Combining residue analysis of floors and ceramics for the study of activity areas at the Garum shop at Pompeii

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Abstract

In this paper, we propose the application—for the first time in the Mediterranean area—of the combination of the study of chemical residues in floors and ceramics, with the aim of providing information about the activities carried out in archaeological buildings. We chose the Garum Shop at Pompeii to test the method. In fact, due to the peculiarity of this archaeological context, it provided an ideal case in which the activities performed are in part known, and the ceramic vessels recovered are still *in situ*.

Floor samples were studied by means of spot tests developed in Mexico aimed at identifying the presence of phosphates, fatty acids and protein residues, while the organic residues preserved in the ceramic matrix of amphorae, *dolia* and other ceramic vessels were studied by gas chromatography coupled with mass spectrometry. Moreover, we integrated the data obtained with specific studies directed at better identifying the solid residues found inside two of the amphorae studied: botanical studies of fruit stones recovered in a Dressel 20 amphora, and the characterization of the lime preserved in an African amphora.

The research allowed for the identification of the traces of some of the activities performed, such as cooking and producing garum in the floors of the building, and the use and re-use of amphorae and dolia before the Vesuvian eruption.

Key words: Residue analysis; Activity areas; Ceramic content; Roman dolia; Garum; Pompeii

1. Introduction

Residue analysis has experienced a great deal of advancement in the last several years. As was first suggested in the 1970s, there is now no doubt about the fact that both archaeological ceramic materials and floors can be analysed to recover information regarding the residues preserved. This allows us to better understand the content, and therefore the use of ceramics (i.e., Condamin et al. 1976; Evershed 1993, 2008; Garnier 2015; Pecci 2009a; Regert 2011; Nigra et al. 2015). Additionally, the analysis of residues preserved in archaeological floors (both plastered and earthen) allows for the possibility of understanding the spatial distribution of human activities and the identification of activity areas (i.e., Barba 1986, 2007; Barba and Bello 1978; Barba et al. 2014; LeCount et al. 2016; Ortiz and Barba 1993; Pecci 2009b, 2013; Rondelli et al. 2014; Terry et al. 2004; Wells 2010; Wells and Moreno 2010; Wells and Terry 2007). Used in combination with other techniques, both ceramic and floors analysis constitute an effective archaeological tool for discerning ancient living patterns, and provide elements to identify what has been defined as ancient "anthropic activity markers" (Rondelli et al. 2014).

In this paper, we propose the application, for the first time in a Roman archaeological context, of the combination of the study of the chemical residues in floors and ceramic vessels originating from the same rooms of an archaeological building to provide a better understanding of the activities performed. Moreover, the study of the content of ceramics has been complemented with other methodologies (i.e., archaeobotany and characterization of lime), which are aimed at better identifying the solid residues preserved inside some of the studied vessels.

Previous studies which combined the chemical analyses of floors and ceramics have been carried out by Barba's group at the UNAM by applying spot tests to Mesoamerican and Colonial contexts (Reynoso 2015). Here we test this methodology in a Mediterranean context, using the spot tests developed in Mexico (Barba et al. 1991) to study the residues preserved in the floors, and gas chromatography coupled with mass spectrometry (GC-MS) to study the residues preserved in the ceramic vessels. Moreover, a new aspect of our study is the integration of chemical analysis with the analysis of the preserved solid content of two amphorae: in one case, the botanical identification of some seeds that were contained in one Dressel 20 amphora; in the other case, the mineralogical characterization of the solid content of an African amphora was proven to be lime.

To test the methodology, we have chosen the Garum Shop at Pompeii (Fig. 1), investigated in the framework of the project "From Fishing to Garum at Pompeii and Hercolaneum. Exploitation of marine resources in the Vesuvian area", directed by D. Bernal Casasola and D. Cottica (2008-2012), as it provided a perfect context where vessels were still *in situ*, and we knew of at least some of the activities performed in the different rooms.

Although the Garum Shop had been excavated during the 1960s by Maiuri (Bernal and Cottica 2013), not all of the floor surfaces had been excavated, and therefore, not all of the ceramic materials preserved on the floors were removed. Moreover, Maiuri did not move the dolia found in courtyard 9 (room E9), nor the amphorae in courtyard 13 (room E13) (Fig. 1). Therefore, due to the peculiar archaeological context of Pompeii, some of the ceramic material recovered during the project was still located where the inhabitants of Pompeii left them, so the study of these materials allowed us to obtain information on the nature and spatial distribution of the activities performed in the building just before it was abandoned.

At least some of the activities carried out in the shop are known, such as the cooking activities performed in the kitchen and the production/selling of garum (the famous Roman fish sauce) and other fish by-products, which is suggested by the preservation of fish bones in the dolia of courtyard 9 (Fig. 1) and those recovered from the floor surfaces thanks to a careful sieving of the earth (Bernal and Cottica 2013). Therefore, our aim was to verify the enrichment patterns produced by these activities and to verify if something more could be said about the use of space and ceramic content in the site.

A challenge of this work was to confirm the possibility of performing chemical analyses of floors and ceramics in Pompeii. It is in fact particularly interesting to understand whether the patterns of absorption of the floors and ceramics were altered by the tremendous consequences of the Vesuvian eruption. The works carried out by Parnell, Terry and Sheets (2002) at El Cerén (El Salvador) allowed for hypothesizing that residues could be preserved, but we still had to verify it.

Because the archaeological project was aimed only at cleaning the previously excavated areas, not at performing new excavations, the original floor was exposed in only some of the rooms during the project. Moreover, in some cases, the floor could not be sampled due to its poor conservation. Therefore, we could only sample some of the floors of the shop (the areas where floor samples were taken are visible in Fig. 1). As for the ceramic vessels, we only studied vessels preserved in situ, five dolia from courtyard 9 and ceramic materials recovered in the so-called "amphorae courtyard" (E13), possibly related to the production of garum or to the life of the shop.

2. The archaeological context

The Garum shop is located in the *Regio I* of the archaeological site of Pompeii (I, XII, 8) (Fig. 1) (Curtis 1979; Bernal and Cottica 2013). The building was probably a private residence built at the end of the third century B.C., with very few changes until the end of the second century B.C. It was transformed, probably immediately after the earthquake of the age of Nero (62 A.D.), into a shop devoted to the manufacture, storage and sale of garum and other fish by-products (Bernal and Cottica 2010, 2013; Bernal et al. 2008, 2009, 2011, 2012; Cottica et al. 2009). Garum was one of the main marine food products in Antiquity, consumed daily and really widespread in the Atlantic and in the Mediterranean basin, being produced in different regions (Curtis, 1991). This fish sauce is the result of fermentation of not-flesh parts of big fishes such as tuna (blood, bones, viscera…) with other ingredients (herbs, wine, small fishes, shells…) in salt during approximately three weeks, resulting in the production of a sort of paste, as mentioned in ancient literary sources such as Gargilius Martialis or the Byzantine manuscript called Geoponica (García Vargas et al. 2014, 68-70). Afterwards this semi-solid product was pressed, obtaining an amber-coloured liquid (garum) and a solid residue (allec). Both of them were used in gastronomy and medicine, at different levels, due to their high content in vitamins and energetic properties (Etienne and Mayet, 2002, 43-53). The chemical composition of these so appreciated products can vary depending on the added ingredients. In general we were expecting that the fish processing areas were rich in phosphates, protein residues and fatty acids identified with the spot tests applied (see section 3.1).

Similarly to the whole city of Pompeii, the Garum shop was buried by the eruption of Vesuvius in 79 A.D. The Garum shop is composed of several rooms that are organized around a central courtyard (courtyard E9), which was likely the real laboratory, as the presence of six dolia, which still contain fish bones, suggests (Bernal and Cottica 2013; García et al. 2014) (Fig. 1). At the back of the building there is the so-called "amphorae courtyard" (E13), where upside down amphora were found *in situ* (Bernal et al. 2014). The kitchen (E6), is located to the east of courtyard 9 and probably belonged to the original house, together with three rooms (room 1, 2 and 3) facing Castricio Street, which could not be sampled, and room 12, which we studied (Bernal and Cottica 2013; De Luca et al. 2015) (Fig. 1).

3. Materials and methods

3.1. Floor samples

A total of 153 floor samples was analysed (Fig. 2, 3 and 4). Samples were obtained with a drill and/or a scalpel at the intersections of a square grid covering the rooms. The dimension of the grid had to be adapted to the different areas sampled. When the floors could not be sampled because they were not preserved, or for conservation needs (i.e., in room E12, where the floor was a *signinum*), samples were recovered with an attempt to respect certain regularity, as suggested by Wells (2010). The floors of the courtyards were beaten earth floors; the kitchen had a plastered floor; the surface of the oven of the kitchen was also plastered, with a better quality of plastering ,because it shows a high cohesion and there are no macroscopic weathering phenomena; the floor of room E 12 was an *opus signinum* floor. The samples were ground and analysed using spot tests developed at the UNAM (Mexico), where these analyses were first used (Barba 2007; Barba et al. 1991). These tests have also been successfully applied to archaeological and ethnoarchaeologcal contexts out of Mesoamerica (Ortiz et al. 2013; Pecci 2009b, 2013; Pecci et al. 2013a; Rondelli et al. 2014). The spot tests used aimed to identify the presence of phosphates, protein residues and fatty acids. The specific methods used are published in Barba (2007: 442-443). These are semi-quantitative tests that allow to identify the presence of residues in the samples but do not provide information on the exact quantities, nor the exact origin of the identified compounds (e.g. if fatty acids derive from animal products or plant oil). However they have shown to be useful in the identification of activity areas and the interpretation of the use of space (Barba 1986, 2007; Barba et al. 2014; Ortiz and Barba 1993; Pecci 2009b, 2013; Rondelli et al. 2014).

The results of the spot tests were plotted on the plan of the rooms studied using a Geographical Information System (GIS). They were then interpolated with Inverse Distance Weighting (IDW). This permitted us to obtain distribution maps showing the concentrations of each chemical compound in the floor. Although recent studies have shown the potentiality of different interpolation methods (Rondelli et al. 2014), inverse distance weighted (IDW) interpolation was used here because this method has proven to be useful for the study of small scale areas (Pecci 2013). At the interpretative stage, the distribution of the different residues were considered together to evaluate the relations between the distribution of the different compounds. The different characteristics of the floors and substrates were taken into account at the moment of the interpretation of the results of the analyses , because the application of spot tests and the results mapping allows to observe the distribution in a relatively homogeneous substrate (which in our case is a human made surfaces), therefore allowing to understand where there are concentration and absence of residues for each room/substrate. This was especially important in the kitchen, where the floor and the surface of the oven had a different quality of plastering. Beaten earthen floors can be enriched with phosphates present in the earth before human activities are carried out on them (Barba et al. 2014; Pecci 2013).

The distribution of residues was then related to the other archaeological materials found on the floors during excavation, to trace the spatial distribution of activities at intra-site level.

3.2 The study of ceramic vessels

Residue analysis of ceramic samples was performed on a total of 12 ceramic samples coming from the two courtyards of the shop that were analysed (Table 1). Five dolia found in the central courtyard of the workshop (E9) were sampled (Table 1, Fig. 1 and Fig. 5). They preserved the original content: a great quantity of fish bones, which archaeozoological studies verified were uniform and belonged to complete anchoes that had been used to produce a sauce (García et al. 2014; Rodríguez and Marlasca 2011). Although the content is known, residue analysis of the ceramic matrix of the dolia was performed because it could provide information on specific preparation techniques of the fish by-products (i.e., with wine or oil), on the possibility of a re-use of the dolia and on the presence of coatings of the dolia. Among the ceramic materials recovered in courtyard 13, we sampled the ceramic body of one Dressel 21-22 (sample 6), one Dr 20 (sample 9) and one African amphora, possibly an Ostia 59 amphora (sample 10), to understand their content (Fig. 6). The African amphora had a whitish filling that was also sampled and analysed to verify that it was related to the original content of the amphora (sample 11) (Fig. 6). Moreover, we sampled a fragment of a dolium found in the courtyard (sample 7), and a Red Pompeian ceramic (sample 8).

The samples were pulverized after mechanically cleaning the ceramic, and extracted using the following methodology: **a.** The total lipid extraction and its hydrolysis was carried out following the methodology proposed by Mottram et al. (1999), using 1g of grounded sample. 5 µl of a standard solution of octacosane (3 mg/ml) were added to the powder before the solvent extraction. After the total lipid extraction, a hydrolysis on the solid residues was carried out following Pecci et al. (2013a). For the identification of wine markers, the extraction developed by Pecci et al. (2013b) was carried out on 500 mg of sample. The derivatization and GC-MS analysis was performed using the same instrument and parameters published in Giorgi et al. (2010). Peak assignment was made by comparison with the NIST library and standards.

The whitish solid residue present in the inside of the African amphora, possibly an Ostia 59 amphora (sample 11), was also studied by X-ray Powder Diffraction analysis (XRPD), using a Bruker D8 Advance X-ray powder diffractometer with Cu-Ka radiation, operating at 40 kV and 40 mA. Scans were collected in the range 3°–65° 2θ, using a step interval of 0.02° 2θ and a step counting time of 0.4 s. The EVA software program (DIFFRACplus EVA) was used by comparing experimental peaks with PDF2 reference patterns to identify the mineralogical phases in each X-ray powder spectrum.

Some carpological remains were recovered during the archaeological excavation of the fill in the Dressel 20 amphora (sample 9). They were analysed under a binocular microscope and separated according to the morphological traits: all of the remains were dried fruit stones composed of two valves. The entire fruit stones were counted as ‘‘individuals’’, the single valves were counted as “fragments”. The taxonomical identification was carried out by comparing them with the reference seed collection of the Department of Agricultural Sciences of the University of Naples Federico II, atlases and specialist literature (Renfrew 1973; Schoch et al. 1988).

4. Results of the analyses of the floors

The results of the analyses of the floor of courtyard 9 (E9) show very high levels of phosphates (Fig. 7) that, although possibly influenced by the fact that the floor is of beaten earth, are likely related to the activities carried out in the courtyard. In fact, high levels of protein residues and fatty acids are also present in the same area. These residues are probably the consequence of the producing, storing, and possibly the selling of the garum, or of other fish by-products that were contained in the dolia preserved in the room. Although samples were not taken in exactly the same place where the dolia were found, it is possible that the liquid was spilled around when put in or taken out of the dolia to be sold.

Although the analyses were carried out with different methods from the ones used here, and sometimes there are differences in the distribution pattern of P analysed with ICP-MS and phosphates analysed with spot tests (Middleton et al. 2010), the ethnoarchaeological work of Knudson and Fink (2010) on Arctic fish processing, confirms that fish processing is related to an enrichment of P in the floors.

The entrance of the latrina still in courtyard E9 is plastered. The sample recovered there shows high values of phosphates and protein residues, while no fatty acids are present (Fig. 7). Although it is possible that this entrance adsorbed the "grime" of the *garum* production, these residues are also consistent with the typical residues found in latrines, as the analysis of a Roman *domus* at Populonia (Pecci, 2013) and ethnoarchaeological works have shown (Barba et al. 1995, López Varela et al. 2004).

The results of the analyses in the amphorae courtyard (E13) show that the floor is enriched in phosphates, fatty acids and protein residues (Fig. 2 and 7). This is likely to be attributed to the contents of the amphorae that were spilling on the floor when they were stored upside down. In three cases, samples were recovered from the floor corresponding to the inside and outside the rim of the amphorae. No significant differences can be detected among the results of the samples. This is probably because the amphorae were stored in this corner, upside down, not always exactly in the same position; the present position of the amphorae is related only to the last use of the area, meaning that each time amphorae were stored there, the remains of the contents were spilled on the floor, making the whole area "grimy". Few samples in this area are not enriched in residues, probably because they never came in contact with the substances stored in the amphorae or, possibly, as a result of cleaning of the area immediately after the activity, as suggested by Wells et al. (2000) for Piedras Negras.

In the kitchen (E 6) (Fig. 4 and 8), the upper surface of the oven and the one surrounding the silo are very well preserved plastered surfaces. The low values of phosphates could be related to this, as they are usually close to absent in well-made/preserved plastered floors (Pecci, 2013). On the contrary, phosphates are high in the samples from the floor of the kitchen, which is also plastered, but its quality is lower and the continuous walking around has probably damaged it. Anyway, it is possible to observe an enrichment in phosphates of the floor around the oven, which is probably related to the spilling of substances produced by the food preparation and cooking activities. Fatty acids and protein residues are high on the surface of the oven, where the cooking activities were carried out. This enrichment is likely related to the spilling of substances during the preparation and, mainly, the cooking of the food. Similar patterns were identified at the ethnoarchaeological and archaeological levels in Mexico, in Medieval kitchens and in one Roman kitchen in Italy (Barba et al. 2014; Ortiz and Barba 1993; Pecci, 2013). The analyses of the samples recovered from the interior of the oven also show an enrichment in phosphates, protein residues and fatty acids, possibly due to the burning of food and trash.

In room E 12, the level of protein residues, fatty acids and phosphates is relatively high for a plastered floor (Fig. 3 and 8). On the sides of the room some concentrations of residues are present. We can suggest that these enrichments are related to the storage of some liquid or semi-liquid material that could spill on the floor when transferred from a container to another, such as garum, which could have been stored in the room when the *domus* was transformed into a garum shop. The fatty acids concentration on the side of the room could also be related to a lighting activity, such as the oil/fat used in the lamps, which may have spilled out and enriched the floor (Pecci, D'Andria 2014). In any case, more archaeological data are needed to confirm this hypothesis, as unfortunately, the specific materials recovered in the room are unknown.

In general, the spatial distribution of residues indicates that the use of the building as a domus and its re-use for activities related to the production, storage and selling of garum or other fish sauces has enriched the floors of the whole building. In the kitchen it is possible to identify a difference in the distribution patterns of residues. In particular, it is interesting to observe that fatty acids behave as if fat substances had spilled on the oven surface and from there to the floor of the room, as they are mostly concentrated on top and around the oven. On the contrary, all the room is enriched with phosphates and protein residues. As for the other areas investigated, the spatial distribution of residues indicate that they are all enriched and do not allow to identify different activity areas. This is true for the investigated areas of the two courtyards and room 12, where the use or re-use of the room for activities related with the garum production possibly induced the enrichment of the floors with the same residues as the courtyards. Only the intense fatty acid concentration on the east side of the room suggests that some other substance could have spilled on the floor and could be related with a different activity such as lighting.

5. Results of the analysis of the content of ceramic vessels

To obtain more information on the activities performed in the studied rooms, we also analysed the residues preserved in the ceramic samples. As mentioned above, the solid content of the five dolia analysed was known: anchoes bones (García et al. 2014; Rodríguez and Marlasca 2011). However, the ceramic matrix of the dolia was analysed to verify if any other residue related to the content or the coating of the dolia could be identified (Fig. 9 and 10). The results of the analysis of the samples indicate the presence of dehydroabietic and 7-oxodehydroabietic acids in all of them, which are the markers of *Pinaceae* products. In dolia 1, 2 and 4, the presence of retene indicates that the resin of the *Pinaceae* was heated; in dolium 4, the methyldehidroabietate suggests that the *Pinaceae* products were heated directly from the wood to obtain pitch (Colombini et al. 2005). In the dolia cholesterol, together with $C_{18:0}$ is related to animal origin products. Also present in the sample are branched C_{15} and C_{17}, which are associated with the presence of bacteria and usually are identified in ruminant animal products (Mottram et al., 1999). However, these compounds are also present in ceramic vessels where fish broth was experimentally cooked (Pecci, 2005). The possibility that these acids are also related to the presence of fish residues in the samples should therefore be considered. The presence of odd and even long chain fatty acids ($C_{20:0}$ - $C_{24:0}$) could be related to the presence of vegetable waxes, contamination or to fish products. No other acids considered to be markers of fish (isoprenoid fatty acids and phytanic acid) (Craig et al., 2007; Hansel et al., 2004; Malainey et al., 1999a, 1999b; Rottlander 1990), were identified, possibly due to the instrument sensibility or the extraction methods used.

It is interesting to note that in dolia 2, 3, 4 and 5, tartaric acid is present. Although this acid is also present in some fruits different from grapes (i.e., tamarind; Barnard et al., 2011), due to the area investigated, it can be considered a marker of the presence of wine, together with succinic acid (Garnier, Valmonti, in press; Guash-Jané et al. 2004; Pecci et al. 2013b) (Fig. 9 and 10). These markers could be present due to a re-use of the dolia – which would have been wine dolia reused for garum storage or production – or to the last content of the dolia, together with fish. On the contrary, no traces of wine nor oil are present in sample 1, suggesting that at least the fish sauce produced in this dolium was not flavoured with other substances.

As for the "amphorae courtyard", our attention was focused on the study of ceramic vessels in use at the moment of the Vesuvius eruption. Among them, one African amphora, possibly an Ostia 59 amphora, was analysed. The characterization of the whitish solid residue present in the inside of the amphora (sample 11) indicates it was pure lime. In fact, the diffractogram of the sample (Fig. 11) shows the presence of portlandite ($Ca(OH)_2$) and calcite ($CaCO_3$). The GC-MS analysis of this sample does not show any organic residue, in accordance with the results of its characterization. The results of the GC-MS analysis of the ceramic matrix (sample 10) are instead consistent with a plant oil content (Fig. 12). In fact, β-sitosterol and high quantities of $C_{18:1}$ are present in all the extracts, together with azelaic acid. $C_{18:2}$ is also present, suggesting that the oil contained was different from olive oil. This suggests a re-use of the amphora which probably arrived to Pompeii carrying oil and was later re-used to contain lime. Dehydroabietic acid is present in the amphora, suggesting the use of *Pinaceae* products for its coating.

Dressel 20 amphorae are Hispanic amphorae considered to be oil amphorae, as recent residue analyses have confirmed (Allevato et al. in press; Garnier et al. 2011; Pecci, Cau 2014). The results of the analyses also confirm this hypothesis for the Dressel 20 found in the Garum Shop (sample 9). In fact, in the total lipid extract there is β-sitosterol, and the $C_{18:1}$ is relatively higher than $C_{18:0}$, while in the hydrolyses, azelaic acid is high and is the most abundant among the dicarboxilic acids; there are other compounds usually related to oil and indicated by a dot in Fig. 13 (Pecci et al. 2013a, in press). C_9, considered to be formed during the degradation of oil (Dudd et al. 1998), is also high in extract (c). Maleic and succinic acids are present in the extraction for the identification of wine markers, but tartaric acid is absent. They could be related to the presence of fermented beverages of fruits different from grape. The traces of dehydroabietic acid indicate that *Pinaceae* products are present, which were likely used to waterproof the amphora. As said above, fruit stones were recovered inside the *amphora*. The botanical study ascribes them to two cultivated fruit tree taxa, *Olea europaea* and *Prunus avium* (Table 2, Fig. 14). 19 entire dried olive (*O. europaea*) stones were found, while only one dried stone of sweet cherry fruit (*P. avium*) was identified.

In the Dr21-22 amphora (sample 6), there is cholesterol, which is compatible with the hypothesis of a fish by-products content of these amphorae (Botte 2007). However, there are also traces of ß-sitosterol, a marker of vegetal products, while there are no other residues that could better identify the origin of the content. Abundant maleic acid is present, but the absence of tartaric acid suggests that the amphora could have contained fermented fruits or a fermented beverage different from wine. Traces of methyldehydroabietate acid, a marker of *Pinaceae* pitch, are present.

In the *dolium* from courtyard 13 (sample 7, Fig. 15), there are typical animal products residues, with cholesterol and abundant $C_{18:0}$. These data are similar to the data obtained for the dolia of courtyard 9, which contained preserved fish bones, including the presence of branched C_{15} and C_{17} and $C_{20:0}$, - $C_{24:0}$ acids. In the total lipid extract, β-sitosterol is present together with traces of markers that could be related to the degradation of oil in the hydrolysed extract: azelaic acid is higher than the other dicarboxylic acids, C_9 is higher than the other short chain fatty acids, and there are other acids that are usually present in oil. This suggests that some plant oil was possibly also contained in the dolium. If this was the case, its presence could be due to a reuse of the vessel or to the mixing of animal products and oil. Instead, it is possible to assure that no traces of wine are present in the sample. Additionally, this dolium was coated with *Pinaceae* products.

Pompeian Red Wares are supposed to be cooking wares (Peacock 1977). In sample 8, there are only traces of cholesterol and β-sitosterol, indicating a vegetal and animal content of the vessel, but it is difficult to know if the vessel was used for cooking. The scarce residues present in the samples from this area of the courtyard might possibly derive from the intense heat that must have occurred in the courtyard, which is evident from the burnt traces in the other archaeological materials, including a burnt fish trap (Di Pasquale, pers. com.).

In all of the ceramic materials analysed, residues of *Pinaceae* products (resin or pitch) were identified, confirming the widespread use of these products to coat ceramic vessels designed to contain liquids.

6. Discussion

The results of the chemical analyses of the floors show that it is possible to identify the residues of at least some of the activities carried out in the workshop, despite the Vesuvius eruption. Through the study of the spatial distribution of the chemical residues, it is still possible to identify patterns of enrichment which are characteristic of certain types of human activities. Cooking activities performed in the kitchen left residues on the oven surface and on the floor around it. On the other hand, the enrichment patterns in the courtyard E 9 should be related to the garum production and storage, while that of the NE corner of the so-called amphorae courtyard should be related to the spilling of the materials contained in the upside-down amphorae.

All of the rooms analysed show traces of residues, so no areas that could have been used for resting were identified, not even in the room next to the kitchen, which was a possible candidate for such activities. However, as floors adsorb all of the substances that came into contact with them, what we see is the result of the sum of the activities performed over the floors; if the room had this function before the use of the building as a garum workshop, the residues produced by this last activity would overlap the absence of residues involved in resting activities.

The study of the ceramic vessels recovered *in situ* show that, in general, the analyses confirm the hypotheses about the activities performed in the Garum Shop and provide clues to go deeper in their understanding. The analysis of the dolia with preserved fish by-products identifies wine in four of them, suggesting that they were re-used or that the fish sauce produced was possibly flavoured with wine. Additionally, the dolium from courtyard 13 had a similar use to the others, except for the presence of wine.

The interdisciplinary study of the African amphora (possibly Ostia 59) shows that it probably arrived to Pompeii carrying a plant oil different from olive oil and was re-used to store lime. The lime could have been used either in building renovations or in the elaboration of fish preserves for reducing their acidity, as suggested by García et al. (2014:78, Fig. 9).

The comparison between the chemical analysis of the content of ceramic vessels and the carpological analysis provided evidence of the use and re-use of the amphora Dressel 20. According to the chemical analysis, this

amphora contained oil and probably arrived at Pompeii from *Hispania* containing it. The carpological identification of several olive stones found inside suggest the reuse of the Dressel 20 for fruit storage. Although the import of olives in oil might not be excluded (in this case, the residues identified could be related to the sum of the residues of the oil and the olives), the presence of the *P. avium* stone can be interpreted as remainder of a previous storing of cherries. Thus, it may be assumed that the amphora Dressel 20 was reused *in situ* for keeping local fresh fruits. The presence of maleic and succinic acids and the absence of tartaric acid, could be related to the presence of fruits different from grapes or to a further reuse of the amphora for containing a fermented beverage.
According to the scant archaeobotanical remains and the garden wall paintings (Jashemski et al. 2002; Meyer 1980), in Pompeii the sweet cherry had a great role as cultivated ornamental tree in the house gardens, and its fruits were burnt in ritual offerings or consumed as food (Murphy et al. 2013; Robinson et al. 2002). Archaeobotanical data from Pompeii and the Vesuvian area show that olives were used for human consumption and olive pickling whereas olive pressing waste was used as a possible fuel source (Jashemski et al. 2002; Meyer 1980; Murphy et al. 2013; Robinson, 2002); olive trees were cultivated on the slope of Mt. Vesuvius, and wood was used as timber and firewood (Allevato et al. 2010, 2012). However, although archaeological evidence of oil mills have suggested the local production of oil in Pompeii and its district (Allevato et al. in press; Benedetti 2006; Della Corte 1921; Pasqui 1897), pollen data from the Gulf of Salerno show that massive olive cultivation in Campania started only in the Middle Ages (Russo Ermolli and Di Pasquale 2002). This suggests that Roman olive stands were probably small-sized and were used mainly for the production of table olives, satisfying a local consumption, while the demand for olive oil was mainly supplied by imports from the Mediterranean area.

8. Conclusion

Residue analysis of floors is a well established method for the study of activity areas in Mesoamerica, where this research line was opened by Barba and his team at the UNAM, and followed by other scholars, applying different techniques of analyses to investigate different contexts. However, the Roman world, and Pompeii in particular, have been for long disregarded by these studies. This paper, providing the first evidence of the chemical residues produced by the production of garum, and new data on the residues that characterize Roman kitchens, which supplement those obtained at Lecce and Populonia (Pecci 2003, 2013; Pecci, D'Andria 2014), has shown the potential of such approach to investigate Roman production and domestic buildings. It has also confirmed that the spot tests developed by Barba et al. in 1991 are useful to investigate food production and preparation areas of the period.
The results of the study confirm that "chemical analysis provide a powerful means to reconstruct past human activities" (Wells at al. 2000). In particular they show that the combination of the study of ceramics and floors provides a deeper understanding of these activities. At the Garum shop, although it was not possible to investigate all of the floors and ceramic material recovered in the building, the method used showed that the combination of the study of floors and ceramics coming from the same archaeological context provides a deeper understanding of the activities carried out. We were able to identify the traces of cooking, producing and storing garum in the floors, and the use of dolia and amphorae at the moment of the Vesuvius eruption.
Moreover, the paper has shown the need of better understanding the use and re-use of vessels and amphorae in particular, taking into account the specific context in which they are found. Although the organic residues study

of Roman vessels is improving (Cramp and Evershed R. 2015; Garnier and Pecci, in press; Garnier et al. 2011; Pecci, Cau 2014; Pecci et al. 2017), this case study shows the importance of correlating the study of ceramic vessels to the specific context where they were found. In fact, the use and function of ceramic vessels is strictly related to the use and function of the building where they recovered. This is particularly true for dolia and amphorae: those found in the amphorae courtyard of the Garum Shop have shown evidence of re-use (prunus stone in a Dressel 20, lime in an African amphora) which are possibly related to the last use of these vessels at the shop. Recent studies on amphorae show that the re-use phenomenon of amphorae was more common than usually expected (see e.g. Pecci et al. 2017, in press). However, these vessels can also be studied to look for their primary content, as the same examples of the Dressel 20 and African amphora have shown, indicating the traces of plant oils in the samples.

In general, the study has provided a first insight into how the combination and integration of different analytical techniques, such as the study of residues in floors and ceramics, and the application of other techniques to better understand the content of ceramics (in our case archaeobotany and the characterization of lime) is useful to better understand ancient human activities and the use of space in buildings. This method has the potential to be applied to the study of archaeological contexts of different periods and geographical areas.

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Table captions

Table 1 Ceramic materials sampled for residue analysis

Table 2 Absolute count (Ac) of the dried (d) carpological remains from the Dressel 20 amphora of the Garum Shop in Pompeii

Figure captions

Fig. 1 Location of Pompeii (a) and of the the Garum shop (b). Map of the Garum shop showing the sampled areas in grey (c). Upside down amphorae from the so called "amphorae courtyard" (E13) and dolia from the central courtyard (E 9).

Fig. 2 Sampling of the so called amphorae courtyard

Fig. 3 Sampling of the central courtyard (E9) and of room 12

Fig. 4 Sampling of the kitchen

Fig. 5 One of the dolia of the central courtyard (E9) with fish bones inside

Fig. 6 To the front the African amphora analysed, with a close up to sample 11 and the solid content inside (sample 12). On the back the Dressel 20 amphora analysed.

Fig. 7 Distribution maps of the results of the spot tests for the identification of phosphates (to the left), protein residues (center) and fatty acids (right) on the floor samples of courtyard 9 (E9) (upper images) and of the amphorae courtyard (E13).

Fig. 8 Distribution maps of the results of the spot tests for the identification of phosphates (to the left), protein residues (center) and fatty acids (right) on the the samples recovered in the kitchen (E6) and on the floor samples of room 12. The upper-left square in the kitchen indicated the upper surface of the oven, which was used to cook.

Fig. 9 Chromatograms of the analysis of dolium 2 from the central courtyard.

Fig. 10 Chromatogram of the extract for the identification of wine markers of dolium 4 from the central courtyard.

Fig. 11 Diffractogram of the solid content of the African amphora (possible Ostia 59)

Fig. 12 Chromatograms of the extracts a and b of the ceramic matrix samples of the African amphora (possible Ostia 59)

Fig. 13 Chromatograms of the extracts of the Dressel 20 amphora.

Fig. 14 Fruit stones from the Dressel 20 amphora A02 of the Garum Shop in Pompeii: 1. Olea europaea, four different stones; 2. Prunus avium. The bar scale is 5 mm.

Fig.15 Chromatograms of the extracts of the dolium recovered in the amphorae courtyard (sample 7).