

Identifying social learning between Roman amphorae workshops through morphometric similarity

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Abstract

The aim of this study is to identify interactive dynamics within amphorae workshops in the Roman Empire. The *Baetica* province (currently Andalusia, southern Spain) hosted for almost 300 years a massive infrastructure that supplied olive oil to the Western provinces of Rome. A large number of workshops produced the same type of amphora to ship the product through maritime and riverine transport networks. Despite the amount of evidence it is difficult to find an archaeological proxy able to tell us how were these workshops organised.

We apply here an evolutionary framework to understand potential links between workshops through morphometric similarities in the amphorae they produced. By exploring small yet statistical significant differences in the amphorae made in 5 different workshops the approach is able to identify how individual potters acquired and transmitted technical skills. Our approach applies multivariate statistical methods to cluster a variety of amphorae based on morphometric measurements. Other studies have developed similar approach to analyse handmade pottery but we show here that the method can be also applied to large-scale production of a standardized amphora type (i.e. Dressel 20).

Results suggest that morphometric similarity is inversely correlated with spa-

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tial distance between workshops. This outcome suggests that pottery-making techniques were transmitted through vertical transmission with little or no movement of potters between distant workshops. The work also highlights that morphometric similarity may be an effective proxy to identify social learning dynamics even amongst workshops producing exactly the same amphoric type.

Keywords: Roman Empire, amphorae, Dressel 20, social learning, cultural evolution

1. Introduction

The archaeological record can help us identify the mechanisms by which humans learn from each other (Richerson and Boyd, 2005; Schillinger et al., 2016a). Cultural transmission dynamics can be identified by analysing archaeological proxies able to capture the distinct variability generated by different social learning mechanisms (Shennan and Wilkinson, 2001; Eerkens and Lipo, 2005). This approach has been successfully applied to the material culture generated by small-scale societies but it has been seldom explored in the case of large-scale production (Shennan et al., 2015; Neff, 1992).

This paper explores the social dynamics of specialized production in the Roman Empire. We focus here on analysing large-scale production of a single amphoric type (Dressel 20) in a specific area. An evolutionary framework has been used to identify social learning dynamics between pottery-makers (Mesoudi, 2015; Shennan, 2008a). Following a large number of authors (Cavalli-Sforza and Feldman, 1981; Hosfield, 2009), pottery production can be learned on different modes of cultural transmission depending on the level of production in the communities. Vertical transmission is a mode of transmission when the teaching of the production is done from master to disciple while in horizontal transmission individuals teach pottery techniques to other individuals within the same level and those workers spread the knowledge to their community (Epstein, 1998).

Artefact variation should also be affected by geographical distance (Björklund et al., 2010; Shennan et al., 2015; Van Strien et al., 2015). If vertical transmis-

sion is predominant then culture should be similar in nearby groups with high degrees of interaction (Hart, 2012). The underlying consequence is that it should
25 be possible to identify interaction between workshops by quantifying similarity amongst the amphorae they produced; if apprentices moved between distant workshops then no differences would be found on this proxy while a more strict vertical transmission would be revealed by distant workshops exhibiting less similarity.

30 The debate on social learning processes is hindered by the challenge of detecting the different modes of transmission in the archaeological record (Roux, 2015). In the case of archaeology, several studies have analysed this process focused on the production of handmade pottery (Steele, James et al., 2010) or with stylistic variations (Neiman, 1995; Shennan and Wilkinson, 2001). Our
35 work aims at identifying learning processes even in the case of the standardized massive olive oil production common during the Roman Empire (Gandon et al., 2014; Bevan, 2014).

Olive oil was one of the most important products of the Classical Mediterranean world as it was used in almost all aspects of daily life including cooking,
40 lightning and hygiene (Mattingly, D.J., 1988). The *Baetica* province (currently Andalusia, southern Spain) developed a massive infrastructure of olive oil production to face the demands of the Roman Empire. The product was shipped in large amounts of amphorae to distant provinces all along the Western provinces. One of its most important clients was the Roman army as olive oil was supplied
45 to tens of thousands of legionaries in places such as Britain (Funari, 2005; Carreras Monfort, 1998) and Germania (Remesal, 1986).

For this reason, this ancient province became an important support for the production and distribution of olive oil to the rest of the Empire during three centuries (Chic, 2005; Berni, 1998; Remesal, 1998). *Baetica* provided a strong
50 connectivity through riverine transport that allowed inland producers to use an important trade network through the Mediterranean and Atlantic (García Vargas, 2010). The exponential production growth required the creation of over a hundred amphora workshops supporting olive oil shipment. These workshops

were located along the Guadalquivir river and its tributaries. The majority of
55 amphorae produced in this area are classified as *Dressel 20* type divided into a
variety of subclasses (Berni, 2008; Martin-Kilcher, 1987). Dressel 20 were used
mostly to transport olive oil for around 300 years in order to satisfy the demand
within Roman Empire (Remesal, 1977).

This specialized production was highly standardized both in terms of prod-
60 ucts and processes and did not vary much. The same type of amphora was
produced over 300 years with small differences while similar stamps and infor-
mation was recorded on them Rubio-Campillo et al. (forthcoming). Despite
our knowledge of the process little is known on how learning was organised in
these workshops. Did they have different traditions and apprentices worked in
65 the place where they were trained? Did potters work in more than one work-
shop? Were changes in production decided by workshops or by external actors?
All these questions are linked to the social learning processes that took place
in the workshops. If the system was organised based on vertical transmission
mechanisms with no potters moving to distant workshops then amphorae pro-
70 duced in nearby workshops might share more similar traits than with the rest of
the production. On the other hand, if horizontal dynamics were common then
this correlation with spatial coordinates should not be present as workers would
share their methods (Hosfield, 2009).

The paper can be summarized as follows. The next section introduces the
75 dataset and the methods used to analyse it. Section three presents the results
while the last part discusses the outcomes and highlights the main conclusions
of the work.

2. Material and methods

Our sample consisted of 413 Dressel 20 amphorae collected from the 5 Dressel
80 20 workshops that have been more intensively excavated in the last 4 decades.
The workshops were located at Malpica, Cerro del Belén (hereafter, Belén) (Díaz
Trujillo, 1992), Parlamento (García Vargas, 2000), Villaseca (García Vargas and

Morena, forthcoming) and Las Delicias (Fernández et al., 2001; Mauné et al., 2014) (see Figure 1).

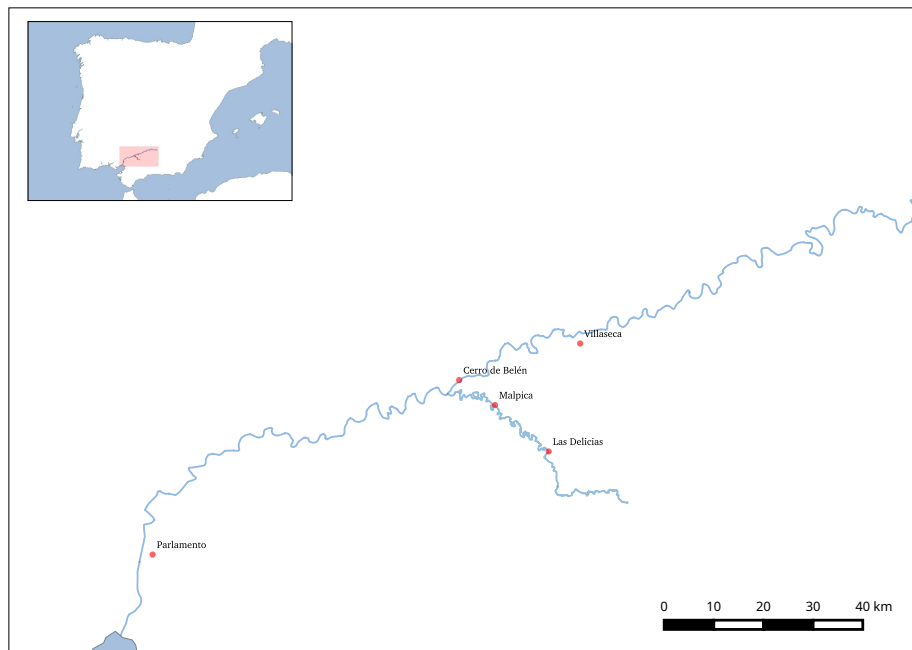


Figure 1: Map from *Baetica* province during the Roman Empire depicting the location of the 5 analyzed workshops. Dressel 20 workshops were mostly distributed along the rivers Guadalquivir and Genil.

85 The sample was roughly uniformly distributed amongst the 5 workshops (80-100 samples for each of them). These workshops were located a diversity of locations so spatial dynamics could be potentially identified. All of them had overlapping long chronologies so differences in amphorae could not be inherently explained by temporal variation. This trait is reinforced by the fact that the

90 Dressel 20 type did not show any remarkable change in shape for almost three centuries (Berni and García Vargas, 2016). We analyzed Dressel 20 of the three most abundant variants spanning three centuries (Dressel C, Dressel D, Dressel E) (Berni, 2008; Martin-Kilcher, 1987). All the variants were found in the 5 workshops so no intrinsic bias was generated by them.

95 Eight different measurements were taken from each amphora. The metrics

were focused on the rim sherds as this section presents the best preservation for most archaeological contexts and they present good indicators of variation (Berni, 2008). Other interesting proxies such as handles and bases were found in lesser quantities and for this reason they would be less useful for quantitative approaches due to low sample size. The measurements can be seen in Figure 2; they were divided into exterior diameter, inside diameter, rim height, rim width, shape width, rim inside height, rim width 2 and protruding rim.

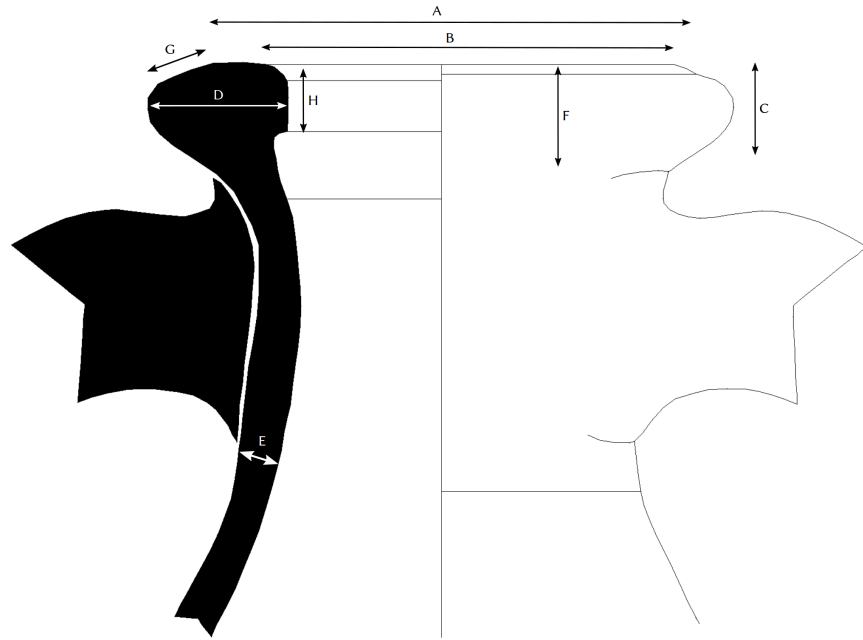


Figure 2: The 8 morphometric measurements taken for all amphorae. A: External diameter. B: Inside diameter. C: Rim height. D: Rim width. E: Shape width. F: Rim inside height. G: Rim width 2. H: Protruding rim

2.1. Principal Component Analysis

Principal Component Analysis (PCA) was used to simplify the large number of variables in our dataset. The method allowed us to synthetise the data by focusing on a small number of Principal Components (PCs) while retaining

a majority of the variation which was in essence what we wanted to explore (Jolliffe, 2002). PCA is a common method in archaeology in scenarios studying intrasample variation (Shennan, 2008b; Li et al., 2014; Schillinger et al., 2016b).

110 2.2. Discriminant Linear Analysis

The next step was focused on evaluating if differences in the two main Principal Components are linked to the workshop where the amphorae were made. This idea was explored with the application of clustering algorithm and the evaluation of a Confusion Matrix. If the amphorae made in two workshops are
115 easily confused then their average measures are similar; on the other hand, if the rate of misclassification between two workshops is very low then the amphorae made in these locations are distinctively different.

The choice of clustering method was Linear Discriminant Analysis (LDA). Training was performed using a randomly sampled dataset with equal sample
120 size for each workshop. The trained LDA model was then applied to the entire dataset as we were interested on how well workshop attribution could be predicted relying exclusively on morphometric measures. A Confusion Matrix (CM) was used to quantify under what extent the amphorae of different workshops can be identified. CM computes this quantity as the probability of misclassification
125 between each pair of groups in the dataset (e.g. the workshops). This method has already been used in similar scenarios aiming at identifying differences in artefact production (Charlton et al., 2012; Thorpe et al., 1984; Aguilera, 1998)

2.3. Spatial Distance

The last step of this method was the comparison of the similarity distance provided by the Confusion Matrix against the spatial distance between
130 workshops. A significant correlation between these distance matrices would suggest processes of isolation-by-distance typical from vertical transmission (Crema et al., 2014). Euclidean distance was used to measure distance amongst workshops as they were aligned following the river course. The evaluation of these two
135 distance matrices (morphometric distance and spatial distance) was computed

using a Mantel test. Mantel test evaluates the degree of pairwise correlation between two matrices and has been particularly useful in archaeology to explore the spatial dimension of cultural change (Mantel, 1967; Diniz-Filho et al., 2013; Crema et al., 2014).

140 3. Results

The Principal Components of the dataset are listed in Table 1

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Exterior diameter		-0.195			0.281	-0.217	0.369	0.829
Inside diameter			0.105	-0.414	0.838		-0.257	-0.202
Rim height			-0.143	-0.425	-0.242	-0.744	-0.424	
Rim width		-0.524	0.136			-0.342	0.582	-0.497
Shape width		-0.170	-0.920	0.253	0.232			
Rim inside		0.156	-0.299	-0.750	-0.240	0.345	0.377	
Rim width 2		-0.789		-0.113	-0.219	0.393	-0.369	0.139
Protruding rim	0.989							

Table 1: PCA results. The *Protruding rim* captures a majority of the variation.

Values for the two main Principal Components can be seen in Figure 3. Exploratory analysis suggests that the second PC exhibit different dynamics for the most distant workshop (Parlamento). Additionally, the first PC also tends
145 to display more similar values for amphorae made in nearby workshops such as Belén and Malpica.

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LDA was applied to the two main PCs. For the analysis, a total of 93 samples
150 were correctly classified while 113 were incorrectly classified, as shown the Fig. 4. The results showed a similarity into three groups (Belén, Malpica and Villaseca) while two groups depicted a different pattern (Las Delicias and Parlamento). This could be caused by the geographical proximity, being Parlamento and Las

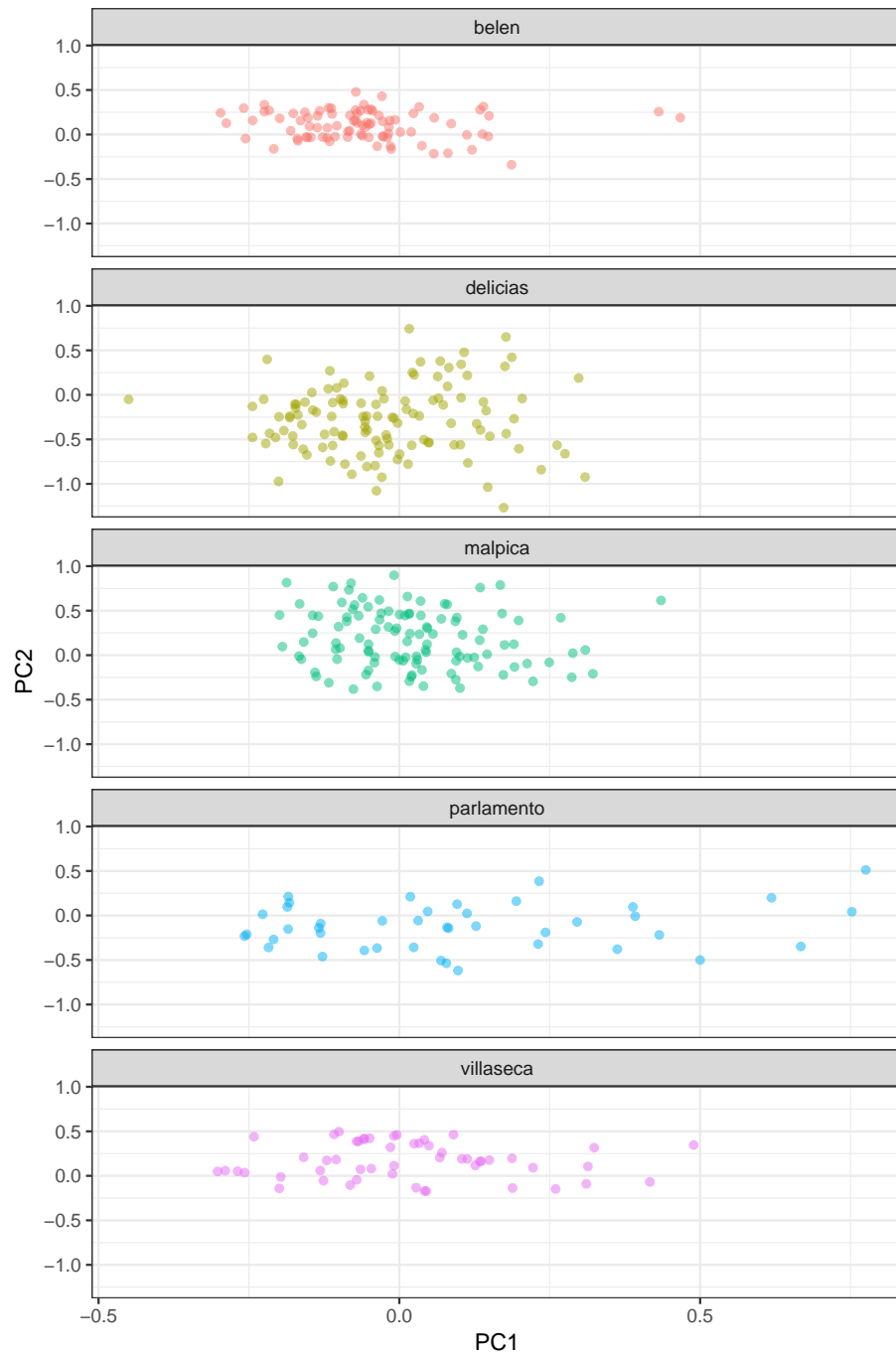


Figure 3: Scatter plot for the First and Second PCs. Sample is split by workshop

Delicias both workshops with the geographical distance more farther than rest
of workshops.

	PC1	PC2
Standard Dev	0.3480758	0.1873301
Proportion	0.5747347	0.1664696
Cumulative	0.5747347	0.7412043

Table 2: Result values from the first two principal components

Discriminant Analysis was used to analyse the results obtained from PCA.

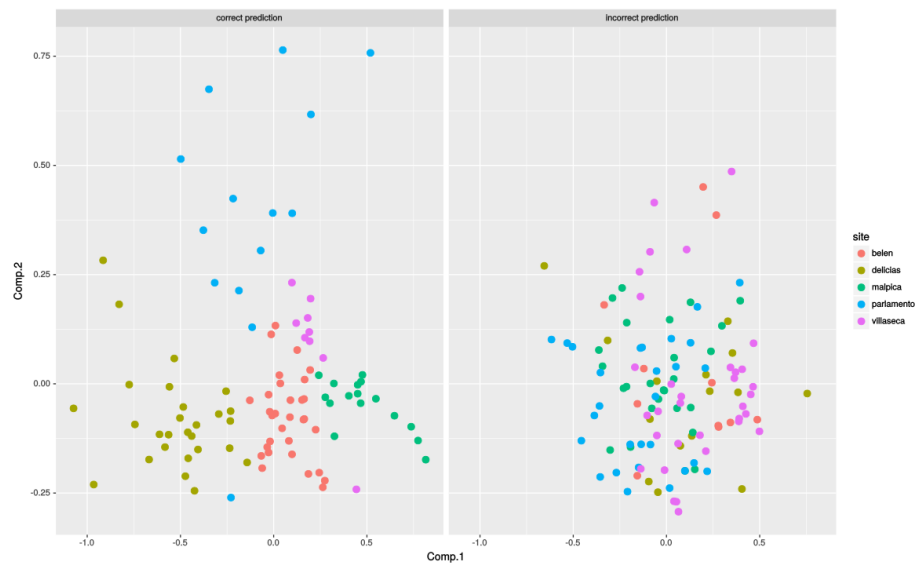


Figure 4: Plot with the correct and incorrect predictions result of Discriminant Analysis

The results of Confusion Matrix proved that workshops with a minor spatial distance such as Malpica and Belén had more troubles of being distinguished due to the similarity in the results obtained (see Table 3). Classification test
with the whole dataset gave an accuracy percentage of 50.61%. Applying this to
a training dataset reduced the accuracy to 46.19%. Therefore, spatial distance
could be inversely correlated with making techniques processes of amphorae in
the case of *Baetica* area.

	Belén	Delicias	Malpica	Parlamento	Villaseca
Belén	31	6	12	11	13
Delicias	2	27	6	13	1
Malpica	6	4	16	2	13
Parlamento	3	2	3	14	6
Villaseca	0	3	5	2	9

Table 3: Confusion Matrix with rows pointing out the workshops analysed. The sample analysed gave an accuracy percentage of 46.19 %. Results of P.Value <0.01.

We calculated the correlation between spatial distance generated by the Euclidean distance and the distance among amphora measurements, calculated using the Confusion Matrix. The workshops were chosen with different geographical distance in order to prove the correlation between spatial distance and variability of the amphora production techniques. Mantel test indicated results more reasonable (rm= 0.3841; p= 0.025 with 199 permutations). The analysis shows that morphometric distance of the amphorae are strongly correlated with the spatial distance of workshops. Accordingly closer workshops tend to be more similar than the rest: when geographic distance is low, as the example of Belén and Malpica, the morphometric distance seems more similar whereas when distance is higher, as Parlamento, the morphometric distance displays differences with the rest of workshops. Thus, the results suggest that the variability on the making-techniques processes might depend on the spatial distance.

4. Discussion and Conclusion

Differences on the making techniques processes among workshops show a variability correlated with spatial distance. The analysed morphometric traits suggest that the similarity between amphorae decreases with the spatial distance between the workshops where they were produced. As a result, amphorae made in nearby workshops with a minor spatial distance share more traits than

amphorae made in pottery workshops farthest. In other words, the variability
185 on the making techniques processes was more difficult to differentiate in nearest
workshops. In our case, Malpica and Belén workshops where the geographical
proximity is the closest shared more traits in comparison with other workshops
(Parlamento and Las Delicias). Thus the probability of interaction between
workshops is increasing when the proximity is closest while this likelihood de-
190 creases when the possibility of interaction is low.

We have observed than rivers courses could have affected in the transmission
factors. In the case of the commerce, rivers and its tributaries played an impor-
tant role for the transport of goods. The huge demand within Roman Empire
and the good conditions for the loading and unloading of products (Bevan, 2014)
195 might have influenced the mode of transmission due to the continuous contact
between workshops.

The results also suggest that vertical transmission could be the main cul-
tural mechanism to explain the variability between workshops. The different
morphological traits among workshops seem proper of a low contact between
200 potters from other workshops. The evidence confirms therefore that these pot-
tery techniques were transmitted with high fidelity and few changes during three
centuries. It would mean that the disciples could have remained the learning
techniques in the workshops where they were trained. By contrast, horizontal
transmission doesn't seem to be the most probable process. The continuous
205 contact between potters from different places generated a greater homogeneity
in the technical practises. As results, workshops were sharing the same produc-
tion techniques that it would generate a social network where potters within
the same generation worked in different workshops at the same time. Our result
suggest a progressive contact with closer workshops instead. Moreover, the fact
210 that isolation by distance is detected suggests a limited displacement between
distant workshops. Thus, vertical transmission would be explained with this
observed process. However, the diversity of social learning processes are clearly
complex. In other words, the transmission of technical skills between master
and disciple did not discard that horizontal transmission played an important

215 role in this process as well. It can be a process where this vertical transmission
dominated at first in the same workshops but consequently this transmission
would be affected by workers who exchanged ideas or workers moving to other
workshops.

The combination of empirical analysis with statistical method have provided
220 a strong baseline for a better understanding of the amphora production in the
Roman Empire. These methods offer also an alternative complement to other
methods as archaeometry for the characterization of production sites and places
of consumption. We have identified measurable differences in the techniques by
observing and we have tested those particularities using multivariate methods
225 and Mantel test. Our analysis provides a useful guideline for the exploration
of the social learning processes related with amphora production in the Roman
Empire. Hence, the results have lightened to understand the link between social
learning and archaeological evidence in a diversity of scenarios.

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Wien with Pleiades template.

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