



Past grapes, present insights: an investigation of grape use in Roman north-eastern Iberia using geometric modern morphometrics (GMM)

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Abstract

The cultivation and uses of *Vitis vinifera* L. (grapevine) during the Roman period are known from both ancient sources and archaeobotany, in which various methods have been used to distinguish between wild and domesticated subspecies. The present analysis uses Geometric Modern Morphometrics (GMM), taking as a case study the Roman town of Iesso (modern Guissona, Catalonia, Spain) to shed new light to these issues. Five wells dated from the first century BCE to the fifth century CE with waterlogged material were excavated in Guissona, from which a large number of grape pips have been recovered and studied to identify whether the grapes were wild or domesticated, as well as which of the distinct groups of domesticated varieties. The results of this study indicated a significant number of wild type grapes, which are explained by the climatic conditions at this time, which may have prompted the inhabitants of the area to grow grapevines with genotypes closely related to the hardier wild subspecies, together with the market demand of the period and local taste preferences. Finally, among the domesticated grapes identified from Guissona, varieties suitable for wine making appear to be predominant, with the Balkan variety group being the most common.

Keywords Geometric modern morphometrics (GMM) · *Vitis vinifera* · Grapevines · Iberian peninsula · Iesso · Roman period

Introduction

Viticulture, grape consumption and wine making were very important in Roman times as shown both by archaeobotanical results (for example, Peña Cervantes 2010; 2020;

Thurmond 2017) and historical references (for example, Pliny the Elder, *Natural History*; Columella, *De Re Rustica*). Wine consumption was part of everyday life for people throughout the Roman empire and held a special place in various rituals and ceremonies (Thurmond 2017, p 218). It was also an essential part of legionaries' lives, and they took this habit with them to various Roman colonies, thereby boosting both the wine trade and local production (Thurmond 2017, p 218). As early as the second century and particularly during the 1st c. BCE, the large-scale production of amphorae for exporting wine from Italy to other parts of the Roman Empire demonstrates the extent of the wine trade (Laubenheimer 2013, p 99). Amphorae found in various shipwrecks testify to the amount of wine transported during the Roman period. Taking the shipwrecks found near Italy as an example, some appear to have carried a small number of amphorae containing wine (for example Cavalière, Var), while others appear to have carried up to 10,000 (for example Albenga; Laubenheimer 2013, p 103).

In the Iberian Peninsula, there are finds of *Vitis* sp. from prehistoric times (for example, Buxó 1997; Ramil Rego

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and Aira Rodríguez 1993; Burjachs 2012) and vine charcoal and grape remains have been found at various prehistoric sites across the peninsula, suggesting that grapes were indigenous, collected for consumption, but not in a systematic way (Buxó 2008; Alonso et al. 2016). Systematic consumption of grapes and wine production seem to have only developed from the Iron Age onwards, particularly following the arrival of the Phoenicians in the 1st millennium BCE who also brought along new techniques for wine making as well as for the growing of a great variety of fruits and nuts (Pérez-Jordà 2000; Peña Cervantes 2010, p 153; Pérez-Jordà et al. 2021). The establishment and then expansion of viticulture spread unevenly from south to north (Alonso and Pérez Jordà 2019, p 52). In our study area in the northeast of the Iberian Peninsula, remains of *Vitis* sp. appear from as early as the 7th–6th c. BCE in most areas (for example between 675 and 625 BCE in Sant Martí d'Empúries; Buxó 1999), except in Vallès and the Llobregat river valley, where evidence dates to the 5th c. BCE (Pérez-Jordà et al. 2021, pp 13, 15).

Later, in the Roman period, further regional differences in grape distribution have been revealed by archaeobotanical studies, with more evidence of *Vitis* sp. in the north and dominance of *Olea europaea* L. (olive) in the south of Iberia (Peña-Chocarro et al. 2019). In the northeast, the second most common category of plant remains identified after cereals is fruit, with grapes being the most ubiquitous (Peña-Chocarro et al. 2019, Figs. 2 and 4).

Wine production and export thrived during the Roman period, and in particular during the late Republic (146–31 BCE) wine exports from the Italian Peninsula grew significantly, which coincided with a change there from small farms to commercial villas with presses (Van Limbergen 2020). However, by the reign of Augustus (27 BCE–14 CE), the wine trade from there declined (Panella 2010). In the 1st c. CE, parts of the Iberian Peninsula, especially the provinces of Baetica and Tarraconensis, became specialised in producing wine (Étienne and Mayet 2000, p 11), together with other products like olive oil and fish-based *garum* for export (Pavón Torrejón 2019; Keay 1987, 383). Iberian wine exports to other parts of the Roman Empire peaked between the 1st c. BCE and 2nd c. CE (Carreras Monfort in press). Trade data for the Iberian Peninsula between the second and fourth centuries CE are limited (Pavón Torrejón 2019). However, by the early 3rd c., imperial intervention in trade decreased and internal trade within Iberia appears to have grown, with products from various provinces circulating there (Keay 1988, pp 106–107). It has been suggested that the export of wine from the peninsula decreased from the 3rd to the 5th c. CE, since the overall production and presence of amphorae from that period was limited (Carreras Monfort in press), while it is also possible that exports

could have been made using more perishable containers than amphorae, such as wooden and leather containers that are not usually found archaeologically. New regional studies, however, have indicated that this general pattern may, in reality, be more variable. For instance, a recent pollen study in Lisbon has shown that the amount of *Vitis* pollen increased from the 3rd c. CE onwards, while at the same time there was an increase in the production of amphorae there for wine export (Currás et al. 2021). Therefore, both the scale of wine production and export in Iberia is a complex issue, which seems to follow different patterns in each region.

To better understand these processes, there has been a proliferation of studies on the grapevine, its domestication status and diversification through time and space, with the application of a variety of methods to grape pips (breadth-to-length ratio, Stummer 1911; use of distance measurements in discriminant analysis, Mangafa and Kotsakis 1996; traditional morphometric features, Ucchesu et al. 2016; Coradeschi et al. 2023), including Geometric Modern Morphometric analysis (GMM) which has achieved the most significant results to date (Pagnoux et al. 2015; Bouby et al. 2021).

These studies (such as Bonhomme et al. 2021; Ucchesu et al. 2024, 2025) have indicated that as late as the Roman period, wild varieties of grapes were still being grown, sometimes widely. In fact, the process of grape domestication remains a subject of debate, with the most recent studies suggesting that it was slow (for example Bouby et al. 2013; Ucchesu et al. 2025). The region where the domestication of grape is thought to have begun is in the Middle East and the Caucasus at some point between 6000 and 3000 BCE (Zohary et al. 2012; Bouby et al. 2021). Some of the earliest genetic studies have suggested the presence of secondary centres of domestication in both Italy (Grassi et al. 2003) and the western Mediterranean (Arroyo-Garcia et al. 2006; Cunha et al. 2020). However, several recent genetic studies suggest that domestication occurred in western Asia (Freitas et al. 2021; Magris et al. 2021; Dong et al. 2023) and that during the Bronze Age through to the Classical period, the grapevine spread to the Mediterranean (McGovern 2003).

Despite the fact that a number of studies have been done on the domestication of the grape, there are still many gaps in the reconstruction of this process, while in the case of the Iberian Peninsula, and especially its northeastern part, this is still largely unknown. This paper, therefore, aims to add to these studies by investigating the history of grapes in this area using as a case study one of the best suited sites for this, the Roman town of Ilesso, now Guissona, Catalonia, Spain (Fig. 1). Excavations in the town have provided particularly large quantities of well-preserved grape pips recovered in waterlogged conditions, a very rare type of preservation



Fig. 1 The position of Ileso in the Iberian peninsula (by Institut Cartogràfic i Geològic de Catalunya ICGC), licensed under CC BY 4.0)

in the Iberian Peninsula. The objectives are to investigate the diversity of cultivated grapes in this region during the Roman period and early Late Antiquity (ca. 120 BCE–550 CE) through GMM analysis, to provide new insights into the growing and consumption of grapes and their by-products, and finally to contribute to the ongoing debate on grape domestication and cultivation while offering new insights into the Roman economy, trade links and the development of tastes.

The site

Ileso was founded in 120 BCE and occupied until at least the 7th c. CE. A particular and rare feature for the Iberian Peninsula is the waterlogged conditions that were found in parts of the site, which gave excellent preservation of the archaeobotanical material. Specifically, the site had five wells (Fig. 2), which all preserved waterlogged material and were completely excavated. All the sediment was collected

from the point where waterlogged material appeared at the bottom of each well, revealing numerous grape remains among other plant remains. These five wells had different periods of use and were in different contexts. Wells 1 and 2 were close to each other and were situated in a public space within a residential area (Buxó et al. 2004). Well 3 was situated within a house (*domus*) and its construction was contemporary with the last renovation phase in the mid 2nd c. CE, and it then had a second period of use in the 5th c. CE, according to the pottery found in the abandonment layers inside the well (Guitart Duran 2007). It is likely that this secondary use was connected with a nearby wine press (Uscatescu 2004). Well 4 was in an area outside the walls, close to a structure that was possibly an inn (Romaní et al. 2022). Finally, Well 5 was within the garden area of the public baths (Guitart Duran et al. 2023). Each well has a distinct chronology, ranging from the 1st c. BCE to the 5th c. CE (Table 1; for details about the excavation and the recovery of the archaeobotanical material, see Buxó et al. 2004; Baniou et al. 2025). The dominant group of plant remains recovered from all the wells was fruit, with *Vitis vinifera* L. (grape), *Ficus carica* L. (fig) and *Sambucus nigra* L. (elder) being the commonest, with various other cultivated and wild plants, such as *Prunus avium/cerasus* (sweet/sour cherry), *Prunus persica* (L.) Batsch (peach), *Juglans regia* L. (walnut) and various berries together with a few cereals and legumes (Baniou et al. 2024a; 2024b, 2025). It should be noted that the numbering of the wells is based on the order in which they were found and not on the chronological order in which they were used or excavated.

Fig. 2 Aerial view of the site showing the position of the wells and the wine press (photo by Ileso team)



Table 1 The contexts and the origins of the samples; the wells are in chronological order

Well	Spatial position	Year of excav.	Chronology of well (construction- abandonment)	Date of layers with pips	Initial samples per layer	Samples with good preservation per layer	Total nos of pips	Type of preservation
2	Residential area	2000	1st half 1st c. BCE–2nd half 1st c. BCE / 1st half 1st c. CE	Mid 1st c. BCE	Layer 5: 206	Layer 5: 191	191	Waterlogged
5	In the garden area of the public baths	2021	End of 1st c. BCE/first decades 1st c. CE–mid 1st c. CE	Mid 1st c. CE	Layer 1: 1 Layer 2: 36 Layer 3: 150 Layer 4: 150	Layer 1: 1 Layer 2: 18 Layer 3: 125 Layer 4: 102	246	Waterlogged
1	Residential area	2000	1st c. CE–2nd half 2nd c. CE	2nd half 2nd c. CE	Layer 4: 153 Layer 5: 94	Layer 4: 141 Layer 5: 79	220	Waterlogged. Layer 5: dried out during storage
4	Outside of the walls, in the open space of an inn	2017	Mid 1st c. CE–end of 2nd c. CE/beg. 3rd c. CE	end 2nd c. CE/ beg. 3rd c. CE	Layer 5: 200 Layer 6: 200 Layer 7: 183	Layer 5: 178 Layer 6: 190 Layer 7: 169	537	Waterlogged
3	<i>Domus</i> (house)	2023	Mid 2nd c. CE–5th c. CE	5th c. CE	Layer 4: 50 Layer 5: 78 Layer 6: 92	Layer 4: 40 Layer 5: 61 Layer 6: 66	167	Waterlogged

Materials and methods

Samples and sample preparation

The samples of grape pips came from all five wells in the Roman town of Iesso (Table 1). To ensure statistical reliability of the data, as many grape pips as possible per layer were randomly selected, with an initial maximum of 200 pips per layer. Where fewer pips were available, all of them were used (Table 1). In order to ensure a random selection of samples, the following procedure was followed: all available pips from Wells 1, 2 and 3 were used. The pips from Wells 4 and 5 had been stored after the sorting and identification process in various bottles filled with water, depending on the well and layer. An equal number of pips were taken from each bottle randomly, regardless of their shape. The only selection criteria were that they were well preserved and undamaged when checked under the microscope.

All the grape pips were kept in water. However, in the case of the pips from layer 5 of Well 1, the water had evaporated during the long-term storage, and this resulted in the drying out of these samples. After photographing the pips, their shape and length were checked and corrected. The morphometric analysis showed no specific alteration of the pips from Layer 5 compared to those from Layer 4 of Well 1 or the other pips that had been kept wet, so it was decided to include these dried out samples in the final analysis. Only well-preserved whole specimens without breaks or cracks were selected for analysis. The samples from Well 3 used in this study are dated to the second phase of the use of the well. All samples are dated from when the wells were filled, except for well 2, where the samples are dated

**Fig. 3** Examples of badly preserved pips excluded from the analyses

between the last phase of use of the well and the moment of its backfilling.

Image and outline acquisition

Each pip was placed on a blue background and photographed in dorsal and lateral views using an Olympus SZ-ET stereomicroscope and an Olympus DP camera, at the Institut des Sciences de l'Évolution de Montpellier (ISEM). The magnification was 3× and the resolution 1,224×960 pixels for all samples. The images were then converted into black silhouettes (masks) on a white background using Adobe Photoshop v. 24.7.0.

The morphology of grape pips preserved in waterlogged conditions may be altered, particularly in the pointed end of the pip (beak hereafter) (Bouby et al. 2023). All images, therefore, were checked manually to identify specimens with features that could alter the outline analysis. In some of the specimens the beak had become markedly conical, giving the pip a triangular outline. All such damaged seeds were excluded from the analysis (Fig. 3). Of the total pips photographed ($n=1,527$), 89.1% were well preserved and were included in the analysis.

Geometric modern morphometrics (GMM)

The method of outline analysis used elliptic Fourier transforms (EFT) following Terral et al. (2010), Pagnoux et al. (2015) and Bouby et al. (2018). EFT relies on breaking down the outline into a sequence of trigonometric functions, referred to as harmonics. Each harmonic corresponds to four coefficients, which form an ellipse in outline. For this study the method described by Bouby et al. (2024) was followed. The morphometric analyses were done using Manova multivariate analysis in the R environment (RStudio, v. 2024.04.2+764). For each mask, the coordinates (x, y) of 360 equidistant points were sampled along the curvilinear abscissa on each outline. In addition, two landmarks placed at the tips of the pips were added to each image using Image J v. 1.54 k. These landmarks were then used to standardize the position, size, rotation and starting point of the outlines.

Only the five first harmonics for each outline were used, to maximize the shape accuracy of the reconstruction, including more than 95% of the total harmonic power, while minimizing measurement error. EFT was computed separately for each view, and the resulting coefficients were merged into a single matrix. Each pip was ultimately described by 40 coefficients (2 views $\times$ 5 harmonics $\times$ 4 coefficients per harmonic), which were used as quantitative variables in the subsequent statistical analyses.

The length of the pip was calculated numerically from the two aligned pip views, averaging the values from both of them, and calculating it from the outline coordinates, following Bonhomme et al. (2021). Pip length is used as a proxy for size, thereby aiding in the analysis of form, which includes both shape and size.

Quantitative and statistical procedures

Principal component analysis (PCA) was carried out on the raw EFT coefficients obtained from the grape pips to explore differences within the assemblage. Previous studies (Terral et al. 2010; Pagnoux et al. 2015) have indicated that morphometric analyses based on EFT for grape pips allow the discrimination between wild and domesticated grapes, and also groups of varieties (parental and eco-geographical groups) (Bonhomme et al. 2021; Bouby et al. 2024). Comparative analyses of archaeological grape pips and modern reference material in the collection available at ISEM (Bouby et al. 2021; 2024) were done with Linear Discriminant Analysis (LDA). LDA is a statistical method which explains and classifies observations into predefined groups according to predictive variables (Bouby et al. 2021).

Two datasets of predictive variables were used, (1) raw EFT coefficients and (2) EFT coefficients and length

measurements (EFT+L), corrected for taphonomic effects (Bouby et al. 2024). As archaeological material is subject to changes depending on the type of preservation, in this study the shape and length of each pip was adjusted, following the methodology based on experimental work by Bouby et al. (2023).

Here, LDA was used to classify the status of the pips (wild or domestic) and the variety groups, based on a grouping into four Usage and Regional Groups (URG) as established by Laucou et al. (2018) and Dong et al. (2023). The following four groups are distinguished: (1) eastern table grape cultivars, (2) wine cultivars originating from the Balkans, (3) wine cultivars from western Europe and (4) wine - table grapes from the Iberian Peninsula (Laucou et al. 2018; Bonhomme et al. 2021; Dong et al. 2023; Bouby et al. 2024).

It is important to note that the model used in this study was trained to recognise these four main groups, which incorporate the vast majority of the known diversity of cultivated vines (Bonhomme et al. 2021; Bouby et al. 2024). The procedure for the classification of the grape pips was as follows: each archaeological pip was first characterized according to its status (wild vs. domesticated) using 100 balanced LDAs. With 100 predictions per pip, the majority result (≥ 51) was considered to determine the final classification (Bouby et al. 2024). Then, all the archaeological pips assigned to the domesticated type entered a second round of 100 balanced LDAs to assign them to one of the four URGs by comparing them with the modern database (Bonhomme et al. 2021).

Results

Differences in shape by principle component analysis

First, the internal variability in the shapes and forms of the pip samples can be shown by first comparing the archaeological samples from all the wells only with each other (Fig. 4). Statistical analysis indicates a substantial difference between the wells (p -value ($PR(>F)$) = $2.2e-16$), which suggests the presence of pips of different shapes within each well. As expected, no bias has been detected in the pips from layer 5 of Well 1, as the measurements were corrected and the results are consistent with those from the other layers and wells.

Wild versus domesticated morphotypes

The second step of the analysis involved a comparison between archaeological and modern samples of wild and domesticated types; the exact numbers of pips allocated to

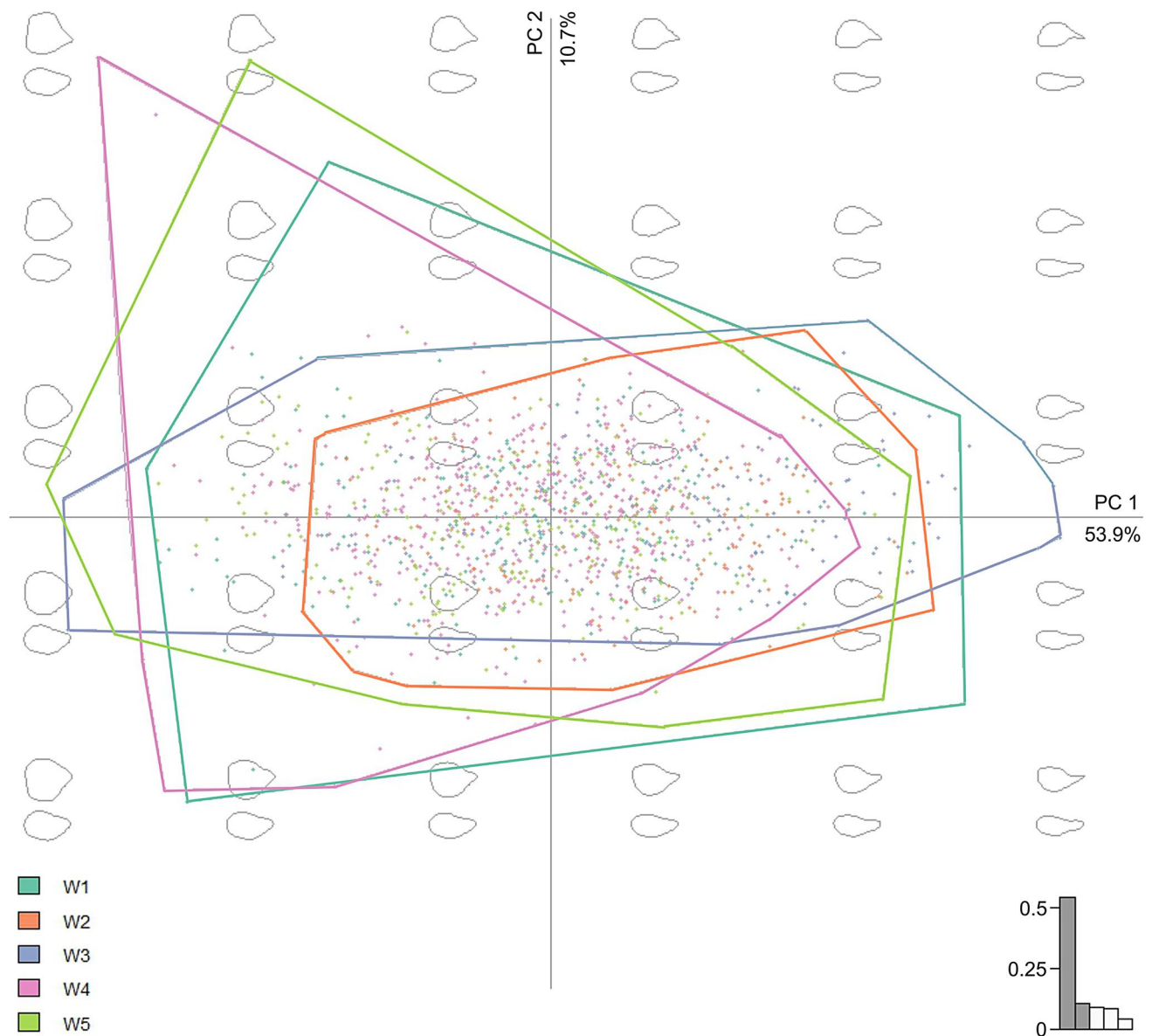


Fig. 4 Principle components analysis of the distribution of grape pips in wells, 1–5. The vertical axis, PC2, divides the plot by placing the pips with wild characteristics on the left and the domesticated ones on

the right side. PC1 is linked to the position of the chalaza (the navel-like depression in the middle of the pip)

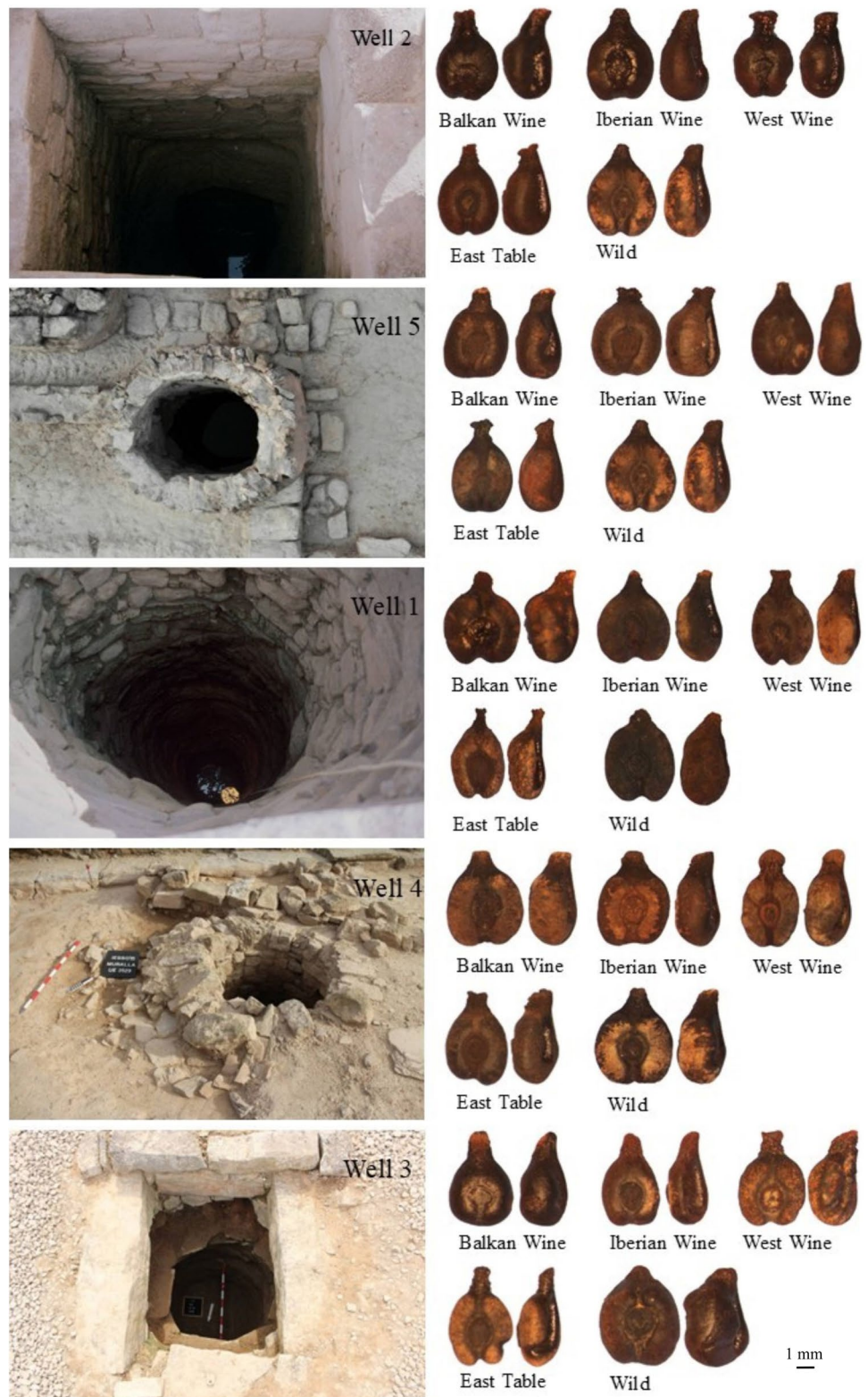
Table 2 Number of pips allocated to wild or domesticated types per well after shape correction; the wells are in chronological order

Context	Wild	Wild %	Domesticated	Domesticated %
Well 2	94	49.2	97	50.8
Well 5	191	77.6	55	22.4
Well 1	159	72.3	61	27.7
Well 4	417	77.7	120	22.3
Well 3	83	49.7	84	50.3

the wild and domesticated morphotypes per well after shape correction are given in Table 2. A comparative analysis (LDA) was done to identify whether the pips matched either modern wild or domesticated morphotypes.

This comparison demonstrated that 70% ($n=947$) of all the archaeological pips were allocated to the wild morphotype and 30% ($n=414$) to the domesticated type. Examples of wild and domesticated pips from each well are given in Fig. 5. No pips corresponded to non-allocated or intermediate shapes between the wild and domesticated types. The ordering of the wells according to their mean dates demonstrates differences between the wells in the amount of wild morphotype pips during the earliest phase of occupation, followed by a large number and finally a decrease in the number of pips of the wild morphotype (Fig. 6). For the identification of each of the pips, see ESM 1.

Fig. 5 The wells and examples of domesticated and wild grape pips from each (photos of wells by Iesso team)



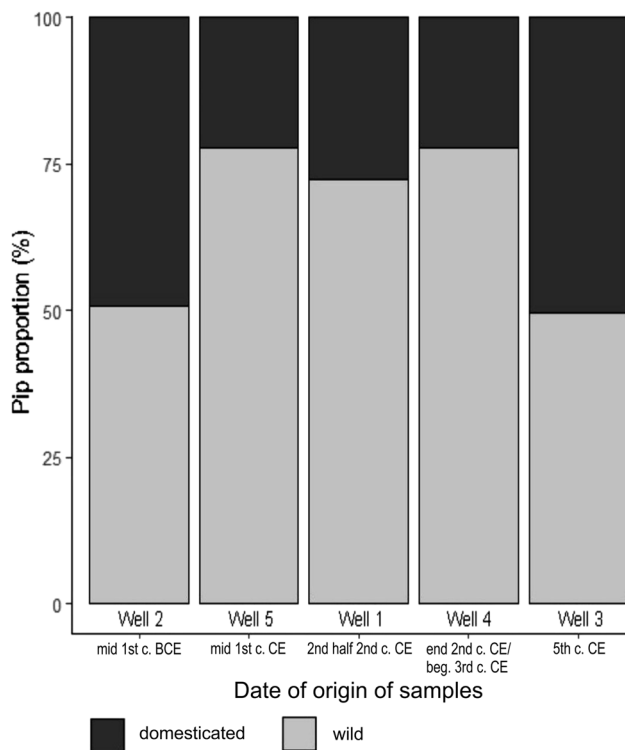


Fig. 6 Chronological distribution of pips (with shape correction) allocated to wild or domesticated types according to the date of the samples

Domesticated groups of varieties

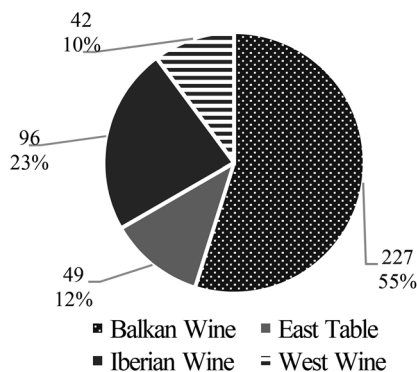


Fig. 7 Pie diagram showing proportions of the archaeological pips allocated to the different usage and regional groups of domesticated varieties from all wells (with shape correction)

Groups of domesticated varieties

In total 429 domesticated pips were identified by the first LDA and were then given a second LDA to be classified into the main groups of varieties. Across the whole site the most prevalent group was Balkan wine. Iberian wine, East table and West wine were also present, although quite limited (Fig. 7). A closer examination of the finds from each well reveals a quite consistent pattern as Fig. 8 demonstrates. In almost all wells, the main domesticated group was Balkan

wine, with the exception of well 4, where Iberian wine was more abundant, followed by Balkan wine, albeit with a small difference. The wells were backfilled in one episode or in a very short period of time. The excavated layers were artificial because it was impossible to identify any archaeological layers within the well deposits. A first assessment showed no significant differences between the layers within each well and thus these are not considered as separate analytical units in the analysis.

Discussion

Wild versus domesticated grape types

There is a change with time in the abundance of wild type pips from Iesso. Specifically, in wells 2 (in use earlier) and 3 (later) there is less of the wild morphotype compared to the other wells, where wild type pips clearly dominate (Fig. 6). It is important to note, however, that the classification of pips as wild should be treated with caution in relation to its implications, as there has been an ongoing debate on how these wild grapes should be interpreted.

Bouby et al. (2010, 2013) suggested that a considerable proportion of the pips identified as wild morphotypes from various Roman and even medieval sites could have been from cultivated grapes. During the Roman period it seems that vine cultivation was less selective compared to modern practices and consequently Roman grapes could have included a wide range of varieties of both wild and domesticated types (Bouby et al. 2013). The presence of wild type pips may be the result of the intentional or unintentional transplanting of seedlings that were present in the surrounding area and had the desired characteristics (Bouby et al. 2013; Figueiral et al. 2015). In fact, cross-breeding of different varieties does not seem to have been accidental but was then a common agricultural practice, as later medieval texts refer to the crossing of different vine types (Bauman 2002, Piero de' Crescenzi, *Liber Ruralium Commodorum*).

To better understand the nature of the grapes, it is important to consider the differences between the reproduction of the wild and the domesticated ones. Wild grapevines reproduce sexually, but domesticated vines are cultivated principally by vegetative propagation of clones to ensure that the resulting grapes will have the desired characteristics (This et al. 2006). Another important difference is that wild grapevines are dioecious with an equal number of male and female plants, which is not the case with domesticated vines where almost all varieties are hermaphrodites (Zohary et al. 2012, p 124).

With this in mind, in order to put the Guissona results into context, it is necessary to investigate the presence and

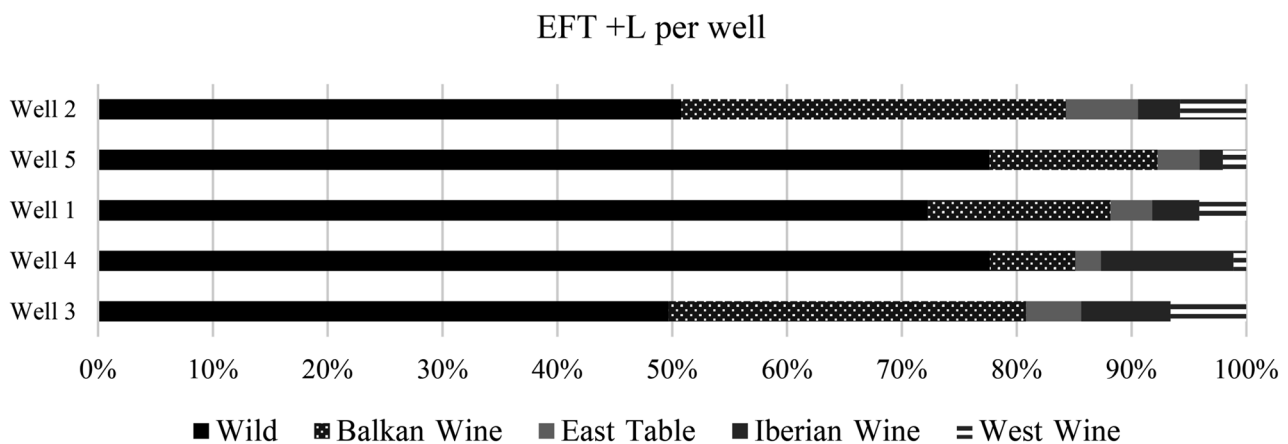


Fig. 8 Proportions of the archaeological pips allocated to the different usage and regional groups of varieties and wild type (with shape correction) per well

abundance of both wild and domesticated grapes across the broader region. The application of GMM to grape pips from Roman sites in the Mediterranean region remains relatively limited, though the studies done to date reveal emerging trends of grapevine domestication and cultivation practices. Various methodologies have been used in different regions, ranging from GMM to distance-based biometric measurements, to distinguish between wild, domesticated and intermediate forms, revealing a complex and regionally variable picture of the development of viticulture (for example, Boso et al. 2020; Bouby et al. 2024). In the Iberian Peninsula, studies of Roman and medieval sites in Galicia and central Portugal have revealed the presence of both domesticated and wild type pips (Boso et al. 2020; Coradeschi et al. 2023). It should be noted, however, that both studies compared the archaeological samples only with modern local wild and domesticated varieties, suggesting continuity with modern local varieties (Boso et al. 2020; Coradeschi et al. 2023). Genetic studies of modern grapevines in the western Iberian Peninsula have shed more light on the processes of grape domestication and management. Cunha et al. (2020) suggested a local secondary domestication episode or introgression process from wild to cultivated vines in Portugal. The study of Freitas et al. (2021) on modern material from the Iberian Peninsula also demonstrated an introgression between wild and domesticated vines, similar to what has been observed elsewhere in Eurasia (for example, Dong et al. 2023). Freitas et al. (2021) further suggested that the domesticated vine varieties that arrived on the peninsula came into contact with local wild types, giving rise to hybrid local domesticated varieties, and rejected the idea that local wild vine varieties were in the process of domestication.

Southern France has had more GMM studies on Roman material, showing that some sites had predominantly wild type pips (Bonhomme et al. 2021), while others had equal amounts of wild and domesticated types or more of the latter

(Figueiral et al. 2010, 2015; Terral and Bouby 2013; Terral et al. 2010). Bouby et al. (2013) synthesized data from 17 sites, revealing a general predominance of domesticated over wild and intermediate/non-allocated pips, suggesting a more gradual domestication process. Moreover, a hypothesis was put forward on the growing of wild type grapes near wine production facilities such as Gasquino, based on archaeological evidence from different parts of France (Bouby et al. 2024). Additionally, the work of Ramos-Madriral et al. (2019) on ancient *Vitis* DNA, using archaeological samples from various sites in France dating back to the Roman and medieval periods, demonstrated a clear correlation between ancient and modern regional cultivated varieties, as some of the archaeological and modern pip samples shared parent–offspring relationships. It is interesting that the early Roman pips from the site of Mas de Vignoles XIV (2nd–1st c. BCE) showed greater genetic similarity to varieties from Iberia and Eastern Europe. In contrast, most Roman and medieval pips from France demonstrated genetic resemblance to modern varieties from Western Europe (Ramos-Madriral et al. 2019). In Italy, a broad study of grape pips through time from 25 archaeological sites revealed that while domesticated grapes seem to have been dominant since the late Bronze Age, there was an increase of wild and non-allocated forms in the Roman period, which was interpreted as the probable result of introgression between local wild and cultivated vines, which may have led to the emergence of new varieties (Ucchesu et al. 2025). More site-specific studies showed that at Cetamura del Chianti, domesticated pips clearly predominated in both late Etruscan (150–100 BCE) and early Roman (37–68 CE) contexts, with only minor occurrences of wild or non-allocated types (Mariotti Lippi et al. 2020). However, at Villamagna, biometric and morphometric analyses identified a high proportion of wild type pips from late Roman and medieval layers. Researchers have offered three explanations: (1)

these grapes could have been domesticated types that had returned to their natural wild state due to the socio-political conditions of this period and the subsequent decline in agricultural activities; (2) cultivated vines in the region might have retained traits typical of wild grapes without being truly wild; or (3) during the Roman period, there may have been little emphasis on selecting strictly domesticated varieties, with wild, domesticated and intermediate types all being used (Carmenati et al. 2024). Overall, these studies demonstrate the variability and flexibility of the growing of grapevines across the Roman Mediterranean region as well as a dynamic domestication process. The evidence points to a viticulture during this period that was not rigid but adapted to local needs, involving varying degrees of human management. The coexistence of wild, domesticated and intermediate/non-allocated forms suggest that the growing of different vine types together facilitated gene flow between them. Although domestication was well on its way during the Roman period, wild type vines were possibly used (see also Arroyo-Garcia et al. 2006; Bouby et al. 2013, 2024) leading to domesticated grapes that were better adapted to the local environments and influencing the development of regional varieties (Freitas et al. 2021; Magris et al. 2021; Cunha et al. 2020).

The environmental conditions during the Roman period indeed probably influenced cultivation choices. In the Mediterranean region from 200 to 500 CE was the time of the Roman Climatic Optimum (Erdkamp 2021, 426). However, Labuhn et al. (2018) showed that this was not uniform across the region, dividing it into four sub-regions. In the Iberian Peninsula, the north experienced drier conditions in the early 1st millennium CE, similar to northern Italy, which became wetter from 500 CE onwards (Labuhn et al. 2018, p 79), a change supported by oxygen isotope data from the Cueva de Asiul (Smith et al. 2016) and pollen analyses of various sites in Catalonia (Riera-Mora and Esteban-Amat 1994). In contrast, southern Iberia, southern Italy, the Balkans and northern Greece were wetter during this time, becoming drier only after 600 CE (Labuhn et al. 2018, p 79). A trend towards greater climate instability since the 3rd c. CE has been revealed by pollen and charcoal analyses in various areas of the northeastern Iberian Peninsula, which coincided with agricultural and social crises in the Roman Empire (Burjachs et al. 2005, p 25; Burjachs 2012).

Growers would have adapted their strategies to this varying climate by using empirical knowledge (Erdkamp 2021, pp 416, 437). Grapevines are highly sensitive to climate changes (Van Limbergen and de Clercq 2021, pp 443–444) and wild vines, while less suitable for making wine due to their small and acidic berries (Zohary et al. 2012, p 122), are more resilient to environmental stress (Cantu et al. 2024). Therefore, the high proportion of wild morphotypes found

at Guissona (Fig. 6) should not be unexpected and may be attributable to a combination of the economic and environmental conditions and the vine growing techniques in the area at this time. It may reflect a response to less favourable environmental conditions, so that various vine types were grown, including genotypes close to their wild ancestors and also ones collected or acquired from the wild. It is thus possible that the cultivation of wild morphotypes at Iesso was partly due to their greater resilience to the drier northeastern Iberian climate of the period. The increased proportion of domesticated grapes in later contexts (well 3) may reflect changes in growing practices, possibly partly linked to wetter conditions in the northern Iberian Peninsula after 500 CE. While environmental factors may have played a role, economic, commercial and cultural influences must also be considered in explaining management choices, as discussed below.

Viticulture, wine trade and the Roman economy

At Guissona, grape pips were abundant in all the excavated wells (Buxó et al. 2004; Baniou et al. 2024a, b) suggesting that grapes were common and were used in some way. Evidence of wine consumption at Iesso dates from its foundation in the 2nd c. BCE, as shown by imported wine amphorae. Among the earliest finds are 44 Italian amphorae, 86.9% of the total MNI of amphorae found in the foundation pits of the town (Pera Isern et al. 2023, Fig. 19), and 33 (65.2%) of them probably contained wine (Guitart et al. 1998; Pera Isern et al. 2023). Greco-Italian wine amphorae from the same period were also identified (Guitart et al. 1998). Organic residue analyses on pottery of the period confirm the transport and storage of wine in various amphorae, including Italian Dressel 1B and Tarraconensian types (Cau Ontiveros et al. 2018), which have also been found at Guissona (Pascual 1 and Dressel 3–2; Carreras Monfort 2004), although no residue analyses have been done for these containers at the site (Baniou et al. 2024b).

It should be noted that Iesso was founded immediately after the abandonment of the Roman military base at Puig Castellar de Biosca, located nearby. The presence of Italian amphorae at Iesso suggested that the potential consumers of the newly founded town in around 120 BCE were of Italian origin, preferring their own products (Guitart et al. 1998; Carreras Monfort 2004). This should not be considered surprising, given that Iesso represents the early stages of Roman presence in northeastern Iberia. Indeed, the period of its foundation coincides with the era of Roman control of the region and the founding of the first cities (Pera Isern et al. 2023). Though located inland about 80 km from the coast, Iesso had access to trade networks, mainly through the port of Tarragona (Pera Isern 2005; Carreras Monfort

2004), but fewer imported amphorae were found at Guissona than at coastal towns (Carreras Monfort 2004). The variety of origins of the amphorae reveals the broad commercial contacts of the town.

From the 2nd to mid 1st c. BCE, imports of wine amphorae, especially from Italy, increased and then declined in later periods. From the mid 1st c. BCE to the early 1st c. CE, fewer wine amphorae were found, mainly Tarraconensis, Italian and Greek types (Carreras Monfort 2004, pp 157–158). The dominance of Balkan grape varieties among the pips along with Italian and Greek amphorae may indicate a preference for those wines. Carreras Monfort (2004, p 159) suggests that Italian amphorae at this time were used for higher-quality and therefore more expensive wines, possibly reflecting the tastes of the wealthier part of the population of Iesso. Between the mid 1st and early 2nd c. CE, amphorae continued to come from Tarraconensis and Greece. From the 2nd c. CE, a few wine containers from Gallia (Gaul) appear, a trend also seen in other parts of the Hispania Citerior province (Carreras Monfort 2004, pp 159–160).

The internal trade within the Iberian Peninsula developed further during the 2nd and 4th c. CE, while imperial control over trade seems to have been more limited (Keay 1988, pp 106–107). The fact that well 4, dating to this period, has a high presence of grapes of the wild type may suggest that more localised practices (and tastes, see below) developed within these contexts to meet the needs of the inhabitants. In the 4th c. CE, there was still an exchange of goods between the regions on the Mediterranean coast, and there was also internal trade between the Iberian provinces (Keay 1987, p 385). This is something that can also be observed from the finds from Guissona, as from the beginning of the 3rd until the 5th c. CE, amphorae for transporting fish-based products from Baetica and Lusitania and oil from the Guadalquivir have been found, while from the 4th to the 7th c. CE, also wine amphorae from the Aegean were present (Carreras Monfort 2004, p 160). It is also important to note that excavated contexts in Guissona from this later period are extremely rare (Carreras Monfort 2004). Consequently, the presence or absence of certain types must be considered with caution.

Returning to the issue of wine production at the site, archaeological evidence only confirms the presence of a wine press during Late Antiquity (late 5th–early 6th c. CE). The base, treading floor and tank (*calcatorium*) were identified, along with unexcavated wall remains which probably belonged to the storage area (Uscatescu 2004, 21). East of the *calcatorium*, the wine press was discovered, made with a dry stone construction which joined two large rectangular stones. The wine press had a central aperture and channel for collecting the must (grape juice) (Uscatescu 2004, pp 22–23). Although its capacity is hard to determine due

to its state of preservation, it was probably small, approximately 3.125 m³. The absence of imported amphorae from the 6th c. CE may indicate that local wine production met local needs (Uscatescu 2004, p 50), unlike in earlier periods. However, this absence could also result from the scarcity of 5th–6th c. contexts at Guissona. Near the wine press, well 3 was fully excavated. Although a direct association between the two structures is unconfirmed, they are the only known structures active in this part of Iesso during the 5th c. CE (Uscatescu 2004; Guitart i Duran 2007, p 11). The GMM results of this study show an almost equal presence of wild and domesticated grape types in the well, including the Balkan wine, Iberian wine, and West wine varieties, suggesting their use in local wine production.

Despite the absence of archaeological evidence for wine presses before the 5th c. CE, wine was probably being made at Iesso before then. It should be considered that apart from the fixed and complex winemaking structures, simple structures (Peña Cervantes 2010, p 40) or mobile structures made of perishable materials, such as wooden barrels (Uscatescu 2004; Brun 2020) that leave no archaeological traces, could have been used for making wine and storing it. The presence of pips from wine grape varieties from the Balkans, the Iberian Peninsula and the West may further indicate the ancient origins and use of these groups of varieties for making wine. The finding at Guissona of Greek wine amphorae and others from the Iberian Peninsula, mostly from the Tarraco region (Carreras Monfort 2004, p 158), indicates commercial interactions with these regions, wine imports and an appreciation and taste for these products, at least by part of its population. Export of wine from Iesso cannot be suggested on current evidence, but wine is likely to have been produced for local consumption.

Grape varieties and Roman tastes

Grapes were used in various ways: eaten fresh, dried as raisins, or pressed for juice, vinegar and cooking ingredients. Ancient authors refer to several of these uses as well as to grape varieties, their management and viticulture in general, while some references are also made to specific regions of the Iberian Peninsula in relation to viticulture, although very few mention the northeastern part (ESM 2).

Despite the scarcity of written sources for the region, archaeological and pottery evidence suggests that the coastal areas of modern Catalonia were engaged in wine production between the mid 2nd c. BCE and the late 2nd c. CE (Peña Cervantes 2020).

Grape pips from archaeological contexts can provide valuable insights into past grape varieties and their uses. Recent studies have shown a relationship between seed morphology and both the use and the geographical origin

of *Vitis vinifera* varieties (Bonhomme et al. 2020), with the use being the most important (Bonhomme et al. 2021). However, this kind of research has not been applied to most Roman provinces except for France, where the analysis of grape pips from several sites with different chronologies has been done (Bouby et al. 2024; Bonhomme et al. 2021). Also, a palaeogenomic study on samples from different sites in southern and north-eastern France dating from the Iron Age to the Middle Ages showed that most grape pips were related to varieties from western and central Europe used for making wine (Ramos-Madriral et al. 2019). Notably, no comparable studies have yet been done on material from the Iberian Peninsula until this study, which is a reference point for this area.

A comparison of the results from Guissona with those from other sites where the study has reached the level of identification of variety groups shows that although the same group of varieties was present at all sites, there are variations in the predominant ones. In almost all cases, however, most of the domesticated varieties are associated with wine making. The presence of several different variety groups could be indicative of their use for making wines with distinct flavours, among other uses of the grapes, suggesting a level of expertise and proficiency in wine making.

The pips from Guissona show a clear preference for the Balkan varieties among the domesticated grapes in all the wells, while West wine was the least frequent. In the three more recent wells (1, 4 and 3), the second most common category was Iberian wine. In contrast, in the first two wells (2 and 5), Balkan wine was followed by the East table variety group, which were mainly for table consumption, possibly reflecting the economic and cultural choices of the earlier inhabitants of the town, which seem to have been largely continued throughout its occupation. It should be noted that the proportion of pips classified as the wild morphotype may provide additional evidence for the growing of locally native vines. However, it cannot be ruled out that these wild grapes may be partly the result of introductions of wild vines from elsewhere, as no geographical groups can be identified within the wild morphotype category.

The fact that the remains from all the wells were dominated by varieties that are best suited for making wine possibly indicates that more attention was given to how the wine was made, while the diversity of grape types could be the result of taste preferences and/or commercial relationships. The high percentage of the local wild morphotype could indicate a conscious selection for more acidic flavours, apart from the environmental reasons as discussed above (Zohary et al. 2012, p 122; Maghradze et al. 2020) or to improve the colour of the wine. An experimental making of wine with wild grapes from various regions of Eurasia showed that, although having little juice, they can improve the colour of

red wines under certain conditions (Maghradze et al. 2020). The same study also found that acidity levels differ by type (Maghradze et al. 2020). Experiments in northeastern Spain also observed a strong red colour in wines made from wild grapes (Ocete et al. 2011a; Meléndez et al. 2016). The higher acidity could potentially help to preserve the wine, but adding wild grape wine to that made from domesticated grapes significantly reduces the alcohol content and does not appear to preserve the wine for longer (Maghradze et al. 2020).

Taste preferences have a strong socio-cultural basis, significantly shaping food experiences and perceptions (Livarda 2013, 2018; Freedman 2005). Ancient Greek and Roman authors described flavours, including those of wine (Boulay 2018; Paulas 2018). Pliny the Elder identified 13 juice flavours, along with their colours and odours (*Natural History* 15.32–33). Wine was described as ranging from sweet to bitter, white to black in colour and varied in consistency (Boulay 2018, pp 201, 205). Diluting wine with water was common to adjust the taste (Bush 2002, p 580). Pliny the Elder noted that sweetness was a key indicator of wine quality (*Natural History* 14.4).

In this context, the high proportion of wild grape types found at Guissona could indicate that they were used and probably grown for a particular quality of wine which was suited to local environmental conditions and taste preferences. Wild grapes were used in Spain until recently for making vinegar, medicine or to alter wine flavour, among other uses (Ocete et al. 2011b). On the other hand, the more limited presence of certain domesticated grape varieties could indicate the production of a higher quality or more desirable kind of wine, according to the standards of the period, perhaps in smaller amounts, directed to certain cultural needs or preferences of parts of the town population or even possibly to activities incorporated within the ‘global’ Roman fashions and economy.

Conclusions

This study has explored grape cultivation and wine making, providing significant new insights into the Iberian Peninsula and its northeastern part, a generally unexplored area of the Roman world. The results obtained by this GMM study demonstrate that pips of the wild grape morphotype generally predominate over the domesticated type at the site through time. The majority of the domesticated pips belong to groups of varieties suitable for making wine, with the Balkan wine group dominating, followed by Iberian wine and then equal amounts of Western wine and Eastern table grapes. The increased presence of wild grape types at various Roman and medieval sites in the Mediterranean region

has been of great interest to researchers and various hypotheses have been proposed to explain this for a period when viticulture was widely practised.

It has been suggested here that it is possible that environmental conditions partly influenced viticulture and led to the widespread growing and use of vine genotypes close to the wild subspecies, which could have grown better in the less favourable climate of the period. Pollen analyses at various sites in the northeastern part of the Iberian Peninsula have indeed indicated the existence of drier conditions during this period (Riera-Mora and Esteban-Amat 1994; Burjachs 2012). Interbreeding between wild and cultivated vines may have resulted in hybrids better adapted to the local conditions.

There is evidence of wine consumption at Iesso from the foundation of the town onwards, as shown by the finds of wine amphorae which had been imported from various parts of the Roman Empire. Over the centuries, however, the proportion of imported amphorae and the regions from which they came changed. This, together with the variations in the presence of the wild morphotype and the different variety groups of domesticated grapes found in the wells suggests that the presence of these grape types at the site was in response to local demand by the inhabitants and also their commercial contacts for trade.

Tastes also seems to have played a role and indeed the use of grapes of the wild morphotype may also be partly an indication of the preferences of the inhabitants of the town or the region for wine with particular kinds of acidity and colour. Also, it has been suggested that there was some degree of specialisation in wine production, based on the coexistence of several domesticated varieties suitable for wine making at the site, which could have been used for the different flavours or qualities of wine that each variety could produce.

Overall, this study has demonstrated how a detailed study of archaeobotanical grape pips with the aid of GMM has revealed the complex interplay between the Roman environment, economy and cultural tastes in the management of agricultural resources and local foodways.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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