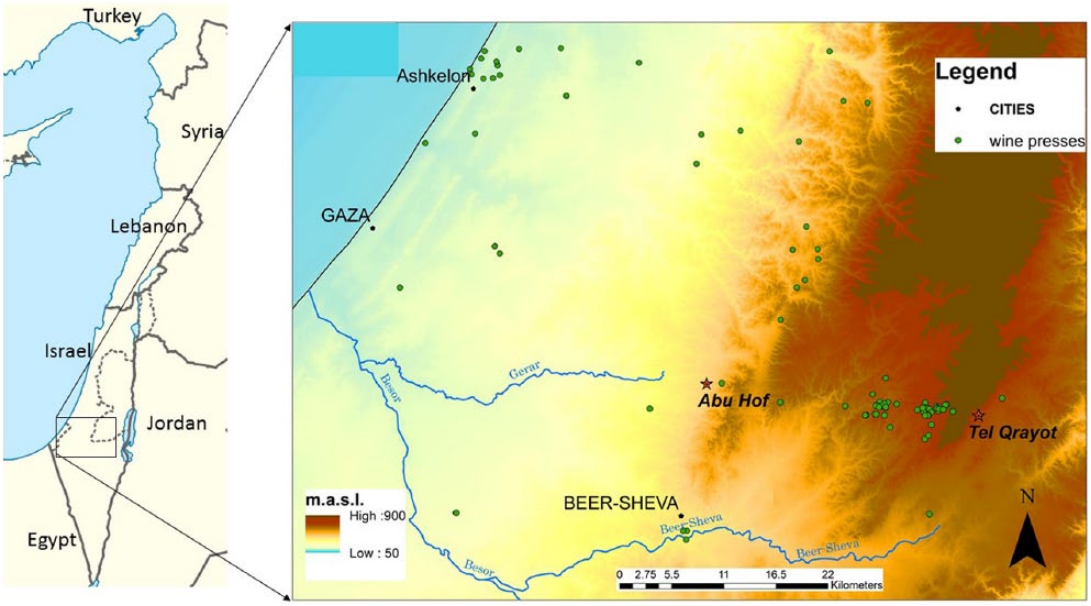

Figure 1. Map of Israel, with an extension of the study region.

the region but not excavated, negating the calculation of their source:sink ratio.

A recent visit to two wine presses at the Khirbet Abu Hof and Tel Qrayot sites, located at the transition zone between the northern Negev, Judean Lowlands, and Southern Hebron Hills, revealed their exceptionally large collecting vats, despite the regular area of the treading floors. Also, for the two sites, an extended rock exposure was found to surrounding the wine press, forming a seemingly large-area drainage basin, which – upon rainstorms – drains into the vat. The objective of this study was to seek possible reasons for the unusual features of these wine presses. The study's hypothesis was that the two wine presses were intentionally designed to be utilized as cisterns for the harvest of runoff water during the agricultural off-season.

Figure 2. The Khirbet Abu Hof wine press.

Materials and methods

Height of the northern Negev, Judean Lowlands, and Southern Hebron Hills ranges between 350 and 700 m.a.s.l. The region is defined as semi-arid, with mean cumulative annual precipitation ranging between approximately 300 mm in the north-western edge of the region and 100 mm in the south-east. Mean daily temperatures in the hottest (July) and coldest (January) months are 26°C and 11°C, respectively. Lithology is dominated by chalk of the Eocene and limestone of the Turonian, and the predominant soil type is Brown Rendzina.

The wine presses at Khirbet Abu Hof (31.38041 N, 34.83779 E, 371 m.a.s.l.; Figure 2) and Tel Qrayot (31.34985 N, 35.12390 E, 652 m.a.s.l.; Figure 3) and their surrounding rock exposures were analyzed via high-resolution, terrestrial 3D laser scanning technology (Arav et al., 2016) using the Leica ScanStation C10. The scanner's accuracy is ±2 mm in range measurement and ±12″ in angular measurement. Vertical and horizontal angular resolution was approximately 0.057°, with each scan consisting of 5.5 million points on average, spanning 360° horizontally and 90° vertically. To overcome topography and vegetation-induced occlusions, several scans (four to six) were taken on each site. On average, an area of 65,000 m^2 was covered by 25 million points with an average point density of 400 pts m^{-2} for each of the study sites.

Analysis of the drainage system in both sites was carried out by first assessing flow accumulation and then by computing the drainage basins. Flow accumulation revealed the drainage pattern within the system based on the underlying topography. This was computed under the premise that a drop of rain that falls in a given cell flows toward the neighboring cell whose surface gradient is the steepest (Jenson and Domingue, 1988; Tarboton et al., 1991). Therefore, gradient maps were computed, enabling the research team to trace the incoming and outgoing flow and to reconstruct the drainage pattern. Basins were computed based on the reconstructed drainage network, where for each sink the contributing region was extracted, thereby defining the individual basins.

Results and discussion

Description of the wine presses

An unusually small source:sink ratio was found for the Khirbet Abu Hof and Tel Qrayot wine presses. In the Khirbet Abu Hof press, a regular-size treading floor of 20.3 m^2 was found, disproportional to the extremely large collecting vat of 7.7 m^3, yielding a source:sink ratio of 2.6 m^{-1}. In the Tel Qrayot press, the treading floor area is 20.4 m^2 and the volume of the collecting vat is 9.9 m^3, yielding a source:sink ratio of 2.1 m^{-1}.

Careful surveying of the wine presses at Khirbet Abu Hof and Tel Qrayot dated them to the Byzantine era. In the Khirbet Abu Hof site, this was identified by the square mortice (a rectangular depression) in the treading floor, known to be utilized during the Byzantine time as a base for a vertical wooden screw. Together with a round stone base, the screw was utilized for pressing must

Figure 3. The Tel Qrayot wine press.

(grape juice) from the trodden grapes, which were put inside a rope wound around the screw and pressed by turning and lowering a wooden nut installed on the screw (Ayalon et al., 2012; Frankel, 1997, 1999; Lewit, 2012). In the Tel Qrayot site, the location of a rectangular stone base, laid on the ground a couple of meters downslope of the wine press, suggested the use of this technique for this site as well.

In addition to the exceptionally small source:sink ratio, while surveying the two wine presses, we found another irregular feature at both sites. This encompassed extended rock exposures next to the wine press, stretching beyond the rims of the treading floor to form a drainage basin, with the seeming draining direction pointing toward this floor.

Results of 3D laser scanning of the wine presses are shown for Khirbet Abu Hof (Figure 4a) and Tel Qrayot (Figure 5a) sites. The reconstructed drainage network (Figures 4b and 5b, respectively) shows how flow is channeled into the treading floor and the collecting vats. The computed basins (Figures 4c and 5c, respectively) further demonstrate the concept of drainage channeling into the treading floor and the collecting vats, allowing the calculation of the contributing source area. The area of the upslope non-anthropogenically modified rock exposure for Khirbet Abu Hof and Tel Qrayot was found to be ~47 and 96 m^2, respectively. If the areas of the treading floor and of the upslope adjacent rock exposure are added together, then the total water runoff drainage area is ~67 m^2 in Khirbet Abu Hof and 116 m^2 in Tel Qrayot, yielding a source:sink ratio of 8.7 and 11.7 m^{-1}, respectively.

Interpretation of the utilization of the wine presses

For the Khirbet Abu Hof site, our suggestion of dual use was further supported by the finding of remnants of ancient plaster, filling 14 gaps (with a total aerial surface of ~11 m^2) in the surrounding rock exposure (see pale-brown patches in the adjacent rock exposure in Figure 2). It is proposed that the plaster was made by the ancient people to enable hydrological connectivity between the upslope and downslope edges of these gaps, allowing the water runoff to flow from a maximum surface area in the surrounding rock exposure to the treading floor, and eventually, to the collecting vat. For the Tel Qrayot site, the chiseling in the adjacent bedrock is notable, visibly shown in the laser scans (Figure 5b inset), whose aim, it is suggested, was to channel runoff water to the treading floor. Therefore, the results of this study reveal light anthropogenic modifications in the surroundings of the two presses, aimed at maximizing hydrological connectivity between the upslope rock exposure and treading floor. To some extent, this accords with previous studies, which highlighted the importance of microtopography in determining hydrological connectivity (Lesschen et al., 2009; Mayor et al., 2008).

These findings confirm the concept of an intentional, dual purpose for these two specific wine presses. We propose that similar to many other wine presses across the northern Negev, Judean Lowlands, Southern Hebron Hills, and elsewhere, these ones were utilized as wine presses during the grape harvest season, which potentially extended (depending on climatic conditions and cultured grape variety) between June and September. At the same time, in accordance with the study hypothesis, the obtained results propose that during the rainy season (October to March: the agricultural off-season), these specific two wine presses were utilized as cisterns for water runoff harvest for domestic use. To some extent, our suggestion accords with Dray (2015), who mentioned that there must be a reasonable ratio between the surface of the treading floor and the volume of the collecting vat.

Calculation of potential water volume collected in the vats of the two wine presses, according to annual cumulative precipitation rates, was conducted according to Eq. 1 (based on a more generic version of an equation, provided by Stavi et al., 2017).

$$V_w = \left(\left(A / a\right) \times \left(C_r \times R_A\right) + R_A\right) \times a \quad (1)$$

where V_w is the volume of water in the sink (m^3), A is the source area (m^2), a is the sink area (m^2), C_r is the runoff coefficient, and R_A is the rainfall depth (m).

Mean annual cumulative precipitation rates were obtained from the Israel Meteorological Service website for the nearest meteorological stations, namely, Lehavim (31º37′ N, 34º81′ E; 308 m.a.s.l.: 244 ± 19 mm, for the years 2000–2013), for the Khirbet Abu Hof site, and Arad (31º25′ N, 35º20′ E; 603 m.a.s.l.: 133 ± 15 mm, for the years 2003–2016) for the Tel Qrayot site. Four assumptions were made for this calculation: (1) precipitation regimes during the Byzantine era were generally similar to those at present (Avni et al., 2013); (2) upper and lower values for annual precipitation rates were set according to the maximal variability of 25% in interannual rainfall depth, which defines semi-arid regions (Bruins and Lithwick, 1998); (3) C_r was selected as representative for the prevailing bedrock types across the region, ranging between 0.25 and 0.65 (Yair and Kossovsky, 2002); and (4) C_r for plaster – which used to be utilized for reducing the roughness of treading floors and decreasing leakage of must in ancient wine presses (Avrutis, 2015) – was at least similar to that of (concrete (C_r of 0.46–0.69; Li et al., 2004), or) the bedrock types which define the study region.

Using this equation revealed that according to the possible combinations of annual precipitation rates and C_r, the potential annual water volume accumulated in the collection vat ranges between 3.9 and 11.9 m^3 for Khirbet Abu Hof and between 2.8 and 9.0 m^3 for Tel Qrayot. According to these combinations, this volume of water for Khirbet Abu Hof ranges between 50% and 154% (or 59% and 136% for the mean precipitation rate) of the volume of collecting vat. This ratio indicates the potential filling of the vat by the collected runoff water + direct rainfall during the rainy season. Implementing the same calculation for Tel Qrayot revealed a ratio ranging between 29% and 91% (or 33% and 80% for the mean precipitation rate; Table 1). For both the wine presses, the relative similarity in size-order of volumes of (potential) water and vat confirms our theory that they had an intentional, dual purpose. Regardless, it is also assumed that throughout the rainy season, at least some of the collected water was lost through: (1) evaporation, (2) leakage through the vat's plaster layer, and (3) utilization for domestic consumption. The water lost vacated some of the vat's volume, which was refilled during the same rainy season with water from later rainstorms and runoff events.

Challenges and solutions

While proposing the dual-purpose concept, we still acknowledge the scientific debate about the mode of operation of wine presses during the Byzantine period. According to one approach, the vat

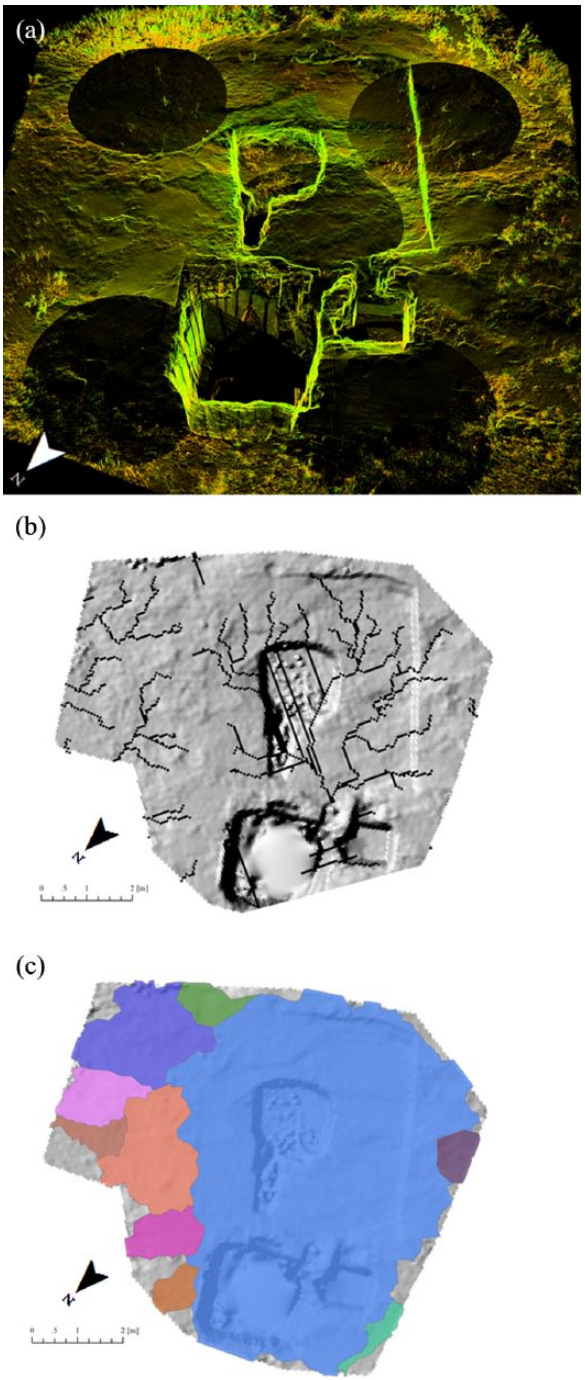

Figure 4. Laser scanning and basin-related analysis of Khirbet Abu Hof: (a) 3D point cloud from the scan, (b) drainage network overlaid on top of a hillshade map that was derived from the scan, and (c) computed basins around the wine-press site.

usage was limited to the collection of must, which was transferred immediately after press to clay jars for off-site fermentation. Regardless, it has also been suggested that under certain occasions, initial fermentation could have taken place in the treading floor (after temporarily blocking the trough between the treading floor and filtration basin; Ayalon et al., 2012). Following the time span of this initial fermentation, the partially fermented liquid was let to flow to the collecting vat, from where it was taken to secondary fermentation in jars (Hadas, 2007a, 2007b). According to another approach, the must was left to on-site fermentation in the collecting vat (Ayalon et al., 2012; Frankel, 2009). One way or another, it is also acknowledged that in order to allow uniform fermentation, no more than a single batch of must was left to ferment at a time in the same volume unit (Ayalon et al., 2012;

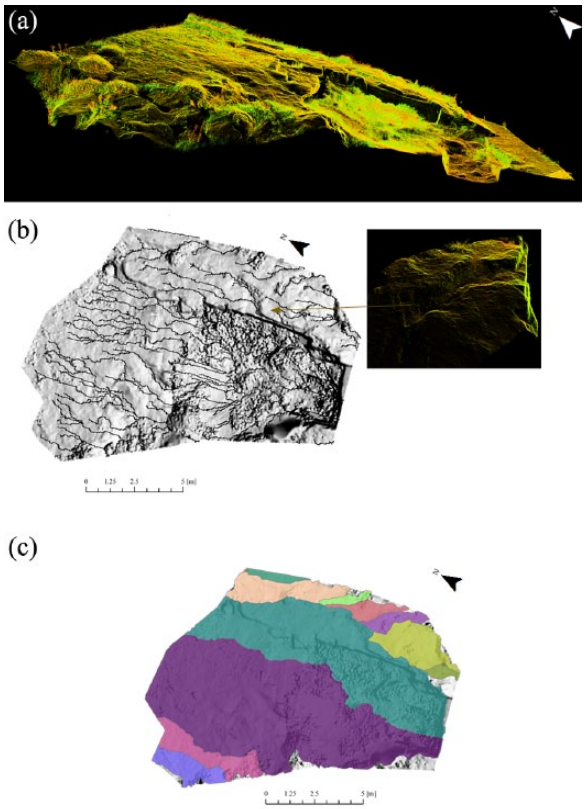

Figure 5. Laser scanning and basin-related analysis of Tel Qrayot: (a) 3D point cloud from the scan, (b) drainage network overlaid on top of a hillshade map that was derived from the scan, and (c) computed basins around the wine-press site.

Frankel, 1999). This negates the possibility of quarrying an unusually large collecting vat for the accumulation of must produced over several consecutive days.

Also, we acknowledge the proposition of using upper level secondary floors, next to the treading floor, for the storage of grapes brought in from the vineyards. It was suggested that the aim of these upper floors was to regulate the timing of the processing of grapes brought from different farms or originating from vines of different varieties (Ayalon et al., 2012). Another possible purpose was to allow pre-fermentation of grapes for the production of high-quality must. This must was self-extracted from the grapes, without pressing, and drained to the treading floor or to secondary, small collecting vats (Ayalon et al., 2012; Dray, 2015). We agree that this practice could explain the quarrying of wine presses in sites with extensive rock exposures, such as the Khirbet Abu Hof and Tel Qrayot. Furthermore, this practice could also explain the plaster filling the gaps in the rock exposure around the treading floor at Khirbet Abu Hof, as well as the chiseling in bedrock next to the treading floor at Tel Qrayot. At the same time, this practice could not explain the disproportionally small ratio between the area of treading floor and volume of collecting vat, which was recorded for the two wine presses.

Therefore, our findings suggest that the dual use of these ancient wine presses was planned in advance for intentionally increasing their effective, year-round utilization. This contradicts the prevalent concept, according to which some of the wine presses could have enabled incidental and unintentional uses – such as cisterns (Dagan, 2011; Pfann et al., 2007), tombs, or storage caves – after the cessation of the original purpose (Dagan, 2011). We claim that in drylands, whenever allowed by the rock exposure's features, including parent material type, aerial surface, depth of solid rock layer, and topographic location, such a dual purpose was taken into consideration during the quarrying of

Table 1. Wine-press structural characteristics, regional climatic conditions, and calculation of potential water volume collected in the vat at the Khirbet Abu Hof and Tel Qrayot sites.

		Khirbet Abu Hof			Tel Qrayot	
Source area (m^2)[a]		67			116	
Vat area (m^2)		4.4			5.3	
Vat volume (m^3)		7.7			9.9	
Source area/vat volume (m^{-1})		8.7			11.7	
Reference evapotranspiration (mm yr^{-1})[b]		1500–1600			1900–2000	
Annual precipitation rate (mm)[c]	214	244	275	116	133	150
Aridity index (P/ETP)[d]	0.13–0.14	0.15–0.16	0.17–0.18	0.06	0.07	0.07–0.08
Potential water volume in vat (m^3)	3.9–9.1	4.5–10.5	5.2–11.9	2.8–6.9	3.3–8.0	3.8–9.0
Potential water volume/vat volume (ratio)	0.50–1.18	0.59–1.36	0.67–1.54	0.29–0.70	0.33–0.80	0.38–0.91

[a]Including the treading floor and the upslope adjacent rock exposure.
[b]Data obtained from the Israel Meteorological Service (n.d.).
[c]Based on data obtained from the Israel Meteorological Service (n.d.) for the years 2000–2013 for Lehavim (nearest meteorological station to Khirbet Abu Hof) and 2003–2016 for Arad (nearest meteorological station to Tel Qrayot). Range of precipitation is based on the assumption of up to 25% variability in annual precipitation rates in semi-arid regions (Bruins and Lithwick, 1998).
[d]Equals the precipitation (P) divided by the reference evapotranspiration (also named potential evapotranspiration (ETP); Bruins and Lithwick, 1998).

wine presses. Under these circumstances, light modifications of the rock exposure surrounding the press might have been needed for maximizing hydrological connectivity with the treading floor. Yet, we do not propose that this intentional, dual purpose was mandatory, even when the prevailing physical conditions allowed such a practice. Regardless, while such a practice is more relevant for arid and semi-arid regions, it could potentially be implemented also in dry-sub-humid and sub-humid regions.

Conclusion

Intentional use of two Byzantine wine presses as cisterns for accumulating runoff water during the agricultural off-season proposes the sophisticated utilization of the prevailing physical settings by the ancient, local peoples, allowing them to maximize the benefits gained from the natural conditions. This was evident from two indicators: (1) a disproportionally small ratio between area of treading floor and volume of collecting vat and (2) physical evidence of light, anthropogenically made modifications in the vicinity of presses, aimed at increasing hydrological connectivity between the surrounding rock exposure and treading floor. Particularly, the findings demonstrate an advanced adaptation strategy for inhabitation of drylands in ancient times.

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