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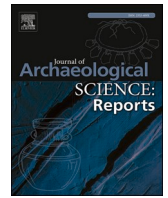
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Viticulture in Iron Age and Roman southeastern France: A reconstruction based on charcoal and seed-fruit data compared to archaeological evidence and wine yields modelling

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ABSTRACT

Winegrowing has dramatically shaped the landscapes as well as the culture and economy of societies in the Mediterranean region. It is generally accepted that it appeared and expanded in Mediterranean France during the Iron Age and the Roman period (ca 750 BCE – 500 CE). Viticulture flourished massively during the Early Roman Empire, when wine was widely exported throughout the Empire.

The objective of this paper is to propose an updated overview of the history of viticulture based on a multi-disciplinary survey combining archaeobotanical, archaeological data and modelling of wine potential yields. We aim to compare the information provided by seed-fruits and by charcoal, and to better understand how these data can be used to trace ancient viticulture in relation to other archaeological data.

We collected and entered into a database all available results of charcoal and seed-fruit analyses from Mediterranean France and the middle Rhône valley. Seed and fruits provide evidence of fruit consumption and processing (table vs. pressing), while charcoal remains are stronger indicators of local cultivation. We also included published archaeological information about wineries and amphorae factories. This provides another

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way of identifying areas of cultivation and processing into wine, and gives hints on the scale of production and the possible destination for export. The reconstructions based on the multi-proxy information contained in the database are compared to the climate-vegetation LPJmL model estimates of wine potential yields and their variations over space and time.

Charcoal and seed evidence concur to show that viticulture started in the 6th-5th c. BCE and developed with the progressive increase of potential wine yields throughout the Iron Age and then with the Roman Climatic Optimum. In the Roman period, the development of specialised winemaking facilities provides impressive evidence of viticulture, but is at the same time less favourable to its record by archaeobotany. Apparently, charcoals and seeds are more frequently preserved in rubbish assemblages when winemaking activities are still associated with domestic activities. While wineries and amphorae factories bear witness to a wine crisis in the Late Roman period, archaeobotanical remains indicate that viticulture persisted, probably in a less specialised mode, and modelling suggests that potential wine yields did not decline in comparison with the heyday of regional viticulture. Archaeobotany also provides consistent evidence of the existence of grapevine cultivation in urban Roman contexts.

1. Introduction

Winegrowing has dramatically shaped the landscapes, human cultures and economies in the Mediterranean area. In southern France during the Iron Age, commercial wine production was dominated by the Greek city of Marseille, while Etruscan and Iberian wines were imported. Although early Marseille has yielded virtually no wine-making facilities, we now know that the town produced well-known specific wine amphorae from the mid-6th c. BCE onwards (Bertucchi, 1992). From the 6th to the 3rd c. BCE, the wine from Marseille was consumed on a large scale by local communities throughout the coastal areas and the Rhône valley, before being replaced by massive wine imports from Italy (Brun and Laubenheimer, 2001; Poux, 2004; Brun, 2010; Olmer, 2018). From this point of view, indigenous societies appear as wine consumers rather than wine producers. As a matter of fact, outside Marseille's territory, archaeologists have found little evidence of specialised viticulture: no specific wine amphorae were made by local societies, and few potential wine-making facilities has been detected so far (Py and Buxo Capdevila, 2001; Bouby et al., 2014). Since archaeologists became familiar with identifying pits and ditches dug for vine plantations, few Iron Age vineyards have been identified compared to the many more numerous examples dating from the Roman period. In contrast, archaeobotanical evidence of Iron Age grapevine exploitation is abundant in Mediterranean southeastern France (Py and Buxo Capdevila, 2001; Bouby, 2014; Bouby et al., 2023). The percentage of sites with macrobotanical vine remains increases significantly after 500 BCE, whether based on seed and fruit or charcoal findings. Moreover, morphometric analyses of grape seeds show that domestic grapevine first appeared in the region about the same time, whereas only wild vines had been identified in earlier sites (Bouby, 2014). Consistent results are provided by quantitative eco-anatomical analysis of *Vitis* charcoals, which detects the earliest samples of the cultivated type in 5th c. BCE sites in the area (Limier et al., 2018). Taken altogether, the archaeobotanical evidence suggests that grapevine was regularly cultivated by local populations, and that grapes were not simply imported to be eaten or gathered from wild vines. There seems to be a sharp contrast between the results of archaeobotany and those provided by the study of Iron Age wine production installations.

The situation was completely different during the Roman period. The region of Gallia Narbonensis was well-known for its wines, widely exported throughout the Empire (Brun and Laubenheimer, 2001; Brun, 2005). Latin texts and ancient graffiti (*tituli picti*) often refer to winegrowing in the Narbonensis province (Brun, 2001; Laubenheimer, 2004; Bigot, 2020). Today, the archaeological evidence of this activity is particularly diverse and extensive. Wine amphorae manufactured in the region for wine export are well known (Laubenheimer, 1990; Mauné, 2013a; Bigot, 2020). These amphorae, particularly the Gauloise 1, Gauloise 4 and Gauloise 5 types, whose sherds are commonly found in the settlements, allow us to trace the consumption of provincial wines on different spatial scales, all the way to Rome and the borders of the

Empire (Laubenheimer, 2018). More and more is known about their manufacturing workshops, thanks to archaeological excavations and surveys (Laubenheimer, 2001; Bigot, 2020; Mauné and Bourgaud, 2020). The same applies to winegrowing installations (Brun, 2005; Carrato, 2017). These wineries are most often recognised by the traces left by the semi-buried large jars (*dolia*) in wine cellars, but also, depending on site preservation, by the presence of vats and wine-presses. More and more often, traces of vineyards are found on the outskirts of production sites, evidenced by the rows of pits or ditches dug to plant vines (Boissinot, 2001; Jung et al., 2013). These archaeological findings confirm the emergence of specialised, commercial viticulture. Evidence from amphora factories and wineries is consistent showing that this viticulture developed from the end of the 1st century BCE (Augustean period) onwards, and flourished during the first two centuries CE. The number of wineries, including the number of large sites, and the total storage capacity on a regional scale, indicate that viticulture reached its peak during the 2nd c. CE (Carrato, 2020). The warmer and more stable temperatures characterizing the Roman Climatic Optimum (RCO) may have contributed to the expansion of viticulture in the Early Roman Empire (McCormick et al., 2012; Bernigaud et al., 2021). The subsequent evolution of viticulture in South-Eastern France and the eventual existence and exact nature of a wine crisis in the last centuries of the Imperial period is still open to question (Brun, 2010; Carrato, 2020).

The first aim of this work is to gain a better understanding of the exact significance of archaeobotanical data on viticulture and the use of vine products during the Iron Age and Roman period. It is essential to compare the information provided by seeds and fruits and by charcoal, and to see how these data complement each other. This will make it possible to better understand how these two types of archaeobotanical data can be used to trace the history of ancient viticulture and to determine the types of viticultural activities recorded. It is a well-known fact that the occurrence of charcoal provides reliable evidence of the local presence of vines and their eventual cultivation (Miller, 2008), while seeds and fruits are first and foremost an indication of the use of fruits, which may have been grown locally or brought from elsewhere. By comparing the spatial distribution of finds of *Vitis* charcoal and seeds-fruits from different periods, we will try to ascertain whether they are evidence of the same viticultural pattern or are the result of different activities. For the Roman period, the spatial distribution of archaeobotanical data will be compared with that of amphorae workshops and wine cellars to verify that archaeobotanical evidence does reflect the scale and specialisation of winegrowing. To help us understand how fluctuations in viticulture may have responded to climatic variations, we will compare the different types of archaeobotanical and archaeological evidence with potential wine yields, as modelled using paleoclimatic data and agro-ecosystem modelling recently adapted to ancient winegrowing (Fader et al., 2015; Bernigaud et al., 2021).

2. Material and methods

The study area covers all the administrative departments in the Mediterranean region included in the former Languedoc-Roussillon and Provence-Alpes-Côte d'Azur regions, as well as the Ardèche and Drôme departments located further to the north, along the Rhône River (Fig. 1). The timespan extends from the Bronze Age to the end of the Roman period (ca 2200 BCE–500 CE).

2.1. Archaeobotanical macroremains

The method for compiling and processing archaeobotanical data on charcoal and seeds-fruits followed and adapted the one used by Bouby et al. (2023). The database includes all the archaeobotanical data currently available, both published and unpublished. In order to gain a better insight into the spatial distribution of the use and cultivation of grapevine in the past, all sites studied from an archaeobotanical point of view have been included in the database, regardless of the identification or not of *Vitis*. Data are first recorded according to the archaeological phases identified at each site, pulling together all the samples from a given phase. The phases considered are Bronze Age (2200–750 BCE), Iron Age 1 (750–525 BCE), Transition IA1-IA2 (525–425 BCE), Iron Age 2 (425–150 BCE), Republican (150–25 BCE), Early Roman (25 BCE–250 CE), and Late Roman (250–500 CE). Cave or rock-shelter occupations (abbreviated to CAVE), rural and urban settlements, as well as ritual or funerary structures (RITUAL), are included as separate categories. In this study we consider a site-phase to be a unique combination of an occupation type (e.g. habitat vs. funerary) of a given site, at a precise time period, for a specific type of plant remain (i.e. charcoal vs. seed-fruit) and a particular preservation (e.g. charred vs. waterlogged). Regarding seed-fruits remains, elements that could be considered as wine-pressing residues (pips, pedicels, entire berries, skin fragments and

bunch elements) were recorded separately. Whenever seed fragments were counted, the Minimum Number of Individuals was estimated by dividing the number of fragments by two and adding the result to the number of whole seeds.

In addition to what was done by Bouby et al. (2023), data were also recorded according to the stratigraphic unit in the different contexts, but only when *Vitis* was present. The main goal was to quantify, at the scale of archaeobotanical assemblages, the importance of putative wine-pressing residues and thus to detect the contexts with higher quantities of these residues.

The chronological evolution of the presence and exploitation of the grapevine in the area was first approached by calculating the percentage of sites where *Vitis* macroremains were recorded for each timespan (referred to as “frequency”). In parallel, we observed chronological changes in the number of *Vitis* macroremains per site (referred to as “quantity”). The number of *Vitis* remains per site, transformed into percentages, was also used to study the geographical changes in *Vitis* distribution from phase to phase. In this case, only site-phases with counts ≥ 100 were taken into account.

Log-transformed numbers of remains were also used at the context level to monitor the occurrence of concentrations of *Vitis* seeds and putative wine pressing residues, within different chronological and social (rural vs. urban) contexts.

2.2. Archaeological sites: Wineries and amphora factories

The identification and location of wineries and wine amphora factories have been reviewed based on the literature (Mauné, 2013a; Carato, 2017; Bigot, 2020) and recorded in our database. Only sites object of extensive excavations were taken into account to ensure that only well-characterised archaeological contexts are represented. Sites only identified by field surveys were excluded from the database.

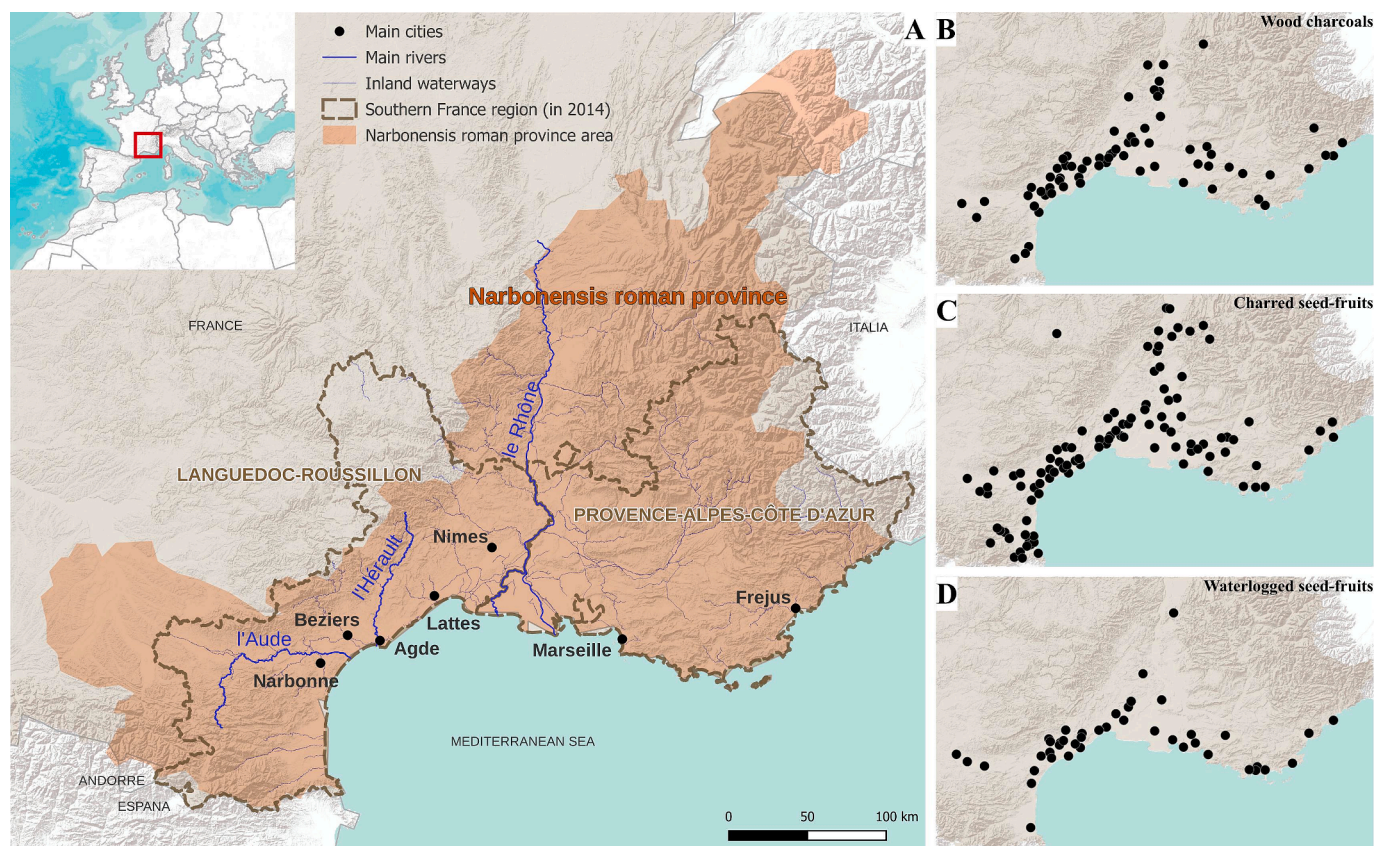


Fig. 1. Location of the study area in southeastern France (a) and distribution of the sites that delivered charcoal samples (b), charred seed-fruit samples (c) and waterlogged seed-fruit samples (d).

Winemaking facilities from the Second Iron Age and the Republican period were not considered due to their small number and to the difficulty to clearly identify some of them. Only sites from the Imperial Roman period have been included. They are dated from the end of the 1st c BCE to the 6th c CE but for the sake of comparability with archaeobotanical data they were classified into two periods, Early Roman (25 BCE–250 CE) and Late Roman (250–500 CE). The evidences taken into consideration to characterise ancient wineries are the structures linked to wine production (foot treading areas, presses, vats) and storage. The capacity of the storage areas identified ranges from 10 to over 450 semi-buried *dolia*.

Amphorae manufactures encompass a variety of products that evolved over time and space. Amphorae production started, on a relatively small scale but across the entire territory under consideration, by imitating Spanish (Pacual 1) and Italian (Dressel 1, Dr. 2–4) tapered types and local flat-bottomed ovoid amphorae (Gauloises 2, 3, 7 and 8) (Mauné, 2013a; Laubenheimer, 2018; Bigot, 2020). By the mid-1st c. CE, the increase in production coincided with a shift towards the Gauloise 1 type, mostly produced in Languedoc and dedicated to regional trade, the Gauloise 4 type, produced throughout the Narbonensis province and dedicated to large-scale foreign trade, and the Gauloise 5 type, mainly made in coastal Provence. During the Late Roman period, amphorae production clearly focused on the Gauloise 1 and Gauloise 4 types.

2.3. Modelling of wine potential yields

Potential wine yields were simulated using Lund Potsdam Jena managed Land (LPJmL) modelling. LPJmL is a process-based dynamic vegetation model simulating land–atmosphere carbon and water exchange flows at the scale of ecosystems, including agro-ecosystems (Bondeau et al., 2007; Fader et al., 2015; Schaphoff et al., 2018). It allows to simulate processes such as photosynthesis and vegetal growth for several functional types of plants and crops. The model uses data relating to climate (daily mean air temperature, precipitation and cloudiness), soil texture and atmospheric carbon concentration.

It was recently adapted and calibrated for past cereal cultivation (Contreras et al., 2018, Contreras et al., 2019) and wine production (Bernigaud et al., 2021), using continuous high-resolution paleoclimate data to produce chrono-spatial estimates of potential yields. Here, we use palaeoclimatic data from a reconstruction of the Holocene climate in the Mediterranean Basin and Southern Europe, based on pollen data and vegetation modelling; they provide a series of maps representing 100-year time spans and giving monthly averages of temperature, precipitation and cloudiness on a grid of points spaced 5° apart in latitude and longitude. (Guiot and Kaniewski, 2015). Monthly reconstructed data are interpolated daily, accounting for the number of rainy days per month. This dataset was spatially interpolated to obtain a grid with 8 x 8 km spatial resolution, covering the whole of southeastern France.

Using the calibrated parameters for present-day viticulture in LPJmL, potential wine yields were simulated for non-irrigated vineyards and maps were generated representing average yields by period: Iron Age 1, Transition IA1-IA2, Iron Age 2, Republican, Early Roman, Late Roman.

3. Results

3.1. Grapevine dynamics based on wood macroremains

Our database includes 330 site-phases for wood remains (Supplementary 1). The large majority of site-phases (94.5 %) concerned charred wood, with the remainder containing waterlogged wood remains. The better documented periods are, in descending order: Early Roman (ERO), Bronze Age (BZE), Iron Age 2 (IA2) and Late Roman (LRO). Waterlogged material is most often found in ERO sites, due to the large number of water wells excavated for this period in the study area. If we examine the chronological dynamics of the presence of *Vitis* in site-

phases on the basis of charred wood remains (Fig. 2, a), we observe that while it was already present during the BZE, its frequency (expressed in site-phase frequencies) increased gradually during the Iron Age. After a distinct decline at the end of the Iron Age and during the Republican period, the frequencies of *Vitis* increased again during the ERO, reaching its maximum towards the end of the 2nd – beginning of the 3rd c CE (more than 60 % of site-phases). They seem to have experienced a further decline during the LRO before increasing again in the beginning of the Middle Ages, but this trend needs to be confirmed as the number of available sites is low.

The number of charcoal fragments identified as *Vitis* in the different sites followed a similar chronological trend (Fig. 2, b). Greater levels of *Vitis* charcoal are recorded from the Iron Age onwards. They reach their highest values during the ERO and then diminish in the LRO. As for its spatial distribution, *Vitis* charcoal is mainly found in the western part of the Mediterranean area (Languedoc), following a northward thrust along the Rhône valley during the Bronze Age and early Iron Age (Fig. 3). However, we must consider that the sites are sparser in the eastern part of the region (Provence) and that it is difficult to assess the significance of the scarcity of vines in this area. From the IA2 onwards, *Vitis* finds are widespread throughout the region. This was certainly also the case during the ERO, but the highest percentages are found in the middle part of the coastal zone, from western Provence to western Languedoc. We can also observe that during the Roman period *Vitis* charcoal fragments are more frequent and reach their highest percentages in rural sites.

The reduced number of site-phases with waterlogged wood prevents the observation of any chrono-spatial dynamics of *Vitis*, as opposed to charred material. However, we can see that grapevine is attested from the 2nd c. BCE onwards and that from then on it is recorded at most sites.

3.2. Grapevine dynamics based on seed-fruit remains

With a total of 464, the number of site-phases with seed and fruit data is higher than for wood (Supplementary 2). In addition, the proportion of site-phases with waterlogged material is higher (17.9 %) and there is also a small proportion of site-phases (3.9 %) with mineralised seeds. The distribution by periods is similar to that of wood as far as charred seeds and fruits are concerned. The best represented period is again ERO and the most poorly represented are the Transition IA1/IA2 (TrIA1-2) and the Republican period (REP), which are also the shortest periods. For waterlogged seeds and fruits, the best represented periods are, in decreasing order, ERO, BZE, LRO and IA2.

The chronological evolution of the frequencies of *Vitis* from charred seeds and fruits (Fig. 4, a) shows a largely similar trend to that of charcoal, but with some notable differences. The grapevine is also consistently recorded throughout the Bronze Age, but its frequency shows a sharper increase in the 6th-5th c. BCE to reach a maximum during the 4th-2nd c. BCE. By then, *Vitis* is recorded in 75 % or more of the site-phases. Although more limited, a decrease is also perceived in the 1st c. BCE. *Vitis* frequencies increase again and then remain stable throughout the Roman period. ERO values are consequently relatively low compared with those of the Iron Age and with the trend displayed by charcoals. There is no visible decline in the frequency of charred *Vitis* seeds in the LRO. The chronological trend based on the number of charred *Vitis* seeds in the site-phases is at the same time comparable and more contrasted (Fig. 4, b).

Seed numbers increase in the Tr IA1-2, reaching a first peak in the IA2. They decline significantly during the REP period, before reaching a new peak at ERO and then apparently declining again at LRO. The finds of charred *Vitis* seeds are spread throughout the region investigated for all periods. However, it is obvious that from the IA2 onwards, the sites with high *Vitis* percentages are located along the Mediterranean coast (Fig. 5).

Grapevine is recorded at the majority of site-phases (90.6 % in total) where waterlogged seeds and fruits were analysed, regardless of the

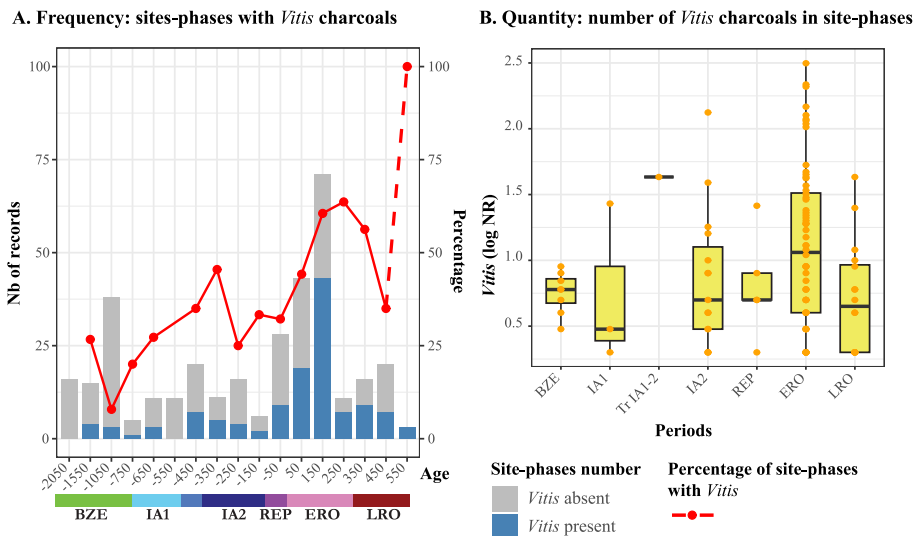


Fig. 2. Chronological dynamics of *Vitis* recorded by charred wood. A) Number and percentage of site-phases with a *Vitis* record per time span (frequency), B) Number (log-transformed) of *Vitis* charcoal fragments per site-phase sorted according to archaeological periods. Only site-phases with ≥ 100 charcoals are considered. BZE = Bronze Age, IA1 = Iron Age 1, Tr IA1-2 = Transition Iron Age 1–2, IA2 = Iron Age 2, REP = Republican period, ERO = Early Roman period, LRO = Late Roman period.

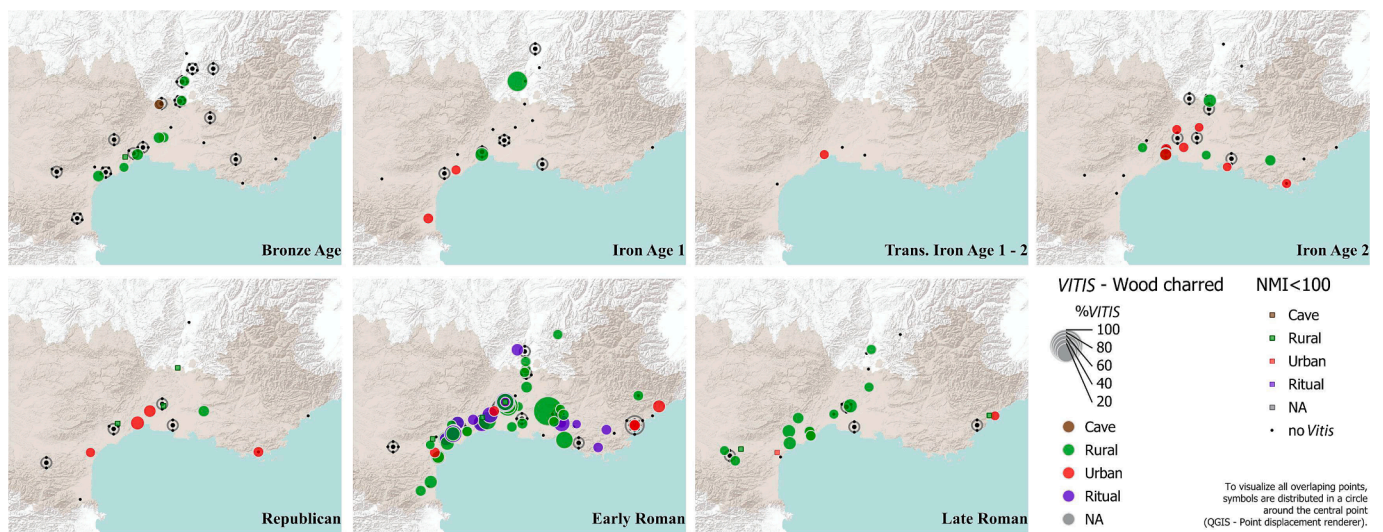


Fig. 3. Spatial distribution of *Vitis* charcoal records according to archaeological periods and site types. Black dots = site-phases where charcoal analysis was carried out but *Vitis* was not identified. Colour dots = site-phases where *Vitis* was identified but the total number of analysed charcoals is < 100. Proportional discs = site-phases with ≥ 100 identified charcoals. The size of the disc is proportional to the percentage of *Vitis* charcoal at the site-phase.

period. As a result, it is not possible to detect a chronological trend from the frequency of *Vitis*. As long as the number of site-phases, which is limited for certain periods, allows a proper overview to be obtained, the numbers of uncharred *Vitis* seeds present a roughly comparable trend to that of charred seeds. There was an increase during the Iron Age, a possible decrease during the Republican period, followed by an increase during the Roman period.

The quantitative representation of the different fruit parts in the archaeobotanical assemblages (scale of the archaeological context) also reveals a chronological trend (Fig. 6). The median number of pips in the assemblages increases from the IA1 for waterlogged material and from the Tr IA1-2 for charred remains. From this time onwards, concentrations of several hundred to several thousands of seeds are reported, mainly waterlogged but also charred. At the same time, the number of remains considered as wine pressing residues (pedicels, undeveloped berries, skin fragments and bunch axes) also increases in the

assemblages. This also applies to charred material. Assemblages containing numerous wine pressing residues are present from the IA1 onwards for waterlogged material and from the Tr IA1-2 for charred remains. However, after their first appearance during the Iron Age, no clear chronological trend could be detected. They are not noticeably more common in the Roman period, when assemblages rich in grape pips and/or containing numerous wine pressing residues are observed in both rural and urban sites.

3.3. The distribution of wineries and amphorae factories

Our database includes 87 wine amphorae factory sites (Supplementary 3) and 106 wineries (Supplementary 4). In both categories, most of the site-phases are dated to the ERO (89.8 % of the amphorae factories and 75.2 % of the wineries) and most of the sites operating during the LRO already existed in the ERO.

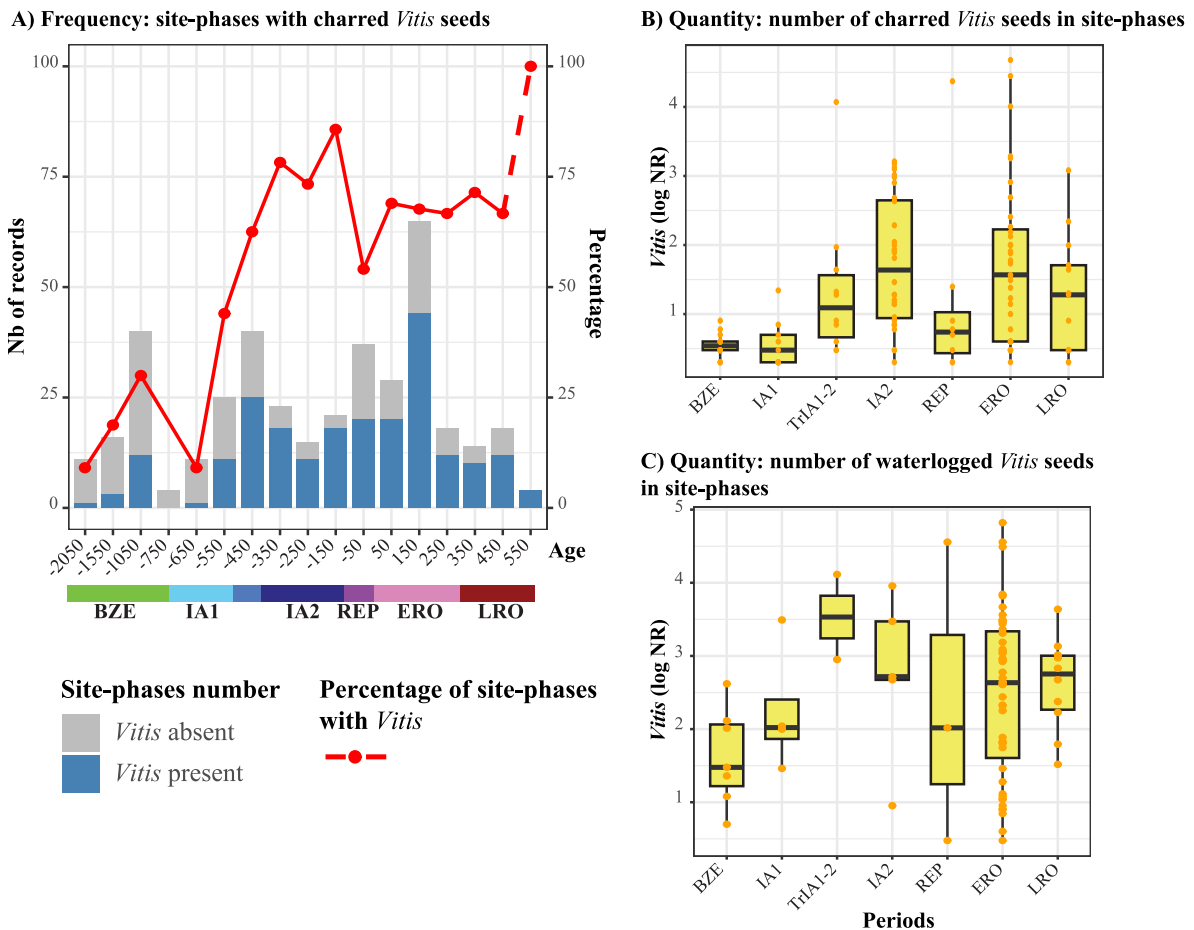


Fig. 4. Chronological dynamics of *Vitis* recorded by seeds. A) Number and percentage of sites with charred *Vitis* seeds per time span (frequency), B) Number (log-transformed) of charred *Vitis* seeds per site-phase sorted according to archaeological periods. C) Number (log-transformed) of waterlogged *Vitis* seeds per site-phase organized according to archaeological periods. Only site-phases with ≥ 100 charred seed-fruits are taken into account. BZE = Bronze Age, IA1 = Iron Age 1, Tr IA1-2 = Transition Iron Age 1–2, IA2 = Iron Age 2, REP = Republican period, ERO = Early Roman period, LRO = Late Roman period.

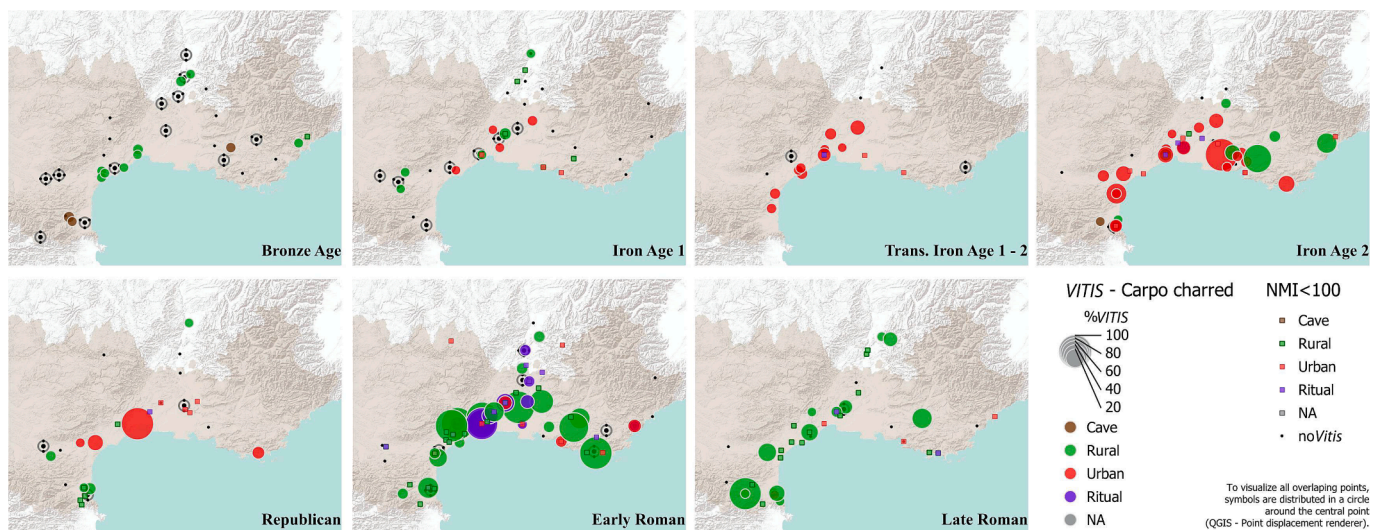


Fig. 5. Spatial distribution of charred *Vitis* seed records according to archaeological periods. Black dots = site-phases where seed-fruit analysis were carried out but *Vitis* was not identified. Colour dots = site-phases where *Vitis* was identified but the total number of analysed seed-fruit is < 100. Proportional discs = site-phases with ≥ 100 identified seed-fruits. The size of the disc is proportional to the percentage of *Vitis* seeds at the site-phase.

The geographical distribution of the two types of sites largely coincides. They are mainly located along the Mediterranean coast, with some diffusion inland, particularly along the Aude and Rhône river

basins. At the very most, we can observe a stronger presence of amphorae factories in the lower Rhône triangle and more wineries in the middle Rhône valley.

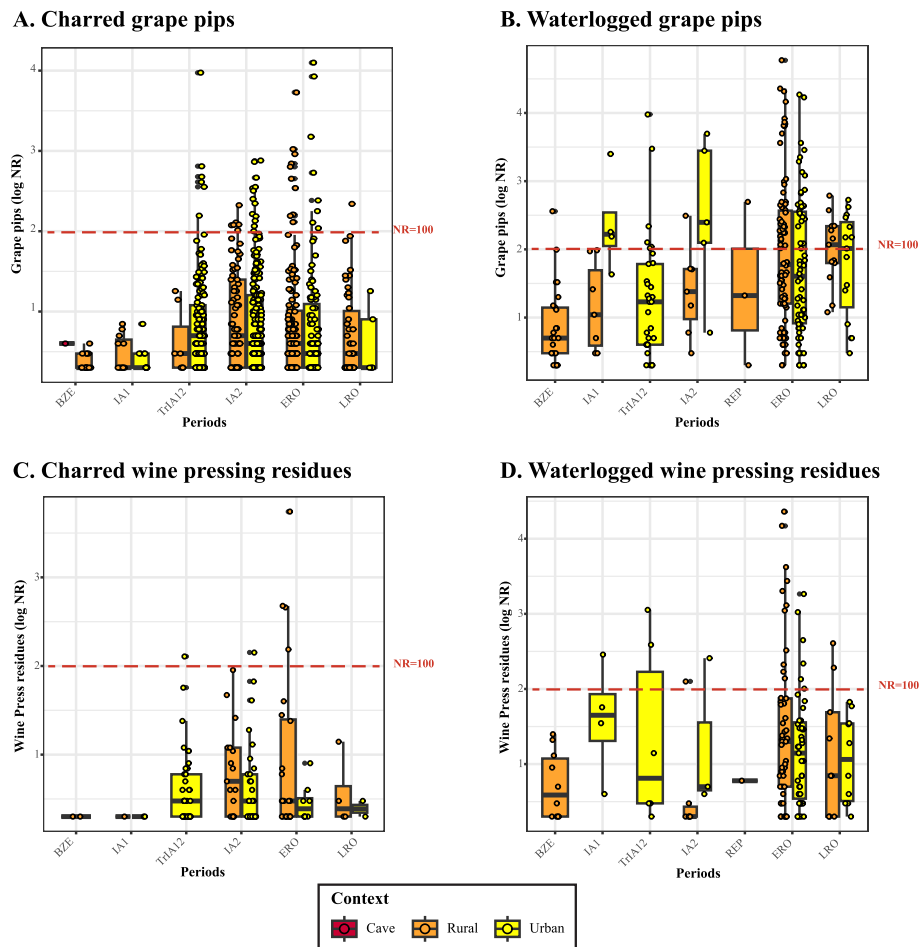


Fig. 6. Composition of the carpological assemblages containing grape remains at the level of the archaeological context (stratigraphic unit). A, B, Log-numbers of charred and waterlogged grape pips. C, D, Log-numbers of charred and waterlogged wine pressing residues (pedicels, undeveloped berries, skin fragments and bunch axes).

3.4. Potential wine yields

Potential wine yields simulated using LPJmL modelling vary considerably over space and time. For the chronological sequence considered, they start from a minimum in the 6th c. BCE, gradually increase throughout the Iron Age (Fig. 7, a) to reach a peak in the Republican period. Potential yields remained below this maximum throughout the Roman period, increasing again at the end of the period. However, it is important to underline that, for each archaeological period, potential yields greatly fluctuated in space, due to the geographical variability in climate conditions. Regardless of the chronology, very low potential yields are observed for the highlands, while the maximum potential yields concern the Mediterranean coastline and the lower Rhône valley (Fig. 7, b). The simulation suggests that during the beginning of the Iron Age, areas of highest potential yields were restricted to the coast, spreading further north, especially to the lower Rhône river basin, as a result of the Roman climate warming. It should be reminded that variations in potential yields are modelled here mainly on the basis of climatic variations but that changes in winegrowing practices (plantation densities, training techniques, irrigation, choices of varieties, etc) could also have had major impacts on yields.

4. Discussion

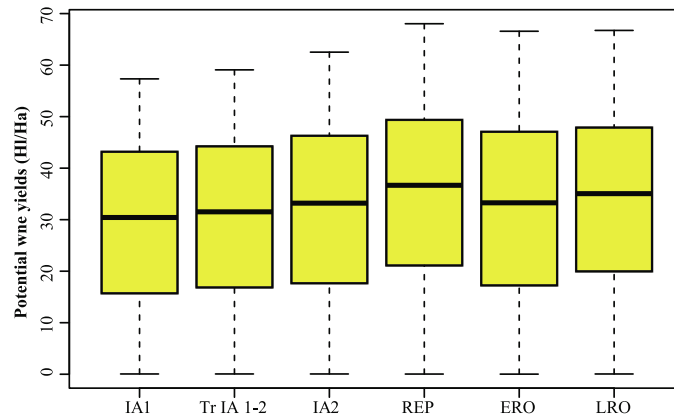
While highlighting differences that reveal the strengths and limitations of each approach, the different datasets used in this study provide consistent results and help us outline a more comprehensive and

nuanced picture of the early history of viticulture in southeastern France. It is noticeable that the observed patterns, provided by the different archaeological and archaeobotanical indicators, largely match the potential yields revealed through modelling. Wood and seed remains provide similar results, while the situation is more disparate when compared with the information from wineries and amphorae factories in the Roman period.

4.1. Evidence of winegrowing in the Iron Age

With the exception of the Greek city of Marseille, the Iron Age emergence of viticulture in the French Mediterranean region is mainly documented by archaeobotanical data (Marinval, 1988; Py and Buxo Capdevila, 2001; Buxo i Capdevila, 1996; Bouby et al., 2014). In accordance with a previous study (Bouby et al., 2023), the similar trends in the frequencies (percentage of sites where *Vitis* is recorded) and the quantities of pips and charcoals suggest that the changes observed reflect variations in the use of grapes and local cultivation of the plant. Indeed, while the presence of pips at the sites is primarily indicative of local grape consumption, that of charred wood is a reliable indicator of vines growing nearby, since firewood is usually collected as close as possible to the habitat. Charcoal from wild vines used as firewood is seldom recorded in early sites. When fuel wood remains include significant numbers of *Vitis* fragments, this is considered as a sign of grapevine cultivation. Its availability is favoured by annual pruning, as this practice generates easily accessible firewood. In addition, local cultivation is suggested by the higher occurrence of wine-making

A) Boxplots of the distribution of potential wine yields per periods for the whole area



B) Spatial distribution of potential wine yields per periods

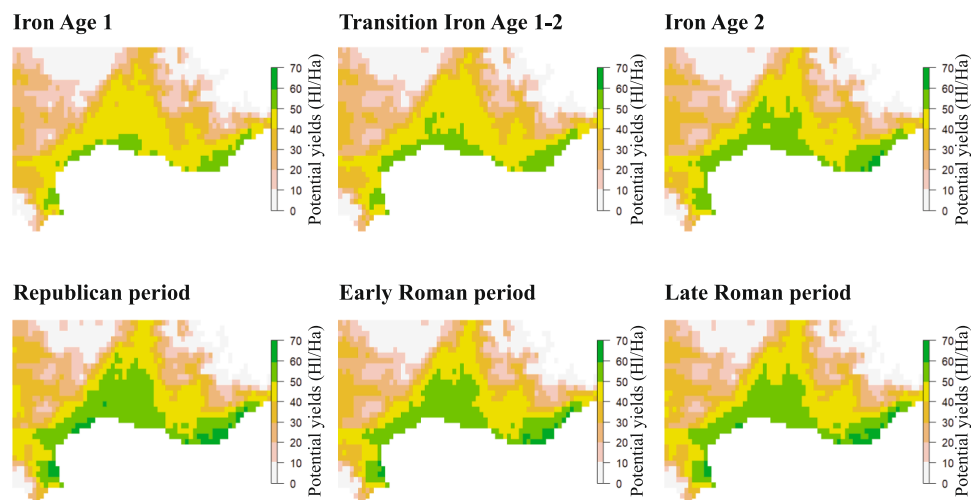


Fig. 7. Potential wine yields simulated using LPJmL. A) Distribution per period for the whole area: IA1 = Iron Age 1, Tr IA1-2 = Transition Iron Age 1–2, IA2 = Iron Age 2, REP = Republican period, ERO = Early Roman period, LRO = Late Roman period, B) Spatial distribution according to archaeological periods.

indicators, concentrations of grape pips and number of wine pressing residues, as grapes are not expected to be transported over long distances before pressing.

Archaeobotanical indicators suggest that viticulture started sometime in the 6th–5th c. BCE. Throughout the Iron Age, it was mostly limited to the Mediterranean lowlands with some expansion northwards along the Rhône valley. Modelling based on paleoclimate information indicates that viticulture emerged at a time of low potential yields compared with later centuries, but that these potential yields increased progressively during the Iron Age. Vinegrowing developed at the same time. However, any environmental determinism should probably be considerably tempered by cultural factors. In fact, the Mediterranean coastline and the lower Rhône valley are areas with the highest potential yields but also the place where the way of life and social organization of indigenous populations were most deeply affected by the influence of Mediterranean peoples, in particular the Greeks of Marseille (Py, 2012; García, 2014). In particular, these areas were a favoured market for the sale of Marseille wine (Bats, 1990). The situation appears to be comparable throughout the western Mediterranean. The first traces of winegrowing in southern Italy and Sardinia, in the second half of the 2nd millennium BC, coincided with commercial and cultural contacts with Mycenaean people (Breglia et al., 2023; Uccesu et al., 2015). In the

Iberian Peninsula, evidence of vine cultivation is reported from the beginnings of the 1st millennium BCE in Andalusia, in relation to the Phoenician colonisation, and spread to the north-east of Spain over the 7–5th c. BCE, in parallel with the development of cultural contacts with Mediterranean peoples (Phoenician, Etruscan and Greeks) (Pérez-Jordà, 2015; Pérez-Jordà et al., 2021).

Nonetheless, early indigenous viticulture in Southeastern France was not exactly similar to that practised by the Greeks in Marseille and did not have the same intensive, speculative nature. As mentioned previously, facilities and instruments that could be associated with specialised viticulture are scarce in indigenous sites. Wine amphorae were not produced in native settlements, with the exception of a few imitations of Marseille amphorae detected occasionally (Chausserie-Laprée, 2005). Winemaking facilities are difficult to identify and do not reflect large-scale production. We can mention the pressing platform used for wine by the end of the 5th c. BCE at the port site of *Lattara* (Py, 2009; McGovern et al., 2013). We can also refer to resin-coated dolia found in a 5th c. BCE domestic context in Béziers (Olive et al., 2009), which indicates that they were destined to contain wine. It seems likely that, in their beginnings, vinegrowing and grape processing were more related to domestic and subsistence farming activities than to speculative production. In the absence of specialised structures these activities left few

archaeological traces (Brun, 2020), but can be well represented by archaeobotanical remains in the domestic rubbish deposits usually studied by archaeobotanists (Bouby et al., 2023).

Similarly, grapevines may have been planted in association with trees, scattered along the tracks, field borders or close to the habitations, which would make them difficult to identify via archaeological excavations (Bouby et al., 2014). As far as we know, the earliest traces of grapevine planting were found at the site of Saint-Pierre, near the port site of *Lattara* (Lattes, Hérault), and date back to the 5th c. BCE (Jung, 2017). The small vineyard is associated to the burial of a woman of high social rank, which clearly suggests the symbolic rather than the economic value of this plantation.

4.2. Evolution of viticulture from the Iron Age to the Republican period

From the 4th c. BCE onwards, more extended and frequent traces of vineyards are reported near the urban centres of Marseille, Entremont, Lattara and Nîmes (Boissinot, 2001; Jung, 2007; Pomarède et al., 2012; Arcelin, 2021). The 4th c. BCE also corresponds to a peak in the frequency of charcoal and grape pips at archaeological sites, which could corroborate the growing importance of viticulture. This is also consistent with the regional increase in the number of *dolia* and the concomitant decrease in the number of imported wine amphorae from the 4th c. BCE onwards.

However, the frequency of *Vitis* charcoal dropped from the 3rd to the 1st c. BCE, while that of grape pips declined during the 1st c. BCE. Does this mean that vinegrowing declined in Mediterranean France by the Republican period, precisely at the time when modelling reveals the highest potential yields of the whole period under study? During this period, the numerous Italian and then *Hispania Tarraconensis* amphorae found on the sites show that Rome imported wine to supply Gaul on a large scale. The Republic, which took control of southern Gaul at the end of the 2nd c. BCE, may have sought to limit local wine production. As mentioned by Cicero (*De Republica*, III, 6), the Roman Senate forbade the southern Gauls to grow grapevines and olive trees, in order to increase the value of Roman products. However, the existence and impact of such protectionist law remains controversial among historians (Bernigaud et al., 2024).

On the other hand, there could be a taphonomic explanation for the decrease in the frequency and numbers of archaeobotanical remains in the Republican sites. The increasing specialisation of wine production structures could have gradually separated these wastes from those associated with domestic activities. These production structures are still poorly documented, but wine farms and a workshop producing Dressel 1a Italian amphorae (2nd-1st c. BCE) were identified on the territory of the Greek town of Agde, in the lower Hérault valley (Gomez, 2013). Archaeological surveys suggest that other Dressel 1a and 1b Italian amphorae production sites existed, in the hinterland around Narbonne and Béziers, as well as in the Rhône valley, during the 1st c. BCE (Mauné, 2013b).

4.3. Contrasting perceptions of viticulture during the Imperial Roman period

From the beginning of the Early Roman Empire onwards, the number of excavated wine cellars and amphorae factories increases dramatically, highlighting the rapid development of specialised commercial vinegrowing and winemaking. While still important, potential yields simulated by the LPJmL model are no longer as high as they were during the Republican period. It is possible that the high productivity of the few wineries in activity during the 1st c. BCE encouraged new vinegrowers to settle, but this was probably fuelled primarily by the favourable socio-economic context. This commercial viticulture was promoted by the need to supply the Roman armies (German limes mostly) and the northern provinces, and by the development of towns, ensuring a regional market for wine. Probably it also benefited from Italian

investments helping to transfer a production system directly from Italy (Brun, 2005; Tchernia, 2011; Laubenheimer, 2017; Reddé, 2023).

It has to be acknowledged that archaeobotanical data do not reflect adequately this boom of the Early Roman viticulture, although peaks in *Vitis* charcoal frequencies and quantities are recorded during the 2nd and 3rd c. CE. The frequency of grape pips is still high but does not reach the heights of IA2. The taphonomic reasons invoked for the Republican period are also particularly relevant in what regards the ERO. With the disconnection between living areas and specialised winemaking facilities, grape remains are less likely to get mixed in charred waste generated by domestic activities. In addition, the concrete floors of Roman facilities and dwellings are less favourable to the preservation of charred botanical waste.

However, grape seeds and charcoals were present more frequently, and in greater quantities, in rural sites during the ERO period, suggesting that in fact archaeobotany primarily indicates areas of production rather than simply consumption.

Sites where *Vitis* charcoals and seeds are most frequent are distributed predominantly in the lowlands, near the Mediterranean coast, and more sporadically towards the middle Rhône valley, together with wineries and wine amphorae factories (Fig. 8) (Buffat et al., 2001; Mauné, 2013a; Carrato, 2017; Bigot, 2020). This is still the area where the highest potential yields are observed. However, socio-economic factors play again a major part in explaining this distribution: this is the area from where wine can be transported most easily via the rivers and roads to the large cities and ports of the Mediterranean. Potential taphonomic causes could also have to be considered. Archaeological excavations and archaeobotanical studies are more numerous in the lowlands, particularly because of the economic activity that gives rise to rescue archaeology. In addition, wineries and amphorae factories are easier to identify by field surveys in the cultivated plains than in the grasslands and garrigues of the plateaux. As a result, wine production in the hinterland may be underestimated, although this does not seem sufficient to account for the concentration seen in the lowlands.

4.4. Viticulture during the Late Roman period

The extent, or even the very existence, of a wine crisis during the Late Roman period has given rise to much discussion (e.g. Buffat et al., 2001; Brun, 2005, 2010; Carrato, 2020). The number of wineries started to decline from the end of the 2nd c. CE onwards, while wine amphorae production began to disappear at the end of the 3rd c. CE. The fact that technical changes occurred at the same time, notably the adoption of wood barrels to store and transport wine, makes it more difficult for archaeologists to identify wine production facilities in the last centuries of the Roman Empire (Brun, 2010). This could contribute to over-estimating to some extent the scale of the wine crisis. Regardless of its true scale, the crisis of commercial viticulture did exist, as the data on specialised wine production facilities do show a shift too significant to be doubted. *Vitis* charcoal frequencies and quantities also decrease during the 4th and 5th c. CE. The quantities of charred seeds also decrease but their frequencies remain constant. Archaeobotanical data suggest that, despite the recession, vinegrowing in the region largely persisted. The crisis primarily affected specialised commercial viticulture, but other forms of cultivation, perhaps as part of more diversified production systems, were able to survive.

Furthermore, the potential yields simulated by LPJmL do not reveal any decline compared to the Early Roman period, which supports the persistence of viticulture as observed by archaeobotany. The crisis that primarily affected commercial viticulture was probably related to social factors. The apparent demographic downturn of the 3rd-4th c. CE may have limited the extent of the markets to sell wine to, but it could also have limited the workforce needed to run the specialised estates (Brun, 2005).

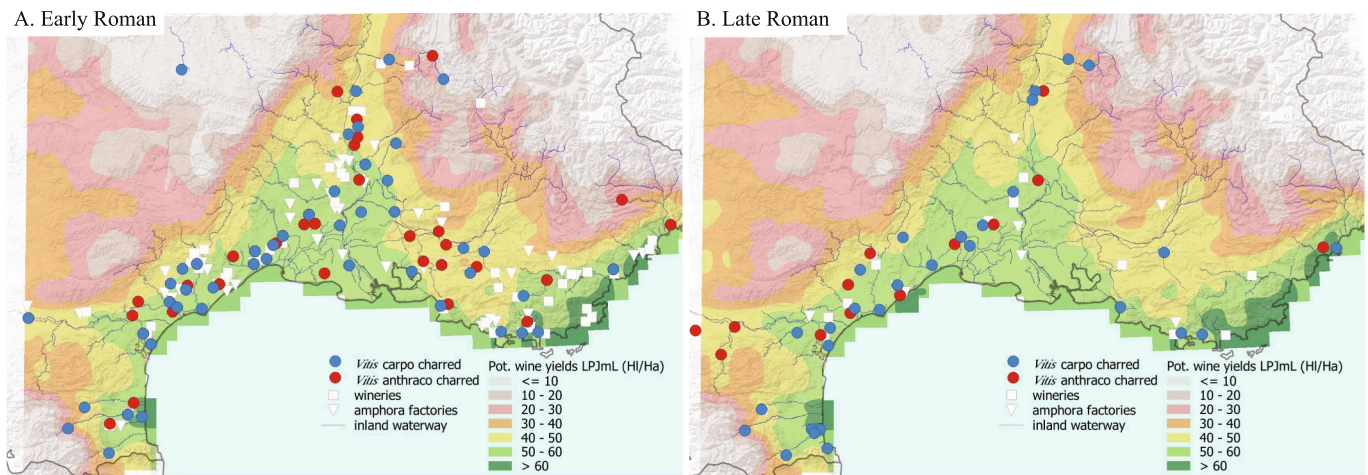


Fig. 8. Comparative spatial representation of potential wine yields simulated using LPJmL (HI/Ha), of wineries, amphora factories, sites with charred *Vitis* charcoals and sites with charred *Vitis* seed-fruits during the Early Roman (A) and Late Roman (B) periods.

4.5. Grapevine in the city

Archaeobotanical and archaeological data indicate that viticulture and wine production began in the Iron Age in conjunction with the development of the first towns in the region. In the Roman period, grapevine cultivation was primarily associated with rural territories, with the rise of specialised commercial vinegrowing. However, grapevine charcoal remains and seeds are still regularly recorded in urban contexts in our database. The quantitative composition of individual archaeobotanical assemblages shows that assemblages containing numerous wine pressing residues are present both at urban and rural sites. This seems to indicate that wine was also produced in Roman cities. Archaeological excavations in secondary urban areas have occasionally uncovered wine production facilities (Carrato, 2017). Known examples are probably too few to be representative but they seem to differ from their rural counterparts in their lower production capacity (smaller presses and cellars). Large *dolia* cellars have been uncovered in major urban areas such as Narbonne, Aix-en-Provence, Marseille and Fréjus, but no production structures could be identified, either because the areas excavated were too small or because they were storage warehouses rather than production units. The only exception is the site of Les Poiriers (Fréjus), where a basin was identified in connexion with a cellar composed of a hundred *dolia* (Excoffon, 2020). Amphorae factories have been found within the perimeter or on the outskirts of various Roman cities, particularly ports (Mauné, 2013a; Bigot, 2020). In these cases, the wine could have been transported in bulk from rural wineries to be transferred to amphorae in port cities and then shipped. Conversely, wine could have been produced and sold directly in towns for local consumption, without having to be sold in amphorae. Lastly, towns could have been places of domestic production, without the need for large-scale specialised facilities. We must also consider that some of the vines may have been grown to produce table grapes rather than wine. This may be suggested by the results of morphometric analyses made on grape pips of the Republican period originating from the site of Mas de Vignoles XIV, in the outskirts of Nîmes. The shape of these seeds matches modern eastern table grapes instead of wine varieties (Bonhomme et al., 2021). For that matter, the Roman agronomist Columella considered that table grapevines should be planted near towns, so that the transport of the grapes to the market could be easily done avoiding damage (*De re rustica*, 3, 2). In urban areas, grapevines could have been grown in small vineyards or in multi-crop gardens and orchards, as it seems to have been the case in the surroundings of Fréjus (Bouby et al., 2011).

5. Conclusion

Comparing the different approaches used in this study reminds us that the grapevine is a plant with multiple economic and cultural uses, which can be integrated into various cultivation, processing and consumption activities and systems. Essentially, the structures identified during excavations are evidence of specialised viticulture destined to wine production, whereas archaeobotanical remains may be the outcome of more diversified uses and production processes, depending on the time period and context studied. These processes, which have decisive taphonomic consequences on the assemblages, are often difficult to disentangle. While archaeobotanical remains provide good evidence of winegrowing areas, they give a less accurate picture of the scale of the activity.

Our results illustrate the joint influence of environmental and socio-economic factors on the evolution of winegrowing. Its development during the Iron Age benefited from the progressive improvement in climatic conditions, which had a favourable impact on potential yields. Within this climatic framework, the changes perceived on the basis of archaeological and archaeobotanical data can be explained primarily by socio-economic factors, as it seems to be the case throughout the Western Mediterranean.

To better understand the inter-relationships between the various archaeological and archaeobotanical indicators used to characterise ancient viticulture will require the more systematic application of precise sampling protocols at site excavation level. Too many archaeological excavations are still being carried out on winegrowing sites without archaeobotanical approaches being taken into account. Conversely, archaeobotanical surveys will have to take greater account of the archaeological contexts in which the samples were taken in order to better understand their composition. The relationships between wine production and climatic conditions could also be better explained by complementary approaches at site level, such as the study of stable carbon isotopes from grapevine macroremains.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2024.104952>.

Data availability

Data is provided as supplementary files attached to the manuscripts

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