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Reviewed Article:

An Experimental Approach to Tannur Ovens and Bread Making in the southwest of the Iberian Peninsula during the Iron Age

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Culinary culture has played an essential role in the configuration and interaction of human societies throughout history, shaping both individual and collective identities. Like the modern Mediterranean diet, Phoenician-Punic subsistence relied on cereals, often in the form of bread. However, literary, epigraphic and material evidence on its production and consumption among

Iron Age communities in the western Mediterranean is significantly limited. This article discusses the results of an experimental project regarding the construction process, use, and maintenance of the pyrostructures (*tannūr* ovens) used to bake bread, establishing comparisons with a selection of previous research from other Mediterranean geographical and cultural settings. The two ovens used, a fixed adobe and a ceramic portable, have made it possible to bake bread and cook other meals using cookware replicas. Thus, technical procedures, such as the timing of baking processes and the estimation of fuel, etc., have been analysed. This experimental and ethnographic approach, combined with the archaeological record, has provided new insight into resource management and production patterns regarding this staple food. Insight into the development of "kitchens" and complex cooking throughout the Iron Age in this peripheral area of the Mediterranean world was also gained.

> "The experimental construction of both models of ovens has made it possible to apply both the indications found in the archaeological records and the aforementioned ethnographic examples. Thus, our experiments have established that the designs proposed based on the Iron Age remains studied were consistent with a fully functional structure suitable for the preparation of different foods.

Opening appetizer

Food and, therefore, the processes linked to its preparation have played a fundamental role in the shaping of human societies throughout history, creating individual and collective identities. They are essential in a strictly biological sense since eating is a physiological need. But there is an associated social sense too, given that it is largely accepted that these daily actions are key to weaving our network of relations, memories, and identity features. For two decades, the so-called *Archaeology of Food* (Counihan, 1999; Meyers, 2002; 2005; Delgado, 2010; Mata, Pérez Jordà and Vives Ferrandiz, 2010; Hastorf, 2017; Gómez Bellard, Pérez Jordà and Vendrell Betí, 2020) has proposed a new approach, a renewed way of studying nourishment in past societies. This refreshing view transcends the mere utilitarian studies - indispensable, no doubt - of diet and food production. It seeks to go beyond materiality to know where and how food was produced, what (and how) ingredients and containers were used and, ultimately, to analyse the human interactions developed around these practices. This approach requires an interdisciplinary methodology, in which traditional historical and archaeological studies (including scientific analyses) have to be supported and enhanced by ethnography and experimental archaeology to investigate how food has influenced the formation of society and its economic, cultural and identity-related materialisations.

The cuisine of the western Phoenician-Punic communities, the set of culinary techniques and ingredients used, constitutes a powerful source of knowledge regarding social structuring and interpersonal relationships within these societies (Hastorf, 2017). One of these gastronomic preferences was bread. Cereals were at the base of the food pyramid of Phoenician populations, both Levantine and Western, as still happens in the Mediterranean diet in modern times. In the Syro-Palestinian region of the Phoenician-Punic times, bread would have constituted 53-55% of an adult's diet (Meyers, 2002; 2005; Spanò, 2004). In western Phoenician enclaves and *emporia*, information is less precise. According to bioarchaeological remains and the household items found (ovens, milling equipment, and ceramic vessels of specific typologies), cereals would have been consumed mostly boiled or cooked in the form of stews or porridges and, to a lesser extent, baked (Spanò, 2004; Gómez Bellard, Pérez Jordà and Vendrell Betí,, 2020). The eastern and western Phoenician archaeological record provides abundant evidence of remains identifiable as key infrastructure linked to its production: the bread-making oven, the *tannūr*.

This term is problematic, since the word *tannūr* finds its roots in Akkadian language (*tinūru*), meaning "oven" (Symons, 2000). However, other terms are frequently used as synonyms for *tannūr*, namely *furn* and *tabun*, which, in fact, refer to fire installations with different characteristics (Fuller and Gonzalez, 2018, pp.113-115, fig. 2). In this paper, we apply the current ethnoarchaeological usage. The term is customarily used to define ovens, both fixed and portable, that meet the following characteristics: 1) it belongs to a domestic environment, mainly rural; 2) it is used to bake flat unleavened bread, although archaeological evidence suggests they could have also been used in the preparation of other types of food (Rova, 2014, pp.122-123). Hence, we refer to cylindrical or truncated cone-shaped ovens made from clay. These structures, to which little attention is usually paid during the archaeological excavation, are mostly limited to their documentation, which is sometimes not very detailed. Their functioning is known through literary, archaeological, and ethnographic sources, as these installations continue to be in use throughout North Africa and the Near/Middle East.

The upper part of the *tannūr* has an opening through which fuel and food are introduced, although, in many instances, a second side opening has been documented for the same purpose. They are installed on the floor in open-air patios or rooms intended for food handling and storage. As a general rule, they were built over or inside a circular shallow pit, in which small stones or ceramic sherds were laid and then covered with clay. The initial combustion and the embers cause the oven walls to heat up and once the flames have died down, breads were introduced into the oven through the upper opening and adhered to the walls (Mulder-Heymans, 2002, pp. 209-210; Campanella, 2008; Delgado, 2010, pp. 32; Rova, 2014).

Excavations in western domestic areas indicated that not all houses had their own bread oven (Delgado, 2010, p. 35). In some places such as Sa Caleta, communal structures for bread baking have been identified in open outdoor areas (Ramon, 2007). Several domestic contexts excavated in the Iberian Peninsula (Lisbon, Doña Blanca, Huelva, Cerro del Villar, Morro de Mezquitilla, Chorreras, La Fonteta, etc.) suggested that facilities and culinary tools connected to cereal preparation and bread-making techniques were widespread among western Phoenician communities (Delgado, 2010, p. 35). These recipes, practices and know-how would have come from the Levantine Phoenician setting as a part of their expansion process to the western Mediterranean and the Atlantic. Thus, *tannūr* ovens like the ones described above have been frequently documented, associated with the domestic units of settlements, but with variations introduced according to the needs of each new environment (resources) and the different geographical and social (hybrid) contexts.

The first research on bread ovens dates back to the 20th century, exclusively focused on the *tannūr*-type ovens of the Syro-Palestinian region (Masterman, 1901; Canaan, 1962). The scientific literature shows a common factor: the application of ethnography to the archaeological record to address the study of domestic architecture. In this way, researchers have established analogies between the ancient ovens that have been documented and the present-day bread ovens still in use in the Levant and North African regions (Weinstein, 1973; Crawford, 1981; Kramer, 1982; Waines, 1987). Mulder-Heymans (2002) laid key groundwork for the investigation of this type of structure by supplementing his ethnoarchaeological study with an experimental replica of a *tannūr*-type bread oven. The information gathered after the experiment allowed him to elaborate a worksheet on this type of structure to maximise the potential information obtained during excavations. Mulder-Heyman's work was pioneering in addressing social issues related to the development and management of this type of oven. Meyers (2007) further strengthened this type of approach with his work, focusing on gender and social significance (see also Di Gennaro and Depalmas, 2011).

From the archaeological point of view, in the western region, it was Gutiérrez Lloret (1991) who first established solid foundations for the study of *tannūr* ovens by identifying them in several early medieval sites in the Iberian Peninsula. Her work also traced clear antecedents in the examples studied in North Africa. However, Campanella (2001; 2005; 2008) carried out the most exhaustive studies on Phoenician-Punic ovens so far, highlighting their importance in the western diet, as well as providing key data concerning their operational sequence and their wide distribution. In recent years, work on domestic facilities related to food management, particularly, and to Phoenician-Punic cooking, in general, has undergone substantial evolution. Previously, the bulk of research focused on purely production sites and topics. However, the research focus has now moved to the analysis of forms of consumption and the processes by which these were developed (Spanò, 2004; Gómez Bellard, Pérez Jordà and Vendrell Betí,, 2020).

Thus far, research with an experimental basis has focused primarily on the area of Syria and Turkey (Mulder-Heymans, 2002; Meyers, 2007; Shafer-Elliott, 2019), as the region offers an optimal setting for ethnoarchaeological studies for two reasons. Firstly, there is a large amount of archaeological evidence associated with these structures. Secondly, bread making in *tannūr* ovens has been preserved, and it is still common in many rural areas in these countries. Though since the beginning of the 21st century, research based on an experimental approach regarding domestic combustion structures has grown exponentially in different chronological and cultural settings of the western Mediterranean (Peinetti, 2013; Teira-Brión, Rey Castiñeira and Ní Líonain, 2014; Cattani, Debandi and Peinetti*,* 2015; Peinetti, Cattani and Debandi*,* 2019; Belarte, *et al.,* 2022).

A New Experimental Approach

There was a lack of research focus on functional aspects of the *tannūr* ovens used in the western Phoenician-Punic sphere. We address this research area in our project design and analysis, and carried it out within a larger project '*Ergasteria. Experimental and virtual archaeology for the study of amphora production and commercialization processes in Protohistory*' (Ref. US-1266376). This larger project is funded by the R&D+i FEDER Andalucía 201’-2020 Program and uses experimental approaches to Iron Age pottery kilns, potters’ wheel throwing (Sáez Romero, Belizón Aragón, and Albuquerque, 2021; Sáez Romero *et al.*, in press; also, http://ergasteria.us.es/).

Based on an experimental and palaeo-technological methodology, the main goal was to deepen our knowledge regarding the processes of manufacture, maintenance and use of *tannūr* ovens in Phoenician-Punic times. Therefore, through an experimental and ethnographic methodology, taking as a key reference the studies carried out in the Levantine area and North Africa (Mulder-Heymans, 2002; Meyers, 2007; Shaffer-Elliott, 2019) and those currently being carried out in the Western Mediterranean (Belarte, 2022), it was intended to empirically verify how these ovens would have been used, and therefore our data would complement research findings from other archaeological projects. Finally, we have established a comprehensive and critical comparison between the two types of *tannūr* ovens studied, ceramic portable and fixed adobe, in order to examine their particularities in terms of efficiency/productivity, usability, maintenance needs, required investment, durability, etc. To this effect, the main variables analysed in all the experiments were: 1) time required (baking process and furnace construction aspects), 2) baking temperature, 3) oven resistance to high temperatures (refractory capacity), 4) baking results, 5) traces of handling, 6) durability and sustainability (ie, necessary repairs), 7) type and quantity of fuel needed.

Experimental replica of fixed adobe *tannūr* oven

The clay was extracted from a source located in the western area of San Fernando (Cadiz, Spain), close to some well-known archaeological sites where several Punic and Phoenician pottery kilns (Villa Maruja – Janer) have been excavated over the recent decades in the insular part of the Bay of Cadiz (Bernal, *et al.,* 2005; Sáez Romero and Belizón, 2018). Proximity to the extraction point speeds up production by providing abundant and immediate raw material. The other essential element for making adobe is vegetable fibre, which, in this case, was obtained through the collection of dry vegetation from the surrounding area. This element contributes to reaching the desired consistency in the mix of clay (marl) and sand. It was not necessary to add additional sand in this case since the local clay naturally contains a considerable amount of rounded quartz/quartzite sand (of less than 1 mm), typical of fluvial environments, which occasionally includes small pebbles of between 5-10 cm in length. The plant material was cut into portions of about 10-15 cm in length, mixing it with the sandy clay at a ratio of approximately one part plant to two parts clay. Some small branches and stems, thicker but flexible, with a greater length and consistency (up to 20-25 cm), were stored and later used as part of the "formwork" of the structure. Following the guidelines set by previous works (Weinstein, 1973; Crawford, 1981; Kramer, 1982; Mulder-Heymans, 2002; Rova, 2014), it was decided that the clay would not be subjected to decantation, since it was to be used as a raw construction component and small stones can provide additional consistency. Water was then added to the mixture until the right texture was achieved.

The floor plan of the circular oven was sketched on a tamped clay base measuring 30x90 cm (See Figure 1a-c) with a diameter of 85 cm, and an annexed exterior area measuring 20x22 cm. Both were covered in adobe (See Figure 1d). Subsequently, to give consistency and to regulate temperature in the lower part of the structure, the foundation layer was reinforced with ceramic fragments (See Figure 2) and covered with a thick clay and sand plaster. This provides a uniform working surface (See Figure 3). The oven walls were raised and inclined progressively towards the centre in layers of 5 cm high and 4 cm wide, until a height of 30 cm was reached. A formwork of small dry (although still slightly flexible) branches was used to increase the consistency of the walls during construction (See Figure 4). Once the process was completed (See Figure 5), the oven was left to dry and abandoned with no maintenance for 1 year to observe its process of gradual deterioration (See Figure 6). Only a first fire of short duration was carried out, but not a complete firing, in order to sufficiently harden the structure and contribute to its preservation. The aim was to determine if this type of adobe structure could resist exposure to rain and other meteorological (wind, drastic changes in temperature and humidity, etc.) and biological (growth of wild plants, insects and other animals, etc.) inclemencies without maintenance. After this phase, the structure was restored, eliminating outcroppings of salt (naturally present in the clay due to the proximity of the source to the ocean) and plant remains, as well as conducting the necessary repairs using the same adobe mixture originally employed in its construction (See Figure 7).

The resulting structure (See Figure 8) was a smaller version (roughly half the size) of the *tannūr* ovens documented in the Bay of Cádiz and, in general, in the southwestern Iberian Peninsula for the Phoenician-Punic period. It was provided with a side opening to feed the fuel and an upper opening to introduce food and fuel, or to hold pots used for boiled or stewed preparations, as verified from archaeological and ethnographic data (Mulder-Heymans, 2002; Meyers, 2007; Gener, *et al.,* 2014).

Experimental replica of a portable ceramic *tannūr* oven

In this case, a professional potter (Cerámicas Ramírez) was responsible for making a portable pottery bread oven, using a potter's wheel (See Figure 9). The reproduction was designed based on the characteristics of the remains of portable *tannūr* ovens excavated at the Punic pottery workshop of Villa Maruja - Janer (San Fernando, Cádiz) (Bernal *et al.,* 2003), located nearby the source where the raw clay was collected. This type of ceramic pyrostructure, like the previously mentioned ones but smaller in dimension (30-60 cm in diameter) and mobile, have also been attested in the Greek world since the second half of the seventh century BC (Claquin, 2018, p. 490).

To conduct the experiment in an environment and with conditions as similar as possible to the Iron Age contexts studied, a rectangular space with a tamped clay base was adapted on which the portable *tannūr* was placed. This was intended to recreate the blackened and circular ash remains unearthed at Villa Maruja and other Punic sites in the area (Bernal, *et al.*, 2003, pp. 52-53 and 201-205). The structure was affixed using small sandstones and a mixture of clay collected from the surrounding area, vegetable material and water - the same materials used in the first experiment (See Figure 10).

Bread making and baking process

For the preparation of the dough, a basic recipe for unleavened bread was chosen, so that it would be as similar as possible to the ones that Phoenician-Punic communities might have used. Therefore, only three ingredients were needed in the preparation of the dough: bread flour (500 g), water (250 ml) and a pinch of salt. The process began with the water at room temperature and salt being added to the flour, hand mixing the ingredients until a complete integration was achieved. This first step allows for the activation of the gluten in the flour, so that the chemical reactions that transform the dough begin to take place. Then, manual kneading produces, in approximately 15 minutes, a slow energy input that increases the dough temperature and favours the natural fermentation of the mixture and the encapsulation of the gases produced during this process. Likewise, this kneading leads to the progressive incorporation of the liquid into the solid ingredients until a completely homogeneous mass is obtained. The resulting dough was left to rest in the form of a ball during the process of ignition and heating of the oven, so that the so-called primary fermentation could fully take place. After this step, it was divided into portions to form the flat bread cakes (approx. 10-12 cm in diameter) typically baked in *tannūr*-type ovens, according to the information provided by previous ethnographic and archaeological studies (Weinstein, 1973; Crawford, 1981; Kramer, 1982; Waines, 1987; Mulder-Heymans, 2002). In addition, the brief references found in some works written by the Greek comic poet Antiphanes in the 4th century BC, state that the breads were arranged in tight rows around the circumference of the oven (Athenaeus, *Deipnosophistae*, III, 112 c-d).

These loaves underwent a new fermentation period, during which the temperature inside the oven was checked. Once the bread was ready, they were moistened with water to ensure their adhesion to the interior walls of the oven. At this point of the experiment, several batches of bread were baked with the aim of analysing the results of different cooking times. Likewise, the distinctive results obtained from baking in different parts of the inside surface, according to their proximity to the ashes and flames, both in the portable oven (See Figure 11a-b) and in the fixed oven (See Figure 11c-d) were also analysed.

The aforementioned details alluded to the first experiment carried out in this project; however, new tests were carried out throughout its duration, both in the fixed and portable ovens, so that the data obtained could be cross-checked with this first set.

Results

The records obtained after the implementation of these tests constituted the initial phase of a larger project which aims to refine soon the experimental methodology applied. Nevertheless, the results already obtained have been significant and provide some considerations on the construction, maintenance and operation of *tannūr* ovens.

The construction turned out to be a relatively simple task and was easily accomplished by a single skilled person in a working day. However, anthropogenic experience was a significant factor in selecting the appropriate season to build the structure (late Spring to late Summer); carrying out the first combustion process; as well as in the choice of raw materials. Additionally, the bread-baking processes also showed the importance of know-how, as the first attempts required much longer baking periods (See Tables 1-2). Experience with fire control, bread placement within the oven, and dough work helped to identify the most favourable conditions to carry out bread baking in *tannūr* ovens. Therefore, later attempts achieved better results. Of the 6 batches of bread prepared in both types of ovens, the optimum result - only 10 minutes per batch – was achieved when the oven walls had reached a temperature between 110-120°C and the bottom of the oven was between 400-500°C.

Portable *tannūr*		
Baking time	Oven wall	Oven bottom
45min	80°C	320-380°C
40min	95°C	345-390°C
30min	95-100°C	350-400°C

TABLE 1. TABLE SHOWING THE RELATIONSHIP BETWEEN THE VARIABLES OF BREAD BAKING TIME, OVEN WALL TEMPERATURE AND TEMPERATURE AT THE BOTTOM OF THE MOBILE *TANNŪR*.

Fixed *tannūr*		
Baking time	Oven wall	Oven bottom
15min	95°C	350-420°C
15min	95-100°C	380-450°C
10min	110-120°C	400-500°C

TABLE 2. TABLE SHOWING THE RELATIONSHIP BETWEEN THE VARIABLES OF BREAD BAKING TIME, OVEN WALL TEMPERATURE AND TEMPERATURE AT THE BOTTOM OF THE FIXED *TANNŪR.*

The firing temperature, one of the most significant factors in our study, was controlled throughout the baking process using an infrared pyrometer model PCE-893. Thus, we were able to verify the maximum temperatures that could be reached in these structures: 757ºC in the fixed oven and 703ºC in the portable oven (See Figures 12-13). The highest temperatures reached in both ovens during the experiments are shown in the chart below (See Table 3). This variable also allowed us to measure how long the structure could retain the heat once the flame had diminished in size. This was especially relevant in the case of the oven walls to check whether the bread could be baked using only residual heat. Although this method of baking was feasible, the baking turned out to be very slow and uneven. Both the small "gate" at the base of the oven and the top opening were never completely blocked at any time during the process. On a few occasions the upper area was used for roasting food on long skewers (used as ancient *obeloi*), and the opening at the base was also used to place pans for baking or frying various dishes, but it was not observed that these procedures led to significant changes in temperatures or in the interior atmosphere, so they did not have a significant impact on the baking of the bread.

Fire Structure	Heat Cycles	Fuel	Weight of Fuel (g)	Duration of the Combustion	Highest Temperature on Surface / In the Flames	RH	Medium Y (°C)	Date
Fixed *tannūr*	1st	Straw, grasses, pine wood	15.130	4h20min	460°C / 596°C	70%	21.6	14/11/2021
	2nd	Straw, grasses, pine wood, pine cones	12.406	2h15min	732°C / 757°C	63%	18.2	15/11/2021
	3rd	Branches, straw, pine wood, organic waste (sardine scraps)	13.961	more than 3h10min	543°C / 671°C	67%	19.7	19/11/2021
Portable *tannūr*	1st	Straw, grasses, pine wood	14.719	3h45min	429°C / 504°C	70%	21.6	14/11/2021
	2nd	Straw, grasses, pine wood, pine cones	13.481	2h40min	358°C / 543°C	63%	18.2	15/11/2021
	3rd	Branches, straw, pine wood	11.705	1h15min	682°C / 703°C	67%	19.7	19/11/2021

TABLE 3. TABLE SHOWING THE EXPERIMENTAL COMBUSTIONS, WITH TYPE AND WEIGHT OF FUEL, DURATION OF THE COMBUSTION, MAXIMUM TEMPERATURES REACHED, RELATIVE HUMIDITY, MEDIUM ATMOSPHERE TEMPERATURE AND DATE.

We also analysed the temperatures retained by the embers, given that several authors had mentioned that these would have been used to carry out not only the baking of bread, but also boiled preparations (Gener, *et al.,* 2014, pp. 30). In this case, it was observed and measured that, even though kneaded bread was cooked in a short period of time over the ashes and obtained the best result when the embers were between 200-250ºC, boiled and fried preparations did require the presence of a flame that provided a continuous and more effective heating contribution in order to complete the process successfully. The analysis of temperatures showed that both ovens are an effective thermal mass highly refractory. In the case of the adobe fixed oven, the first firing allowed the structure to fully consolidate, and partially fired the interior surfaces and those areas closest to the flames and embers. In addition, the temperature control made it possible to verify that figures close to those used in the firing of ceramics were reached (600-750ºC). Thus, these are structures with a high combustion power and potentially (perhaps only occasionally) could have contributed to the production of certain items, such as the pots and pans used in cooking.

The analysis of the results allowed us to identify the different ways in which these communities could have prepared bread, based on the various possible uses of space, and heat available inside a *tannūr*. Thus, in addition to baking inside the oven walls, we were able to verify the possibility of producing the so-called 'ash bread' (Genesis 18: 6; Ezekiel 4: 12). We also confirmed that the baking of bread inside ceramic vessels would have required higher temperatures and longer baking stints. Once the baking was finished, it was observed that different ways of attaching and removing the bread cakes to/from the oven walls had caused different use-wear traces, leaving in some cases remains of bread that needed to be detached afterwards. Likewise, we faced the problem of clay plaster used to repair the oven walls adhering to the bread (resulting in some flatbreads having to be carefully cleaned before consumption) which produced detachments that compromised the integrity of the inner oven surface and its usability (See Figure 14).

Taking all these factors into consideration, the analysis of the durability and sustainability variables has allowed us to conclude that *tannūr* ovens demonstrate great versatility, enabling the preparation of different types of firings and use of the heat produced. Firing following these simple patterns favours the conservation of the structures and subsequently causes a small investment in the manufacture of these ovens to result in structures that may operate for long periods of time and be used for several key household purposes. The preservation of the structures in good condition despite the incidence of uses and atmospheres could be specifically tested in the second replica, by detailed observation of internal and external walls after each use. However, the monitoring and observation of the oven without maintenance processes for over a year evidenced that these structures require preventive maintenance, especially if they were not used daily and/or in indoor areas. Some systematic monitoring would have been mandatory to ensure the integrity of the structures and avoid the development of cracks, detachments, salt outcrops or vegetation growth in the structure. This is consistent with the conclusions reached through direct observation of present-day *tannūr* ovens conducted by different researchers (*e.g.*, Claquin, 2018, p. 490), who highlight the need for maintenance due to the damage produced by the high temperatures reached in the form of cracks that need to be repaired frequently.

Discussion

The experimental construction of both models of ovens has made it possible to apply both the indications found in the archaeological records and the aforementioned ethnographic examples. Thus, our experiments have established that the designs proposed based on the Iron Age remains studied were consistent with a fully functional structure suitable for the preparation of different foods.

The collection of raw material and the construction of these 1:2 (fixed adobe) and full-scale (portable ceramic) models of ovens required a low investment of time, demonstrating that the manufacture and use could be easily performed even by unskilled individuals. However, the ignition and maintenance of the fires would have required specific expertise in order to achieve reasonable timings. The experimental firings have shown that atmospheric conditions are also a variable to take into consideration, as they can condition the level of difficulty of ignition, as well as the need to keep a constant monitoring on the fire to ensure it does not extinguish. Likewise, in addition to the demanding work of fire control, it has been observed that the preparation of certain foods -boiled and fried preparations mostly- required a rigorous control. Archaeological evidence supports that these structures would have been located in sites with certain protections against adverse weather conditions, such as patios or indoor spaces that protected the fire from unfavourable environmental situations like rain or strong winds, phenomena that we experienced during the execution of the second experiment.

Weather conditions of this type and sudden variations in operating parameters would make both ignition and maintenance of combustion more difficult, resulting in the need for a greater investment of resources and energy to obtain the same results. In addition, the surrounding structures would have functioned as useful support elements during the firing process. In the Teatro Cómico excavations (Gener, *et al.,* 2014), two of the elements built near the oven were identified as benches, although these could also be structures used to reach the upper opening of the oven. Likewise, a system of benches in the vicinity could have been used as a work surface where food preparations were placed once removed from the fire without hindering transit areas (or as storage space for cookware and kitchen equipment, ranging from pots and pans to hand mills).

Similarly, another factor to take into consideration in terms of combustion control is the type of oven used. By contrasting the observations made during the fixed and portable oven experiments, it seems that the adobe fixed oven allowed for better control of the fire, flames and temperature, both inside the oven and at the openings. Thus, it was easier to both light the fire and to control the feeding and oxygen flow, consequently obtaining better results. In contrast, the portable ceramic oven was more difficult to feed and control and proved to be more problematic at maintaining the heat source at a constant temperature. In addition, given that we are talking about a portable model, it is likely that these were used *ad hoc* during journeys or among nomadic communities. This was probably the case for the portable ovens of Villa Maruja that served as a model to manufacture the replica used. These ovens would have belonged to (and been used by) the groups of artisans, perhaps seasonally, working at the pottery workshops located in the area. In any case, this is a type of oven that seems to have grown in popularity only from the 5th century BC onwards. Therefore, these would be related to broader changes taking place in the local cooking equipment, since it may be associated in time to the relatively increasing use of brazier-type supports for cooking with pots and pans that suggests to a "Hellenisation" of the local culinary repertoire and tastes (Sáez Romero and Belizón, 2020, pp. 205-221, fig. 8).

In any case, both structures required the provisioning of abundant fuel material since the fires needed to be fed continuously to maintain a constant temperature to cook the food. This highlighted the fact that, given that our adobe ovens were half-scale models, Phoenician-Punic communities would have needed large quantities of fuel at their disposal (and, consequently, efficient and sustainable domestic procurement and storage strategies). In addition, the use of wood collected from the area surrounding the site where the experiments were conducted highlighted the existing differences between the various types of timber. The total amount of fuel necessary to bake flatbread has varied from one tannūr to another, ranging from 10 to 12 kg and combining different materials as fuels. The collection of branches would probably not have an impact on environmental management since they could be collected without the need to cut anything down, but it would require a rather significant daily effort of collection and storage.

However, among the different species available in the area, it was pine wood which is a low-density wood that provided the best results to light the fire. Its ability to quickly ignite the fire was counteracted by an equally rapid combustion, resulting in the need to frequently feed the fire. Likewise, flammability is influenced by a higher or lower humidity and resin content, so the selection of the fuel must also have taken into consideration the environmental conditions at the time of collection. Even so, the collection of these woody species must have been supplemented with the use of other fuel assemblies, among which manure and food remains would have had a special predominance. This system would mean the use of disposable elements that would otherwise be discarded, with the bonus of not needing a new energy investment for its collection. This constant feeding of the fire results in the creation and accumulation of abundant ash, so it is important to distinguish hearths remains from other combustion structures on the base of the characteristics presented by the circular ash pits found in many sites, as other researchers have already highlighted (Mulder-Heymans, 2002; Meyers, 2007; Belarte, *et al.,* 2022).

The main item discussed here, bread, can be obtained from slow cooking when baked on the inside walls of the oven with no burning flame; however, placing it on the still hot ashes or on the embers after the flames have been extinguished results in a faster cooking process, although in need of monitoring to avoid overcooking and the subsequent blackening of the outer surface. In any case, cooking would have required a process of continuous monitoring to ensure a good outcome and for the temperatures and conditions to be suitable to achieve the desired product.

The thickness of the adobe walls and how the bread was attached to them were also important factors. It is worth mentioning other techniques of baking bread that were tested with experiments. Following the biblical mentions of 'ash bread' and in relation to the ethnographic parallels studied, it was decided to place some portions of bread directly on the hot ashes at the mouth of the adobe oven to verify whether the heat these emanated was enough to bake the bread. The result was that the bread baked quickly and evenly, making it possible to bake bread cakes on the remains of an extinguished fire previously used for another purpose. Although the main focus of this work is *tannūr* ovens and their use in bread preparations, the experiment also verified the possibility of using these structures for cooking other types of food. The results and considerations are briefly considered here to complement the functions that these ovens possibly had.

The upper opening of the oven would have been used for cooking both meat and fish on skewers, taking advantage of the heat provided by the flames located at the bottom of the oven. The possibility of roasting fish and meat chunks while baking bread is adhered to the interior walls has been established. On the other hand, some researchers had mentioned the possibility of making stews by placing cooking vessels on the outside of the bottom opening and using the leftover embers as a heat source (Gener, *et al*. 2014: 30). Therefore, an experiment was carried out to examine the plausibility of this practice. Furthermore, this was contrasted with the results obtained from another experiment designed to test the preparation of boiled cereals (stew) over an open fire. However, in none of these cases was it possible to cook using residual heat, as both preparations required the presence of a well stoked fire under them as the main source of heat (replicas of pots and pans contemporary to the ovens were used). Therefore, cooking boiled cereals over embers does not seem to be possible, or, at least, it is not an easy technique, and direct exposure to a fire is required to maintain the necessary temperature until the desired cooking result is obtained. In any case, and as suggested by previous research (London, 2016, pp.111-117), the bread could also have been baked on flat plates or other shallow ceramic vessels, but only over hot embers and not over ashes – unlike when directly cooked over the ashes with no vessel.

On the other hand, the monitoring of the oven after a year with no maintenance work carried out revealed that, in addition to the cracking and accumulation of organic waste inside, plants from the seeds contained in the raw material had grown in the surrounding area, as well as in some of the cracks of the oven itself. Therefore, the abandonment of the structure or the lack of maintenance would have caused its eventual collapse. Finally, the attachment of the bread to the internal surface of the oven walls, leftover from the last batch baked, resulted in the presence of small crusts. After several days and once the remains and the walls of the oven had cooled, these residues could be easily cleaned. However, given that these structures were probably used on a daily basis, the idea of cleaning processes requiring days until a gradual detachment of the residues took place is not feasible. Therefore, other cleaning and maintenance methods must have existed that allowed the removal of these remains without delaying the production of successive batches.

This setback made us re-evaluate the characteristics of the dough at the moment of its introduction in the oven. Following the indications of the ethnoarchaeological studies and of the experiments consulted (Weinstein, 1973; Crawford, 1981; Kramer, 1982; Mulder-Heymans, 2002; Rova, 2014), the surface of the bread cake was slightly moistened in order to achieve a better grip to the inner surface. The first attempts were carried out by completely wetting the side to be attached to the inside of the oven, which caused a complete adherence and increased the presence of residues on the walls when trying to remove the loaves (and, consequently, left traces of clay in the surface of the bread). During the second experiment, the amount of water used was significantly reduced and the results improved considerably. Finally, it was decided to place the bread using only slightly moistened fingertips that allowed the dough to remain adhered to the surface and, when removed after baking, no appreciable residues remained on the oven interior walls. A similar process took place with the thickness given to the breads, reducing it gradually from approximately 1 cm to 0.5 cm. This helped facilitate the baking process, decreasing cooking time and favouring the possibility of baking in different parts of the oven. Therefore, it seems very likely that besides the existence of cleaning and maintenance systems, the right choice in thickness and attachment method to the oven walls were key factors for a better maintenance of these structures.

Conclusions and Future Steps of Research

The analysis of the construction and utilisation processes of these *tannūr* ovens has confirmed the optimal productive capacity of both types, portable and fixed, to bake cereals in the form of flatbreads. Since this is an ongoing project, further experiments are still needed to refine the methods and results and introducing some relevant modifications based on the weaknesses observed during the tests carried out thus far.

Among the future phases of expansion and improvement of the experiment a full-scale reconstruction of an adobe *tannūr* oven is planned. These will take place in La Rinconada (Sevilla), where different initiatives linked to the archaeological site of Cerro Macareno (García Fernández 2020; 2021; García Fernádez, Albuquerque and Guillén Rodrígez*,* 2020) are already under development, such as the project "*Estudio, intervención y recuperación de la construcción con tierra en la Baja Andalucía*" (CrudUS)" (US-1381493). This will facilitate a comparison between the results already obtained with these half-sized ovens. Another goal is to obtain new data regarding different types and combinations of fuel (several wood taxa, animal dung and bones, etc.) to achieve the best possible performance from the ovens.

Another pending task is to carry out the systematic sampling of the ash deposits generated as a result of the functioning of the ovens, in order to compare the data obtained from these with the information provided by domestic ovens dating from the Iron Age (Delgado, 2010, p. 35; Gener, *et al.,* 2014). At present, the experiments focus on systematic observation and in data collection regarding the evolution of the ovens after their abandonment, to analyse how they react to weather changes and the incidence of several factors (insects and fauna, plant growth, rainfall, seasonal environmental temperature changes, aeolian sedimentation, etc.) to obtain more information suitable to improve the archaeological analysis of this type of structure. All this will allow us to refine the methodology for the study of domestic pyro-structures in the region and, probably, will be key to moving towards even more complex issues on both material and social aspects.

Several questions raised at the beginning of our research have been explored; however, new ones have arisen during the course of the investigations: Would these structures have had a special plaster to avoid the cracking of the clay? How was the cleaning process of these ovens carried out after being used? What was their lifespan? To further delve into the environmental resources available to these communities and how they were transformed, an archaeometric characterization study is currently in process. The aim is to characterise the raw materials locally available in different areas. With such data, we hope to conduct specific studies on clay and adobe remains, as well as portable *tannūr* ovens, to discover (and replicate) the "recipes" used by Iron Age artisans.

Although it is necessary to continue refining the experiments presented, we note here how the combination of data from the archaeological record, ethnographic parallels and the use of experimental archaeology is an undeniable asset when it comes to addressing questions that could be answered in no other way regarding the daily life of the Phoenician-Punic societies from the Iron Age.

Keywords furnace, kiln or oven
food
cookery
Country Spain

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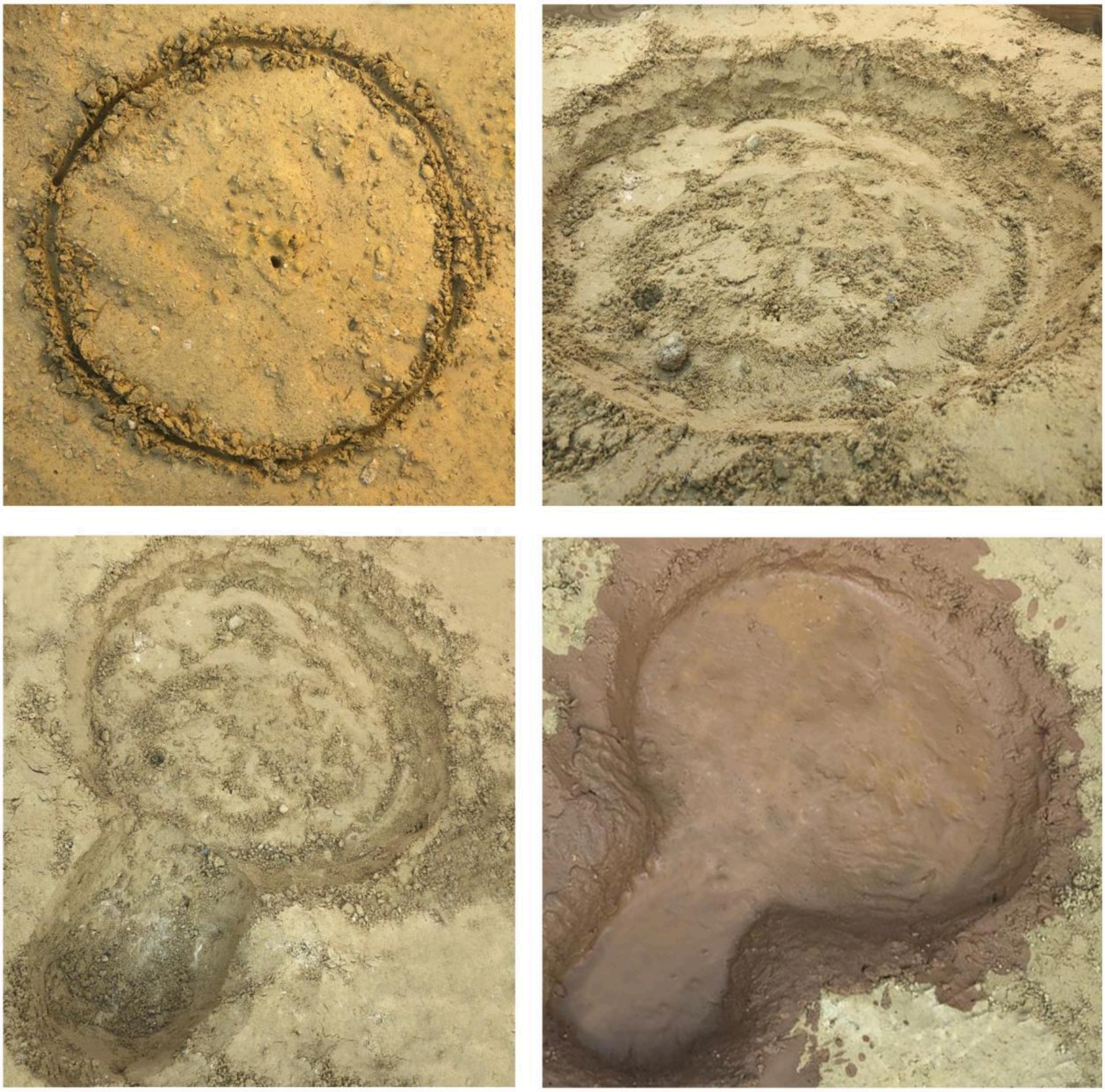

FIG 1. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

FIG 2. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

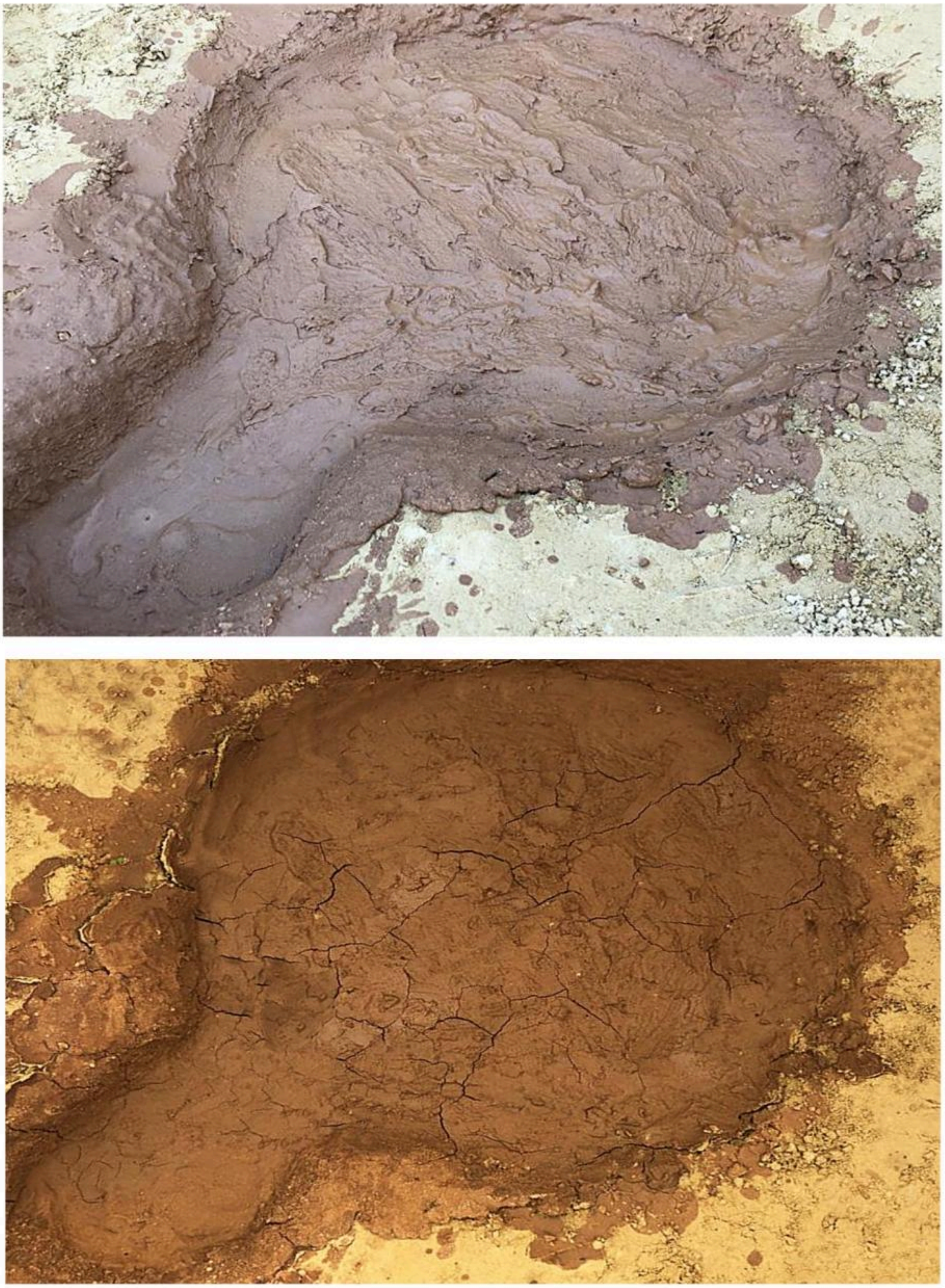

FIG 3. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

FIG 4. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

FIG 5. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

FIG 6. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

FIG 7. PROCESS OF ELABORATION OF THE FIXED TANNŪR. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

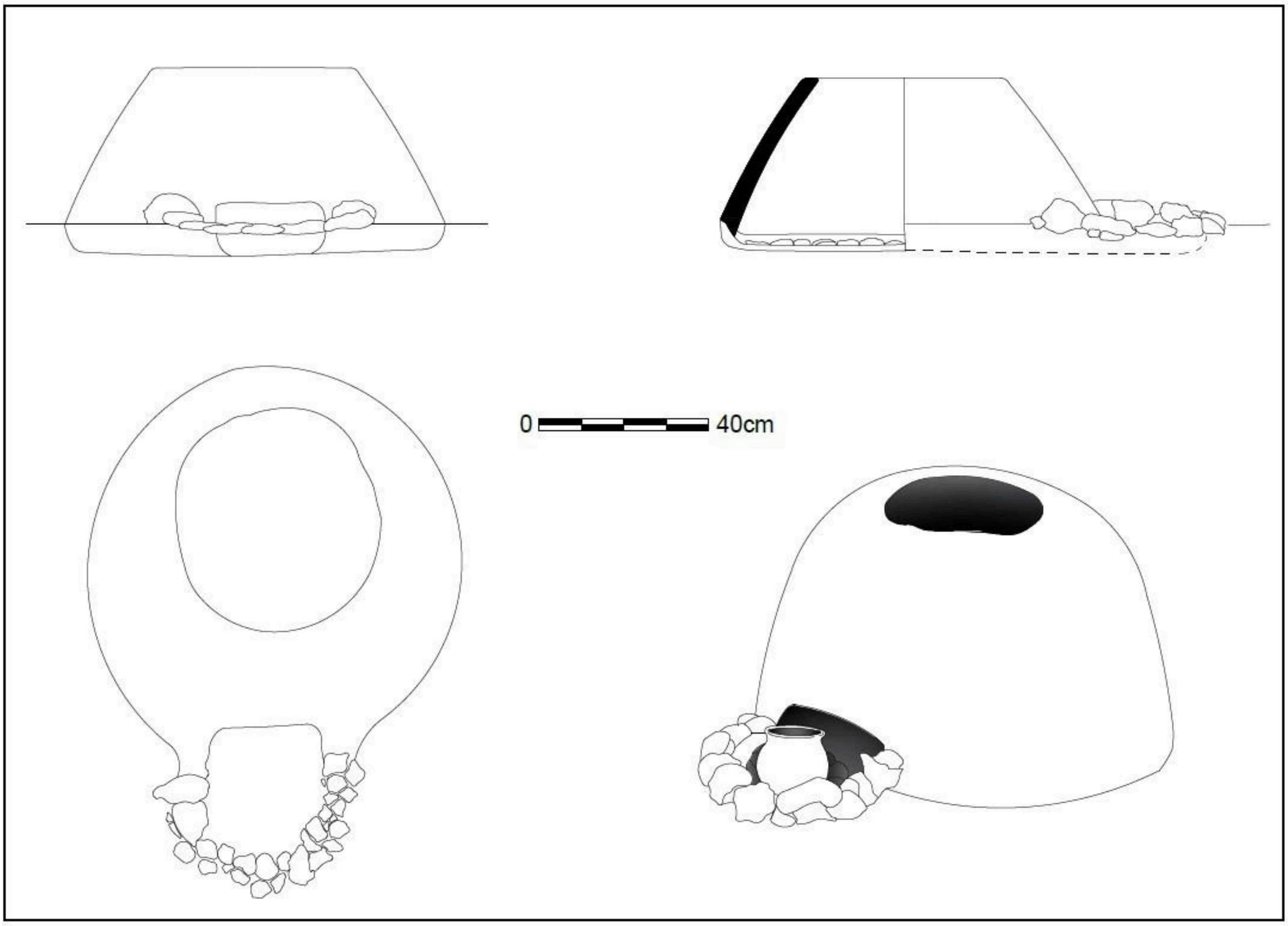

FIG 8. ELEVATION, SECTION, PLAN AND RECONSTRUCTION OF THE FIXED TANNŪR DEVELOPED DURING THE FIRST EXPERIMENT. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

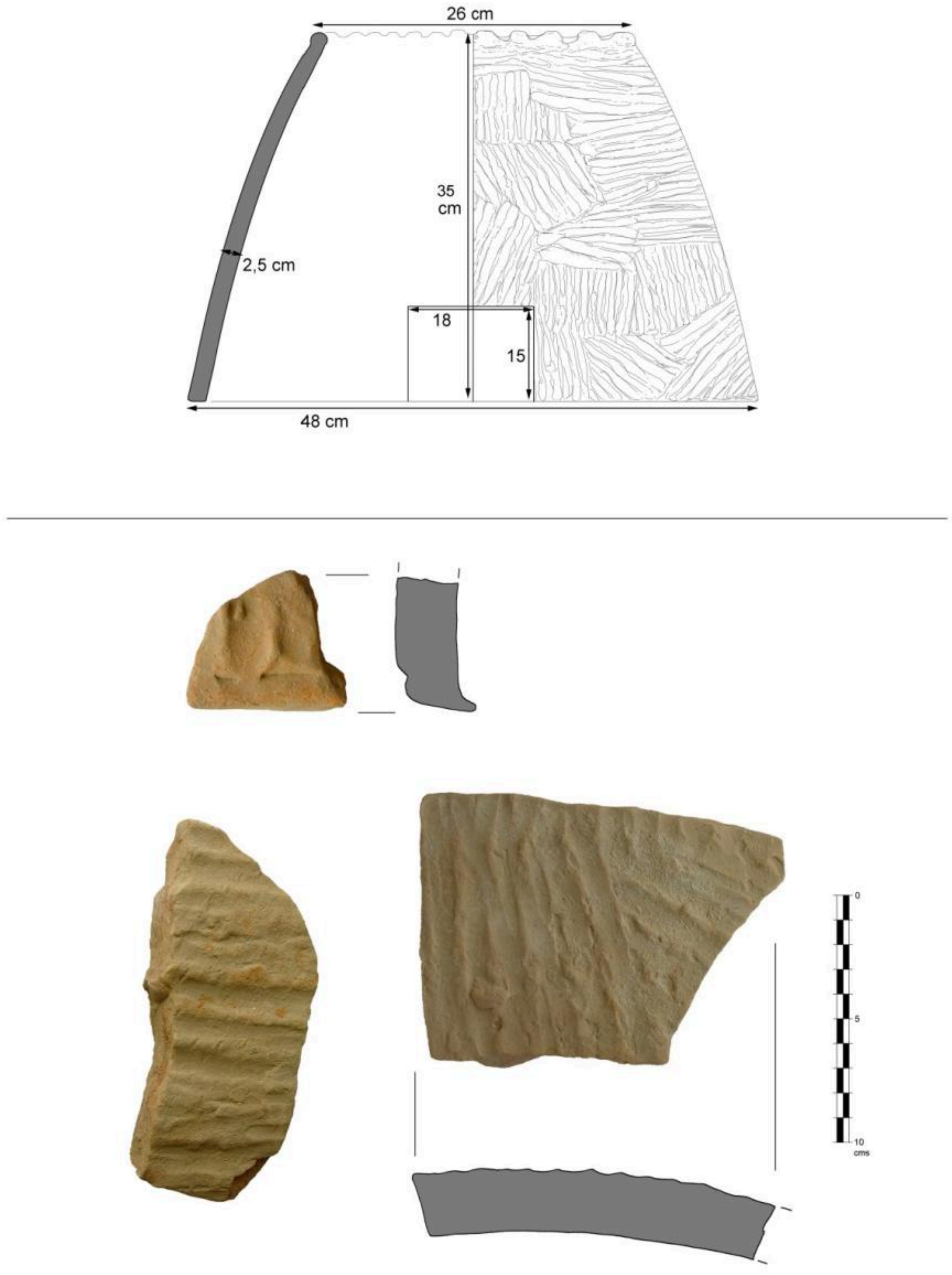

FIG 9. TOP: SECTION OF THE PORTABLE TANNŪR USED IN THE SECOND EXPERIMENT; BOTTOM: REMAINS OF THE PORTABLE TANNŪR DOCUMENTED IN THE PUNIC ALFAR OF THE VILLA MARUJA SITE, WHICH SERVED AS AN ARCHAEOLOGICAL MODEL FOR THE REPRODUCTION. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

FIG 10. MAIN STAGES OF THE PORTABLE TANNŪR CONDITIONING PROCESS. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

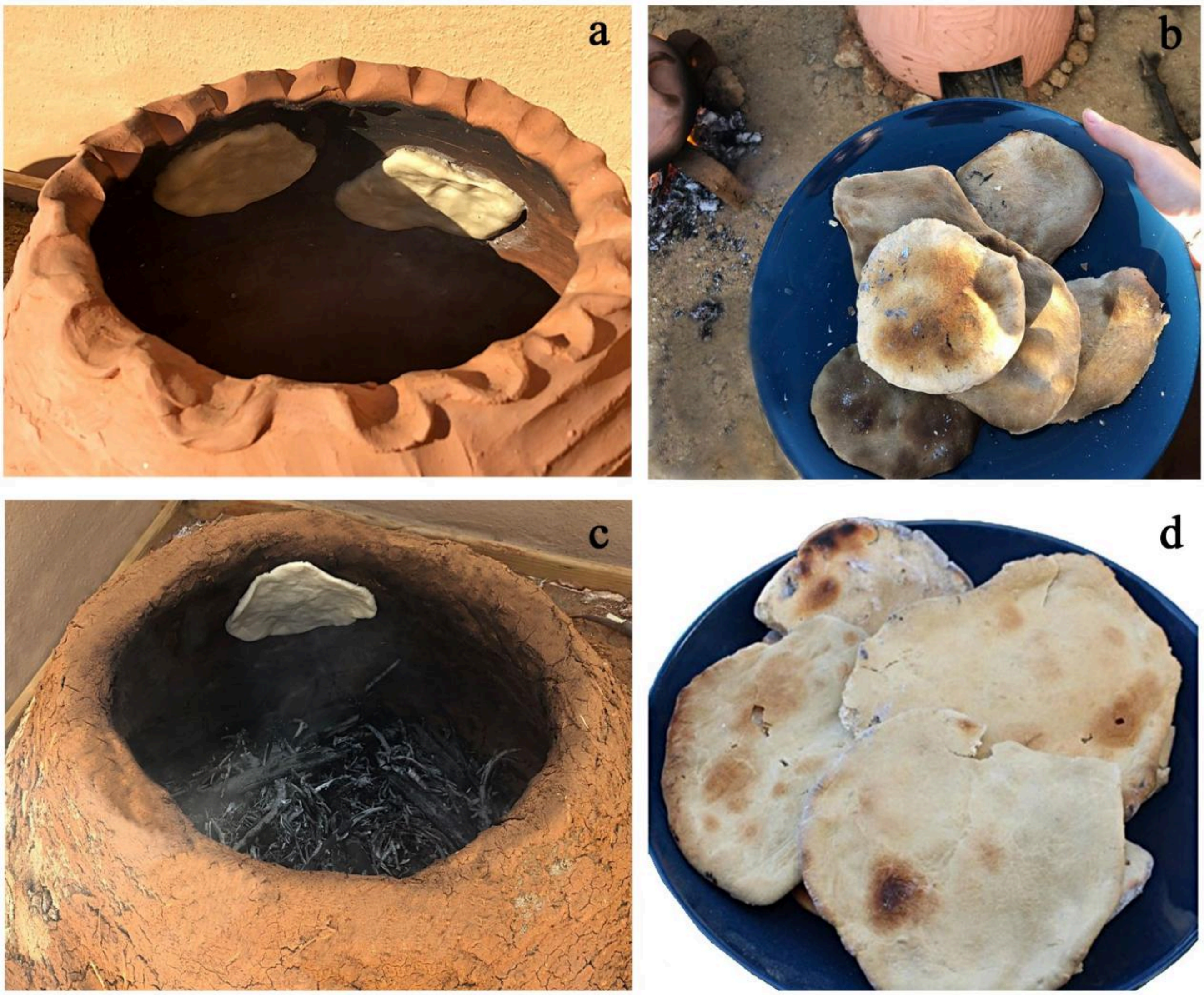

FIG 11. BREAD MAKING AND BAKING PROCESS IN FIXED AND PORTABLE TANNŪR OVENS. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL

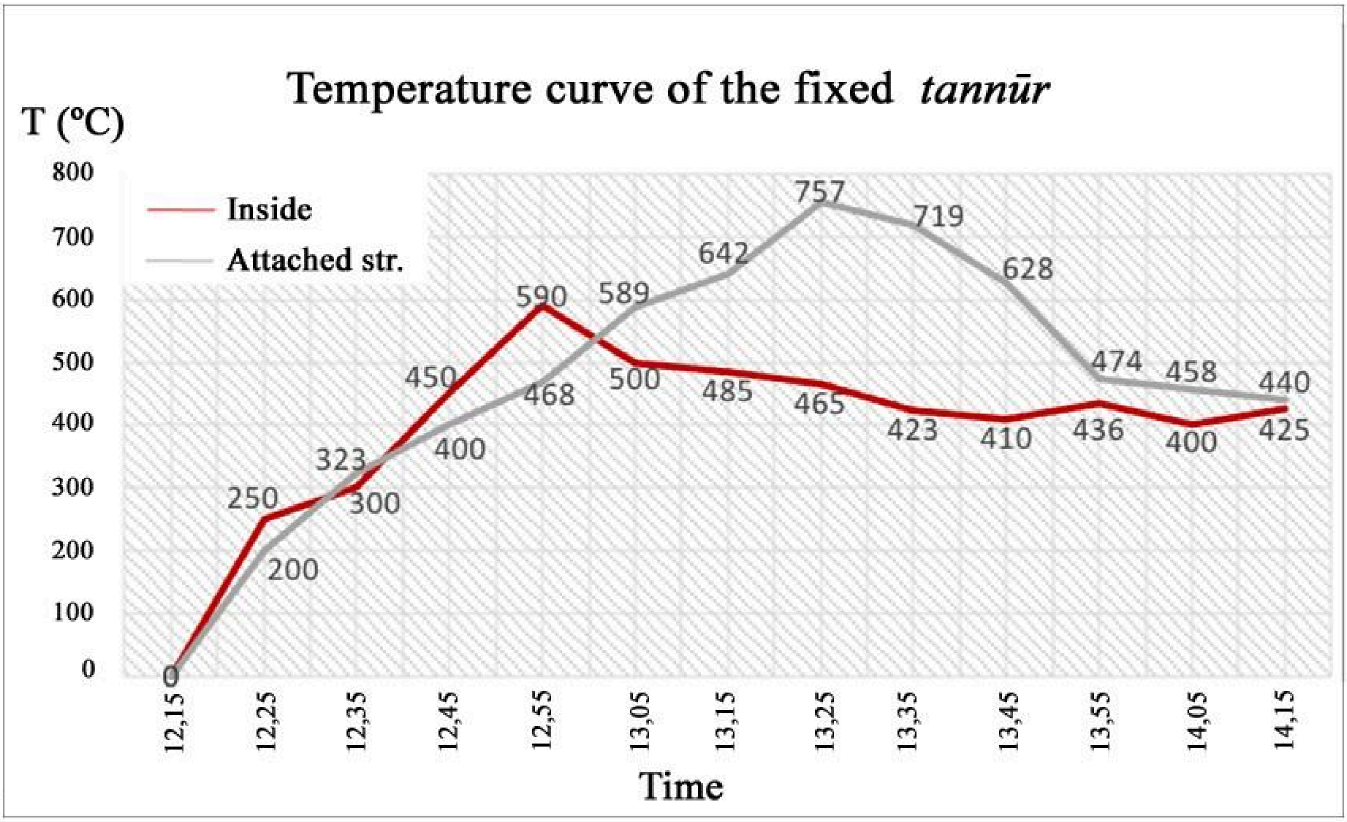

FIG 12. TEMPERATURE CURVE OF THE FIXED TANNŪR, BOTH INSIDE AND IN THE SMALL ATTACHED STRUCTURE, DURING THE BREAD BAKING EXPERIMENT (2ND COMBUSTION).

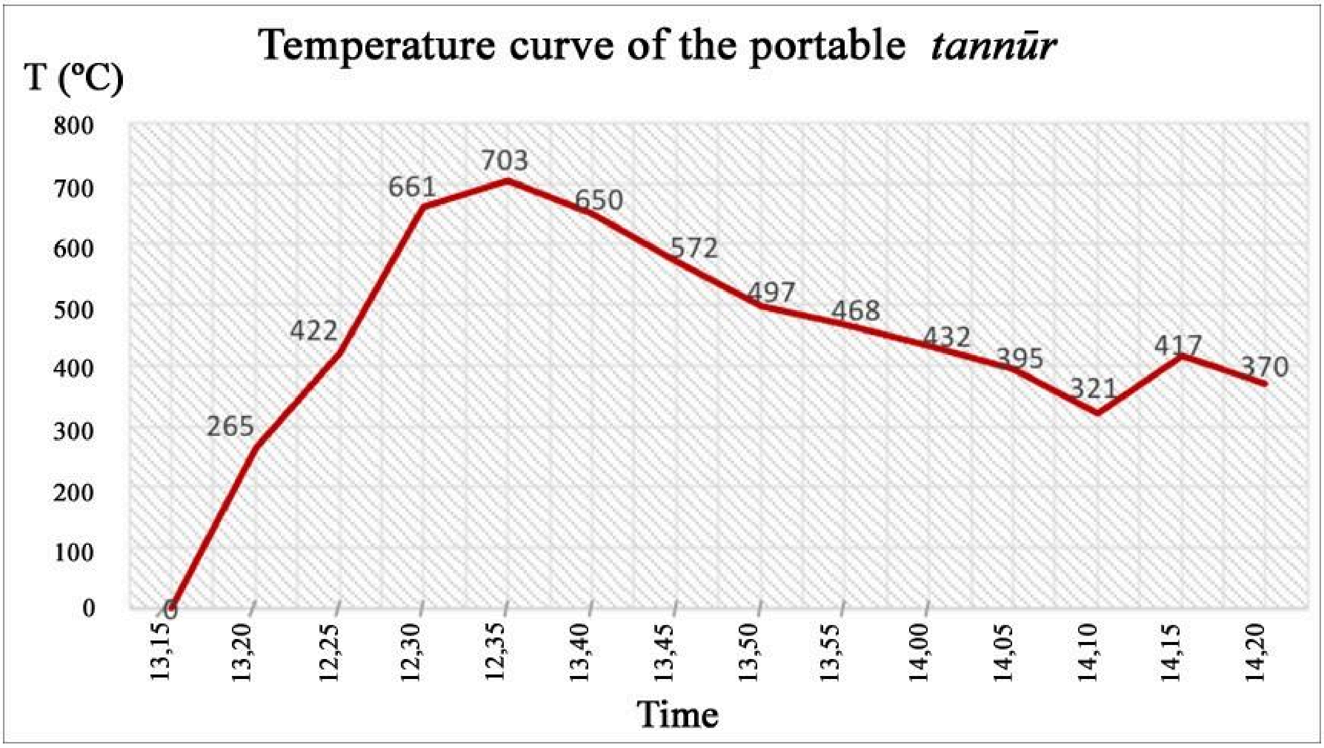

FIG 13. TEMPERATURE CURVE OF THE PORTABLE TANNŪR DURING THE BREAD BAKING EXPERIMENT (3RD COMBUSTION).

FIG 14. DETAIL OF MINOR DAMAGES TO THE INNER SURFACE. PHOTO BY CARMEN RAMÍREZ CAÑAS ET AL