Standardization and units of measurement used in pottery production: the case of the post-medieval botijuela or Spanish olive jar made in Seville

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SUMMARY: The aim of this paper is to determine the degree of standardization of pottery production and the units of measure that regulated their production. The group chosen to test this methodology is known as the Spanish olive jar. It is a series of productions manufactured in the south of the Iberian Peninsula throughout the Early Modern Period. The methodology begins with the morphometric characterisation of each vessel around a series of quantitative variables. Then, the Test for Normality is performed, and the Product-Moment Correlation Coefficient is calculated. Subsequently, a Cluster Analysis identifies different groups of Spanish olive jars. The Principal Component Analysis provides additional information that allows for a deeper understanding of the groups obtained. As a final step, calculating the Coefficient of Variation allows us to know the degree of standardization of each variable. Finally, once all these data are known, the possible units of measure that governed the production system of the Spanish olive jar can be recognized.

INTRODUCTION

The standardization or diversity of ceramic types is one type of evidence provided by the archaeological record that allows researchers to form hypotheses regarding the specialization of pottery artisans. In addition to this evidence, the study of ancient ceramics can also offer us information about production structures, processing techniques and scales of production. All these data shed light on larger productive systems and the crafts of making ceramics. But the question remains, how do we measure the diversity of ceramics? The present article will attempt to outline a functional methodology to answer this question.

There are two mains aims to this research. The first is to define a methodology that identifies the standardization and the units of measurement used in the production of some types of ceramics. The second objective is to test the methodology on a specific ceramic type to obtain previously unknown data about it and to verify the viability of the method.

POST-MEDIEVAL PRODUCTIONS OF THE SPANISH OLIVE JAR

The group researched in this paper as a case study consists of 40 specimens of the ceramic class defined by J. M. Goggin as the Spanish olive jar. These potteries also appear in the archaeological literature under the following labels: anfora, anforeta, botija, botijuela perulera, or botijuela. The terms botija, botixuela and botija perulera derive from its use and...
method of manufacture.3 The sample group includes three specimens (Case 1, Case 2, and Case 3) found in Asturias.4 Nine specimens (Cases 4-12) were found in the Basque Country5 and 28 objects (Cases 13-40) come from Seville.6 The entire sample studied in this work comes from archaeological contexts within the Iberian Peninsula.

This article refers to the vessels as Spanish olive jars since it is certain that all 40 specimens were manufactured in Seville. This term emphasizes the Castilian origin of these pieces, and is a term used in other recent studies.7 This study begins with pieces examined by previous research, all of which firmly established their Sevillian origin.8 The 28 pieces found in Seville comprise scraps from ceramic workshops or pieces with some imperfections that were used in the filling of vaults.9 Additionally, these pieces have undergone archaeometric analyses that confirm Seville as their place of production.10

While there are other specimens of this type of pottery found outside of the Iberian Peninsula, this study is focused on identifying the standardization and the units of measurement used in the manufacture of the Spanish olive jar. Therefore, it is crucial that all the pieces come from the same production centre, and that the same measurements and variables are analysed on complete vessels11. These are the requirements that the ceramic sample must have in order for the proposed methodology to be successful.

RESEARCH AND CHRONOTYPOLGY

Several authors have studied these ceramic forms in the past, and it is not an objective of the present work to review all archaeological literature that pertains to them. However, it is necessary to highlight the most important milestones in their study, especially those referring to their typologies, chronologies and those related to their processing techniques. These three factors are influences in the aspects of the vessel, and determine the degree of standardization and the units of measurement used in their production. One of the pioneers in the study of these containers was Goggin,12 who developed a classification system13 divided into four basic forms (Types A, B, C, and D) and three chronological styles: Early Style olive jar (1500-1580), Middle Style olive jar (1580-1780), and Late Style olive jar (1780-1850). Goggin further refined his chronologies in later works14 into the following styles: Early Style olive jar (1493-1575), Middle Style olive jar (1575-1700), and Late Style olive jar (1700-1830).15 In addition to Goggin’s studies, other Anglophone authors have also been crucial in the systematization of these productions.16

The majority of these kinds of vessels come from Seville, and continuing research has provided new information about its types. This led to a revision of Goggin’s three chronological styles.17 In 1999, G. Escribano and A. Mederos reviewed previous research and created a new typological and chronological framework for these containers. The most commonly used chronology would be the following: Botijuela Type A (1475-1800), Botijuela Type B (1550-1800), Botijuela Type C (1600-1725), and Botijuela Type D (1775-1850).18

ORIGINS

In terms of production, these vessels were manufactured in the region of Andalusia, in the Southern part of the Iberian Peninsula, especially around the basins of the Guadalquivir River.19 The city of Seville is the place where the production of the Spanish olive jar originates.20 This city was the most important ceramic production centre in the Iberian Peninsula during much of the Early Modern period.21 In 1503, the Casa de Contratación de Indias (Indies House of Hiring) was established in Seville, transforming the city into the focus of control and administration of all trade with the New World. In 1717, the Casa de Contratación was moved to Cádiz, making this city the new focal point of economic control with the American Continent.22 Furthermore, the need for ceramic pots to contain the merchandize involved in these large commercial flows caused potters’ neighbourhoods to arise in the vicinity of Seville and Cádiz. In both cities, the majority of pottery production was dedicated to Spanish olive jars. There has recently been an excavation of a potter’s workshop for the production of Spanish olive jars in Cadiz (Puerto de Santa María).23

Ceramic containers dedicated to trade and similar to the Spanish olive jar were made in the Early Modern period in Portuguese ceramic centres,24 as proven by the production site in Aveiro.25 Similar forms were also manufactured on the American continent,26 such as in Peru,27 Panama,28 and Mexico.29 These pieces have not been included in this study because their shapes are different from the Spanish olive jar, and it is assumed that their standardization and units of measurement do not accord with Sevillian production standards. For the type of analysis that we want to carry out, it is necessary to study each ceramic workshop in an independent way, to be able to compare them in successive studies. For these reasons we have chosen the Spanish olive jar made in Seville, to develop our research.

FUNCTIONALITIES

Regarding its functionality, the Spanish olive jar would have been used to store, conserve, and transport liquid and solid products. In addition to this use, they were also used for transportation of goods. A series of secondary uses or reuses are also known, such as in-fill in the domes of certain buildings,30 or
FIG. 1
A: The six quantitative variables analysed in Spanish olive jar. B: Data set of Spanish olive jar (SOJ-Cases) ceramics.

| Cases | Variable 1 (mm) | Variable 2 (mm) | Variable 3 (mm) | Variable 4 (mm) | Variable 5 (mm) | Variable 6 (l) |
|-------|----------------|----------------|----------------|----------------|----------------|---------------|
| Case 1 | 68.6           | 264.5          | 104.5          | 310            | 132.3          | 7.89          |
| Case 2 | 66             | 180            | 28.9           | 296.3          | 75.6           | 1.16          |
| Case 3 | 60.2           | 186.2          | 43.4           | 274.1          | 66.2           | 0.96          |
| Case 4 | 62             | 284.8          | 82.7           | 551.7          | 126.5          | 37.94         |
| Case 5 | 80.6           | 277.8          | 80.9           | 508.5          | 130.9          | 25.38         |
| Case 6 | 79.8           | 281            | 116            | 536.8          | 170.7          | 25.83         |
| Case 7 | 48.5           | 265.5          | 63.8           | 512.7          | 108            | 19.97         |
| Case 8 | 68             | 248.2          | 73             | 534.8          | 152.9          | 22.88         |
| Case 9 | 48             | 244            | 42.8           | 497.1          | 165.5          | 19.74         |
| Case 10| 46             | 237            | 52             | 509.8          | 140.4          | 16.71         |
| Case 11| 57.9           | 246.1          | 79.8           | 281.4          | 120.4          | 5.48          |
| Case 12| 51.7           | 225.9          | 103            | 271.2          | 98.3           | 4.14          |
| Case 13| 79.4           | 348.2          | 53.9           | 539.4          | 223.4          | 26.92         |
| Case 14| 68.1           | 340.6          | 74.7           | 544.1          | 227.1          | 28.20         |
| Case 15| 58.6           | 270.6          | 62.4           | 577.2          | 155.2          | 17.08         |
| Case 16| 58.6           | 391.7          | 94.6           | 719.2          | 249.8          | 57.68         |
| Case 17| 73.8           | 255            | 85.1           | 558.3          | 210            | 27.15         |
| Case 18| 68.1           | 355.8          | 71.9           | 567.8          | 185.4          | 31.87         |
| Case 19| 75.7           | 348.2          | 85.1           | 577            | 208.2          | 32.82         |
| Case 20| 90.8           | 423.9          | 79.4           | 657.7          | 248.8          | 63.99         |
| Case 21| 97.7           | 326.6          | 102.2          | 520            | 170.8          | 38.91         |
| Case 22| 67.6           | 316.5          | 61.9           | 527.5          | 176            | 41.76         |
| Case 23| 61.4           | 289.6          | 64.2           | 490.5          | 152            | 28.38         |
| Case 24| 100.6          | 315.4          | 74.3           | 503.1          | 159.7          | 38.40         |
| Case 25| 76.8           | 267.9          | 59.7           | 418            | 128.9          | 17.29         |
| Case 26| 64.7           | 285.9          | 57.8           | 460.3          | 146.6          | 26.14         |
| Case 27| 73.2           | 256            | 73.5           | 294.6          | 150.7          | 5.94          |
| Case 28| 64.8           | 245.8          | 65.1           | 292.2          | 143.8          | 5.34          |
| Case 29| 66.6           | 247.7          | 80.1           | 290.6          | 120.9          | 5.75          |
| Case 30| 60.5           | 246.5          | 77.2           | 274.1          | 137.4          | 4.93          |
| Case 31| 68.3           | 243.1          | 58.6           | 318.8          | 138.1          | 6.57          |
| Case 32| 72.2           | 212.8          | 94.1           | 246.3          | 109.8          | 2.82          |
| Case 33| 70             | 243.7          | 76             | 317.7          | 118.7          | 7.88          |
| Case 34| 75.3           | 260.3          | 85.9           | 322.5          | 156.9          | 9.45          |
| Case 35| 74             | 244.4          | 66.3           | 285.1          | 116.3          | 5.55          |
| Case 36| 59.4           | 246.9          | 101.3          | 279.3          | 136.2          | 5.61          |
| Case 37| 61.8           | 301.7          | 60.2           | 404.9          | 151            | 15.65         |
| Case 38| 74.4           | 288.2          | 57.7           | 458.2          | 151.8          | 19.88         |
| Case 39| 64.1           | 218.3          | 33.4           | 317.1          | 77.6           | 1.84          |
| Case 40| 54             | 181.5          | 32.5           | 316            | 76.8           | 1.55          |
as drainage vessels.\textsuperscript{31} In the north-west of the Iberian Peninsula, in Asturias and Galicia, mainly in the vicinity of the Eo estuary, we observe these secondary uses. In particular, pieces of the Botijuela Type D were reused as decorative finials in traditional constructions such as granaries, known as hórreos orpañeras.\textsuperscript{32} This same phenomenon has also been observed in Santiago de Cuba.\textsuperscript{33}

**FIG. 2**

A: Histograms of each of the variables where the distribution curve is observed. B: Analysis of normality applying *Shapiro-Wilk Test*. C: *Pearson Correlation Coefficient* results.

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Thanks to the global commercial networks established during the Early Modern period, these vessels were transported far from their place of production. The presence of Sevillian Spanish olive jars in different parts of the world can act as a proxy to better understand these commercial networks. In relation to European trade, these vessels are commonly found in the British Isles, the Netherlands, Poland, and Sweden. Regarding Atlantic trade, they are very common on the American continent, especially around the Caribbean Sea, Mexico, Colombia, Ecuador, Argentina, and in Canada. Related to the Galeón de Manila and trading in the Pacific, these vessels have been discovered as far away as Australia, the Philippines, and the Solomon Islands in Oceania.

**METHODOLOGY FOR STATISTICAL ANALYSIS**

The methodology developed by the author begins by introducing the use of statistical analysis for the classification and study of pottery. In particular, it focuses on the standardization or diversity of ceramic types, and looks for aspects that conditioned their production. The Spanish olive jar was chosen for the application of this methodology because of the possibility of studying complete specimens from which to extract the necessary variables. Various specialist researchers have determined that the 40 specimens analysed in this study were manufactured in Seville. This allows us to define the production of a specific pottery production centre without investigating pieces from other sources, which would make it impossible to carry out such a study. Additionally, this study benefits from using a type that is distributed all over the world, ensuring a robust sample size.

This section describes the following methodological steps. Individual ceramics are first described using mathematical terms to characterize their morphometric shape. Repeating this descriptive process produces a set of characteristics, which can then be compared to other vessels. It is then possible to identify the degree of normality (Shapiro-Wilk Test), and the correlation that exists between each individual vessel (Pearson Correlation Coefficient). These data allow for a Multivariate Analysis in order to create different groups (Cluster Analysis); this step also defines the morphometric characteristic of each group (Principal Component Analysis). Together, these analyses produce a series of pottery typologies, elements which are defined from a series of common attributes, in a place and in a precise chronological moment which distinguishes it from other types. The results of these analyses and their interpretation are not limited to simply grouping similar objects together but can also identify common features shared by two or more material effects of the same social action. Finally, the standardization of each type (Coefficient of Variation) will be calculated. This identifies the degree of the diversity of certain pottery productions, as well as the units of measurement that may have acted as conditioning factors in its manufacturing.

## DESCRIPTION OF THE CERAMIC IN MATHEMATICAL TERMS FROM ITS MORPHOMETRY

The first step in this methodology is to describe each of the vessels through a series of measurements or quantitative variables. The objective is to describe the shape of each pottery vessel in simple mathematical terms. The main classification criterion is the vessel’s form, which creates an initial type based on the measurement of its key dimensions. Classifications resulting from quantitative morphometric variables have already proven effective for ceramic analysis and for other archaeological materials. A series of simple measurements or quantitative variables can be an invaluable tool to differentiate existing groups within a collection.

In this study, the measurements or quantitative variables of the Spanish olive jar (Fig. 1A) have been the following: rim diameter (variable 1), maximum diameter (variable 2), base diameter (variable 3), height (variable 4), height of maximum diameter (variable 5), and volume or net capacity (variable 6). All variables are measured in millimetres, except for volume (variable 6), which is measured in litres. The data obtained is used for all subsequent statistical analyses (Fig. 1B). To calculate these 6 variables, a sample of 40 specimens is enough.

## TEST FOR NORMALITY

The first analysis performed is the Shapiro-Wilk Test, which identifies the distribution of the variables (Fig. 2A–B). The Shapiro-Wilk Test is one of the statistical Tests for Normality used on small samples (less than 50 cases) and has been used successfully in several archaeological studies. This analysis can be applied when the pieces have similar production, which is why the analysed sample is composed of pieces made in the same ceramic workshop (Seville). This test compares the cumulative distribution of values from the archaeological sample with the cumulative distribution expected by the theoretical model. It is very interesting to discover the distribution of the sampled data and to check the normality of any individual variable by performing this type of test. Normality of a variable is indicated by the concrete values that quantitative variables adopt.
As observed for variables 1, 2, 3, and 5 (Fig. 2B), their probabilistic significance is a number greater than 0.05, so it is concluded that they are normalized. On the other hand, the data are not distributed in a normal way for variables 4 and 6, given that their probabilistic significance is less than 0.05. When variables are normalized it means that the vessels have been shaped intentionally, produced by a concrete action, or by larger social principles of work.67 If the data obtained is related to the method of production of the vessels, we may be able to interpret the results of the Shapiro-Wilk Test and hypothesize about what that intentionality was behind such actions.

**THE PRODUCT-MOMENT CORRELATION COEFFICIENT**

The Correlation Coefficient identifies possible relationships between two quantitative variables.68 It is a commonly used analysis in archaeological studies, since it identifies how something varies in relation to something else. This study uses the Pearson Correlation Coefficient or Product-Moment Correlation Coefficient, which measures the strength of the relationship between two correlated variables in intervals or proportions.70 The results of this statistical test clarify the characteristic aspects of morphological variations of the Spanish olive jar (Fig. 2C).

**GROUPING AND CLASSIFICATION BY MULTIVARIATE ANALYSIS**

The previous analyses demonstrate that ceramics do present a series of measurements that can be classified.71 Mathematical descriptions of the vessel shape, the Shapiro-Wilk Test, and the Pearson Correlation Coefficient provide enough data to measure any similarities or dissimilarities between each individual Spanish olive jar. The next step is to identify or classify groups of similar individual vessels with the use of different Multivariate Analyses.

The first grouping method uses Cluster Analysis (hereinafter CA) to create a numerical taxonomy. CA is a type of Multivariate Analysis that is based on similarities or dissimilarities, and its groups or classifies individual examples into a series of categories. This approach is commonly used with success in archaeological research and pottery studies, especially in archaeological investigations that analyse the chemical components of the clay. The results of the CA have been achieved with the use of a hierarchical method with an agglomerative technique, such as Ward’s Method.74

The dendrogram produced from this analysis (Fig. 3) indicates the existence of four types within the sample group of Spanish olive jars. In this case, the CA seems to statistically complement and revalidate previous investigations, although in some cases it has further refined these groups.

**Principal Component Analysis** (hereinafter PCA) is a useful technique for more deeply investigating the groups identified through the CA (Fig. 4B–C). With this analysis, it is possible to define which characteristics most contribute to the variability between each group. The PCA is a multivariate statistical analysis of simplification or reduction, which uses a linear combination of variables to obtain a series of Principal Components (hereinafter PC). The
application of PCA in ceramic research has already been widely tested in archaeology.76

**DEGREE OF CERAMIC STANDARDIZATION**

With the typologies now defined, the next point to be addressed is the degree of standardization within each typology. This assumes that variability can be measured statistically.77 To identify the degree of standardization, the Coefficient of Variation (hereafter CV) will be used,78 which gives a measure of the standardized dispersion. By identifying scales of variability in the production, this measure indicates the degree of specialization of artisanal production79 (Fig. 5C).

To substantiate the statistical results pointing to the standardization of a ceramic production technique, data from ethnographic and ethno-
archaeological studies must be considered.\textsuperscript{80} The ratios of standardization and ceramic production emerging from this methodology should be understood as approximations. They are the only ratios with which we can establish archaeological comparisons.

An equal CV or a value greater than 57.7\% represents the variation expected with vessels produced under random conditions.\textsuperscript{81} In studies of archaeological material, CV values will always tend to be higher.\textsuperscript{82} A CV between 6 and 9\% is associated with small-scale production and part-time specialist workers, with a maximum production of 6000 vessels per year per potter.\textsuperscript{83} Another study showed that the production of skilled potters fluctuates between 2-3\% and 6\% of CV.\textsuperscript{84} In fact, research indicates that a CV between 2.5 and 4.5\% is the minimum error achievable in manual production without the use of external

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig5}
\caption{A: Comparisons of variables 1, 2, 3 and 4 converted to palmos. B: Histogram of variable 6 in each cluster and its coincidence with capacity units. C: Results of the CV for the analysed ceramics.}
\end{figure}
rules or guidelines. A CV between 3 and 6% is associated with a medium-range degree of specialization and ascale of production in which the potters would produce between 4000 and 14,000 vessels per year.

On the other hand, a CV below 3% suggests a large-scale and highly specialized production, with potters producing more than 14,000 vessels per year. It has been estimated that a CV of 1.7% is the minimum variation possible in an artisanal process, given the limitations of human sensory perception. If the CV is less than 1.7%, this implies an automation of production through the use of external rules and regulations.

NORMALIZATION OF CERAMIC PRODUCTION BASED ON SPECIFIC UNITS

Once the CV analysis identifies the degree of standardization, we can try to discover whether specific units of measurement were used in its production. In other words, to identify the external rules that affected the potters in their preparation. Similar studies have been carried out on several ceramic productions from the Roman period.

The Spanish olive jar was a vessel connected to the trade and transport of goods, and it thus seems logical to hypothesize that its production was regulated by standard measures and capacities. To test this hypothesis, variables 1, 2, 3, 4, and 6 have been converted into units of measurement used in Seville at the time of production (Fig. 5A). The contemporary unit of length was the palmo (209 mm); the volumetric units used were the cántara (16.13l), linked mainly to wine, and the arroba (12.56l), related to oil.

RESULTS

This section reviews how the methodological steps detailed in the previous section were carried out on the Spanish olive jar made in Seville during the Early Modern Period. The resulting data will improve our understanding of the production of this vessel.

HOW WERE THEY MANUFACTURED?

TEST FOR NORMALITY AND THE PRODUCT-MOMENT CORRELATION COEFFICIENT

Both the bodies and the bases of the analysed vessels show some traces that indicate their manufacture on a potter’s wheel. Various investigations have indicated that the Spanish olive jar was constructed in distinct phases and then assembled. Some parts of the vessel were made using a potter’s wheel rotating at a low speed. This generates grooves that are not perfectly horizontal, but tend to be sinuous. The different parts of vessels are joined together with the aid of a slip, whose use highlights the external undulations.

The normalized variables are those referring to the rim diameter (variable 1), maximum diameter (variable 2), base diameter (variable 3), and height of maximum diameter (variable 5). This supports the idea that the vessels were manufactured in two parts. The vessel was manufactured up to its maximum diameter, regardless of the size or height that it will achieve (hence the normalization of variables 1, 2, and 5). On the other hand, vessel bodies of varied sizes and volumes were shaped: this supposed randomness justifies that variables 4 and 6 are not normalized. Subsequently the two parts are joined using the wheel (due to this, variable 3 is normalized). This would explain the external homogeneity of the pieces and the clearly present. We have detected traces of finger impressions at the union of the base with the rest of the piece, as well as marks of a possible spoutulation, both of which confirm the manufacture of the Spanish olive jar by parts. Due to the joining process of the two parts, vessels of different sizes are created. All this indicates that the potter who was turning the vessel up to its maximum diameter (variable 2), did not know the final size of the vessel.

The results of the Pearson Correlation Coefficient (Fig. 2C) demonstrates how all of the variables are positively related to each other: as the values of one of the variables increase, the other variable increase as well. There is a statistically significant and very intense relationship between variable 2 and variables 5, 6, 4 and 1 (Fig. 2C). This indicates the importance of the maximum diameter (variable 2) when making these vessels. At the same time, variable 6, in addition to being related to variable 2, has statistically significant correlations with variables 4 and 5 (Fig. 2C). This is a logical relationship, since a vessel with a greater volume (variable 6) requires increased height (variable 4), greater maximum diameter (variable 2), and a greater height of maximum diameter (variable 5). Variable 4 is significantly correlated with variable 5 (Fig. 2C), which allows us to form hypotheses about the method of production. With an increased height of the vessel (variable 4), the maximum diameter (variable 5) and distance from the rim must also increase, likelyto provide stability to the vessel.

It should be noted that there is not a statistically significant relationship between the following variables: rim diameter (variable 1) and height (variable 4), the base diameter (variable 3) and the height (variable 4), nor between the base diameter (variable 3) and the volume (variable 6). These last inferences seem to be related to the two-part composition of the Spanish olive jar, discussed in the previous section.

WHAT TYPE OF CERAMICS WERE MADE?

CLUSTER ANALYSIS AND PRINCIPAL COMPONENT ANALYSIS

It is clear from the previous analysis that the groups created through CA can be defended from an
archaeological and historical perspective. The dendrogram (Fig. 3) indicates the existence of four types within the sample group of Spanish olive jars. The first of them, SOJ-C1, consists of quite compact vessels with a circular profile, which are similar to the Botijuela Type B. The SOJ-C2 group consists of pots with a small size and capacity, which coincides with Botijuela Type D. The group SOJ-C3 is composed of vessels with a large size and capacity and has profiles that tend to verticality and show a certain piriform profile. Some of these pots have been classified as Botijuela Type C, and others as Botijuela Type A. Finally, the SOJ-C4 group is composed of vessels of a greater capacity, all of which coincide with the Botijuela Type A.

As these results make clear, there is a relationship between the clusters and the typologies that have been differentiated and studied about the Spanish olive jar made in Seville. Therefore, the CA seems to statistically complement and revalidate the previous investigations, in some cases further refining these groups.

Regarding the PCA more than 79% of the variability is determined by the first two PCs (Fig. 4B). More than 61% of the variability depends on PC-1 (Fig. 4B) and consists of a very high positive contribution of variables 4, 2 and 6, that is, variables related to the vessel’s height, maximum diameter, and volume (Fig. 4C). In this way, the Spanish olive jars that were created to contain a larger volume of liquids have very high values (SOJ-C3 and SOJ-C4), while vessels with a lower height and capacity have negative values (SOJ-C1 and SOJ-C2). This means that PC-1 represents a direct ratio between the size of the vessel and its capacity.

More than 17% of the variance comes from PC-2 (Fig. 4B). Of the variables in PC-2, there is a positive contribution of variables 3 and 1, related to the rim diameter and the base diameter (Fig. 4C). At the same time, there is a negative contribution of variable 4, dealing with vessel height (Fig. 4C). Vessels with the largest rim diameter and base diameter score positively (SOJ-C4 and SOJ-C1), while elongated pots score negatively (SOJ-C3 and SOJ-C2). Therefore, PC-2 refers to the shape of the vessel, namely of more rounded and open vessels and those with more stylized and pointed forms. The rest of the principal components are more difficult to interpret, because of their small contribution to the set of variability (only 21%).

If the data obtained through PCA are cross-referenced with the data resulting from the CA, the nature and distribution of our groups becomes more clear (Fig. 4A). Through a graphic representation it is possible to observe which characteristics and which variables define each of the created typological groups. As can be seen in the graph (Fig. 4A), the PC-1 and PC-2 scores classify the Spanish olive jar groups created through CA into clearly defined groups.

**IS IT A STANDARDIZED PRODUCTION? COEFFICIENT OF VARIATION**

For all of the variables, the CV of the clusters of the Spanish olive jar (Fig. 5C) is lower than 57.7%, which must be interpreted as an elaborated and non-random production. Among the typologies, SOJ-C4 has higher CV rates, making it less standardized. The variability of SOJ-C4 can be explained because of the large size of the vessels that define this group and the fact that the standardization decreases as the size of the vessel increases. The typology SOJ-C2 is the most standardized typology. The SOJ-C2 has a lower CV with four highly standardized variables, all of which are lower than 10%. The SOJ-C1 is the second most standardized typology, with one of the variables lower than 6% of CV.

When analysing the standardization of individual variables within each cluster, variables 2 and 4 are the most standardized, while variable 6 presents a greater variability. Nine of the analysed variables show a CV of 10% or less, indicating a regular production by skilled potters with a part-time dedication, which would create about 6000 vessels per year per potter. Two of the variables have a CV of 6% or less, indicating a production of skilled potters that could produce 14,000 vessels per year per potter. About 80% of the measurements of the Spanish olive jar coincide with multiples or fractions of the palmo (Fig. 5A). Furthermore, as regards variable 4, there seems to be two main sub-groups. One of these fluctuates around 2.5 palmos and the other around 1.5 palmos. In variable 2, all the vessels are grouped mainly around 1.25 palmos. As regards variable 3, there is a preference for measurements that are classified between 0.4-0.3 palmos. The same happens for variable 1.

On the other hand, the histogram (Fig. 5B) shows how the capacity of the Spanish olive jars tends to be grouped mainly around multiples or fractions of the cántara and arroba. In fact, the existence of a specialisation of each cluster can be observed since they coincide with the specific capacity units of a certain type of liquid.

Thus, the SOJ-C1 group, with an average capacity of about 6 litres (Fig. 5C), coincides with the measures of one-third of the cántara (5.37l) and, above all, with half of an arroba (6.28l). At the same time, they are close to 1.5 celemínines (1 celemín is 4.624l), a measure of capacity for solids, and a cuartilla (8.066l), for liquids. The celemín and cuartilla are cubic measures used in Castile in the Early Modern Period. In addition, pottery analysis of vessels traded between the Canary Islands and the American continent have indicated that a botija would have an average capacity of 7.5l, so it would fall within the SOJ-C1 group. In this way, a SOJ-C1 vessel would most likely transport half an
arroba of oil, or perhaps a third of a cántara of wine, or one and a half celenin of cereals.

The SOJ-C2 group, with an average capacity of 1.3l (Fig. 5C), coincides with two multiples of Castilian cubic measures linked to the wine\textsuperscript{105}, namely the cuartillo (0.5l) and the azumbre (2l). This group is also related to the libra (0.5l), which was used as a measure of oil.\textsuperscript{106} Therefore, SOJ-C2 vessels could transport 3 cuartillos or 1.5 azumbres of wine, or 3 libras of oil.

The SOJ-C3 group, with an average capacity of 23.8l (Fig. 5C), is grouped around different multiples of the cántara or arroba, with some examples ranging from 1 to 2.5 cántaras, and from 1.5 to 3 arrobas. According to the documentation of trade from the Canary Islands, a botijaperulera would have a capacity of 22.5l,\textsuperscript{107} very similar to those of SOJ-C3, so the botija perulera could refer to SOJ-C3. A SOJ-C3 vessel was very likely used to transport 3 arrobas of oil or 2.5 cántaras of wine.

Finally, the SOJ-C4 group has an average capacity of 37l (Fig. 5C). As in the SOJ-C3 group, the capacities of these vessels coincided with cántara and arroba measurements, although in this case they seem to be more related to the latter. The capacities would oscillate between 2 and 5 arrobas.

DISCUSSION

Through the presented analyses, some conclusions can be proposed regarding the production of the Spanish olive jar, including its method of production and its functional applications. In terms of the manufacturing of these vessels, comparing the normalization observed in variables 1, 2, and 3, with the non-normalization of variables 4 and 6 indicates that the vessel would be constructed in two parts that would be united later. The negative correlation between variables 1 and 4, and between 3, 4, and 6 seems to confirm this fact (Fig. 6).

As far as standardization is concerned, the data offer clear conclusions. It should be repeated here that archaeological vessels have been studied, and these tend to have a higher CV. In addition, the broad chronology for some of these productions would lead to its greater variability. The well-known existence of more than one place of production of these vessels in...
Seville should also be considered as potentially affecting the data. All of these factors would be expected to negatively influence standardization. Despite this, the CV data demonstrate a high level of standardization of the Spanish olive jar made in Seville. This could be caused by its marked functionality, which minimizes vessel variation.

With regards to the level of the artisan’s professionalism, this standardization suggests a medium-high degree of specialization. The fact that the labor devoted to the production of these vessels was seasonal, or that pottery was combined with other activities certainly accounts for this result. Even so, the CV data indicate that each potter could produce at least 6000 vessels per year. The results also suggest that its manufacture should be seen at a medium-high scale of production, which would explain why these vessels are spread all over the world.

In addition, standardization seems to indicate the existence of external rules governing its production. This can be observed in the height of the vessels, which exist in two groups around the measures of 1.5 and 2.5 palmos. It may be that the potters used some kind of tools (such as a rope or a wooden ribbon) to maintain this measure (Fig. 6).

Regarding the volume, the recurrence of measurements such as the cántara and the arroba corroborate the hypothesis that the production of these vessels is linked mainly to the transport of liquids. Given their capacities, the containers of the SOJ-C1 group are the only ones that could be dedicated both to the transport of liquids and solids. The capacity of SOJ-C2 vessels relates them to the transport of liquids, mainly wine. Finally, the measurements of the SOJ-C3 vessels suggest that they could be used to transport wine or oil, while the SOJ-C4 group seems to be related only to transporting oil. These data corroborate the theory that the main destination of the botijuelas was undoubtedly the transportation of wine and oil for the Indies, products whose cultivation was soon banned in the American Continent by Royal Decree. Along with these two products the botijuelas would transport: olives, vinegar, chickpeas, capers, beans, honey, fish, rice, flour, or soap. These products appear on the freight lists of goods departing the port of Seville to the American Continent. Carrying out subsequent archaeometric analyses of any residues conserved inside any of these pieces could confirm it. However, as with all ceramic vessels, there is no limit to their possible contents. Our results only confirm the primary intended use of the Spanish olive jar made in Seville.

Therefore, the production of Spanish olive jars would be regulated by the palmos as a unit of length and by the cántara or the arroba as volumetric measures. These norms or regulations must originate from some institution that controlled and regulated the trade of the merchandise transported by these vessels. The results of this study shed light on the discussion whether there was any legislation on the measures of the botijuelas. Our theory, supported by a strong statistical argument, is that there was some kind of legislation dictating the physical shape of the botijuelas. Whether potters always followed this rule or it changed over time remains an open question.

In conclusion, the methodology outlined above has produced quantitative statistical data and has identified the level of standardization used in the physical production of the Spanish olive jar. Additionally, it has identified the units that likely conditioned and normalized the production of the Spanish olive jar, relating each of the types with specific units of measurement. These conclusions were not known previous to this research. Furthermore, from the point of view of its manufacture, this study has confirmed that the vessel was produced in two separate stages and was joined together in a later stage. Additionally, the use of statistics has provided new insights into the morphological and typological study of the Spanish olive jar.

Among the analyses carried out, the most useful have been the Test for Normality that has given us new information about the way the pieces are produced; the Cluster Analysis through which we have been able to create typological groups based on statistical criteria; and the Coefficient of Variation that, after all the process developed, has allowed us to know the standardization of the pieces and put them in relation to units of measurement used at the time. The Product-Moment Correlation Coefficient and the Principal Component Analysis were not as conclusive as initially thought, although they have helped to contextualize the rest of the analysis.

Future research would observe how our analyses behave with the introduction of a greater number of samples. It would be also be useful to explore the role of different workshops in Seville and to compare our data with archaeometric analyses of different fabrics. Along the same lines, it would be very interesting to analyse the standardization and units of measurement that conditioned related pottery productions. So, we could find out if the Portuguese and American workshops followed the standards of Seville.

The application of the methodology outlined in this work has produced these quantitative conclusions. The goal of this methodology is to know the degree of standardization and the units of measurement that were taken into account for the production of a certain type of ceramic. In order to obtain meaningful results, it must be applied to at least 30 examples or ceramic individuals, which are proven to originate from the same place. Each of these individuals must have a number of morphometric variables that can be measured. If the sample meets these
characteristics, we can apply the methodology and produce interesting results from other ceramic types.\textsuperscript{13}

The following analyses were performed on the variables dealing with the shape of each specimen: Test for Normality, Product-Moment Correlation Coefficient, Cluster Analysis, Principal Component Analysis, and Coefficient of Variation. As a result, it has been proven that Multivariate Analyses are a valid method for classifying ceramics and can complement more traditional approaches. Therefore, the approaches presented here can be applied to other studies that explore the standardization, the units of measurement, or the system of production used in any pottery manufacture.

Special thanks go to Yayoi Kawamura and J. Avelino Gutiérrez Gonzalez from the University of Oviedo, for providing me with knowledge and helpful advice. I am also very grateful to Enrico Cirelli from the Università di Bologna, and Joanita Vroom from the Leiden University, all of whom have kindly given me useful information on several aspects of pottery manufacture.

RECORD OF ARCHIVE DEPOSIT

The finds have been deposited at: Museo Arqueológico de Asturias, Calle San Vicente, 3-5, 33003 Oviedo, Spain (www.museoarqueologicodeasturias.com); Euskal Arkeologia, Etnografía eta Kondaira Museoa, Plaza Miguel de Unamuno, 4, 48006 Bilbao, Spain (www.euskal-museoa.eus); and Museo Arqueológico de Sevilla, Plaza de América, s/n, 41013 Sevilla, Spain (www.museosdeandalucia.es/cultura/museos/MASE/).

NOTES

\textsuperscript{1} Orton & Hughes 2013, 144-9.
\textsuperscript{2} Goggin 1960.
\textsuperscript{3} Zunzunegui 1965, 23.
\textsuperscript{4} Díaz Díaz 2016, 244; Busto-Zapico & Fernández López 2018.
\textsuperscript{5} Azkara Garai-Olaun & Núñez Marcén 1990/1991, 173-82.
\textsuperscript{6} Amores Carredano & Chisvert Jiménez 1993, 308-11.
\textsuperscript{7} Velasquez & Salgado-Ceballos 2018.
\textsuperscript{8} Díaz Díaz 2016; Azkara Garai-Olaun & Núñez Marcén 1990/1991; Amores Carredano & Chisvert Jiménez 1993; Escribano Cobo & Mederos Martín 1999; Busto-Zapico & Fernández López 2018.
\textsuperscript{9} Amores Carredano & Chisvert Jiménez 1993.
\textsuperscript{10} Ferrer et al. 2015.
\textsuperscript{11} This investigation aims to define the productions manufactured in Seville so that subsequent research can include examples from other manufacturing contexts. This would determine whether Sevillian standards were followed or modified in different places. If this study included pieces with unknown places of production, the statistical analyses would not be conclusive, even if the sample analysed exceeded 40 specimens.
\textsuperscript{12} Goggin 1960, 1968.
\textsuperscript{13} Goggin 1960, 23-8.
\textsuperscript{14} Goggin 1968, 228.
\textsuperscript{15} In the present study, the vessels classified by Goggin as: Type A - Early Style olive jar (or cantimploras) have not been considered. Not enough specimens have been found from which to extract the necessary variables for the statistical analyses.
\textsuperscript{16} Deagan 1987; Lister & Lister 1987; Marken 1994.
\textsuperscript{17} Amores Carredano & Chisvert Jiménez 1993; Pleguezuelo-Hernández et al. 1999.
\textsuperscript{18} Escribano Cobo & Mederos Martín 1999, 183, 199-200.
\textsuperscript{19} Avery 1997, 130-48.
\textsuperscript{20} Goggin 1960, 5; Zunzunegui 1965, 23; Lister & Lister 1987, 165; Amores Carredano & Chisvert Jiménez 1993, 286; Pleguezuelo-Hernández 1993, 39; Marken 1994, 46-8; Avery 1997, 130-48.
\textsuperscript{21} Pleguezuelo-Hernández 1993, 39.
\textsuperscript{22} Benito Domínguez 2010, 16.
\textsuperscript{23} López Rosendo & Ruiz Gil 2012.
\textsuperscript{24} Loureiro & Martín 2007; Newstead 2015.
\textsuperscript{25} Costeira da Silva 2018.
\textsuperscript{26} Goggin 1960, 5.
\textsuperscript{27} Rice 2011; Kelloway et al. 2016.
\textsuperscript{28} Ferrer et al. 2015; Gómez Ferrer 2016; Kelloway et al. 2016.
\textsuperscript{29} de la Vega et al. 2013.
\textsuperscript{30} Amores Carredano & Chisvert Jiménez 1993; Pleguezuelo-Hernández et al. 1999.
\textsuperscript{31} Azkara Garai-Olaun & Núñez Marcén 1990/1991.
\textsuperscript{32} Rodríguez Asensio & Noval Fonseca 1996; Díaz Díaz 2016.
\textsuperscript{33} Goggin 1960, 7.
\textsuperscript{34} Molas Ribalta 1998, 136-40.
\textsuperscript{35} All the Spanish olive jars discussed below and those that have been discovered in such distant places were all identified as Sevillian productions. Therefore, they are parallel to the forms studied and analysed in this investigation.
\textsuperscript{36} Gutiérrez 2012, 39.
\textsuperscript{37} Gawronski et al. 2012, 185.
\textsuperscript{38} Djalal 2010, 68.
\textsuperscript{39} Carlsson, Forsblom Ljungdahl, & Gustavsson 2017, 26-7, Fig. 23.
\textsuperscript{40} Ness 2015, 317.
\textsuperscript{41} Escribano Cobo & Mederos Martín 1999, 182-3.
\textsuperscript{42} Velasquez & Salgado-Ceballos 2018.
\textsuperscript{43} Alzate Gallego 2016.
\textsuperscript{44} Jamieson et al. 2013.
\textsuperscript{45} Pasquali & EscribANO Ruiz 2013.
\textsuperscript{46} Escribano Ruiz & Barreiro Argüelles 2016, 33.
When studying its standardization and the measures that condition its production, this study focuses on morphometric variables. We have excluded other variables such as the use or absence of glaze, because they are not relevant for this study's proposed objectives.

Working with more variables would require an increase in the size of the ceramic sample. In archaeological contexts, it is difficult to ensure that more than 40 complete pieces come from the same production centre.

The volume or net capacity has been calculated through the Ramos Gil method (2010) and the use of computer-aided design (Busto-Zapico 2015, 207-13). At present, calculating volume is beginning to have greater importance in ceramic studies as a method of quantification (Poulain 2013, 110). To perform the statistical analyses, the results of variable 6 has been squared to minimise possible errors.

These 6 variables define the shape of the pieces. When studying its standardization and the measures that condition its production, this study focuses on morphometric variables. We have excluded other variables such as the use or absence of glaze, because they are not relevant for this study’s proposed objectives.

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Résumé
Standardisation et unités de mesures utilisées dans la production de céramique; le cas de la botijuela postmédievale ou la jarre d'olive espagnole produite à Séville

Cet article vise à déterminer le degré de standardisation de la production de la poterie et les unités de mesure qui ré gulent sa production. Le groupe choisi pour tester cette méthodologie est celui des jarres d'olives espagnoles (botijuela). C'est une série de productions manufacturées dans le sud de la péninsule ibérique au début de la période moderne. La méthodologie commence avec la caractérisation morphométrique de chaque poterie autour d'une série de variables quantitatives.
RIASSUNTO
Standardizzazione e unità di misura usate nella produzione di ceramica. Il caso della botijuela post-medievale, ossia l’anfora da olio spagnola realizzato a Siviglia

Scopo di questo contributo è stabilire il livello di standardizzazione di una produzione ceramica eguali unità di misura regolassero la sua realizzazione. La tipologia scelta per testare questa metodologia è nota come anfora spagnola da olio (botijuela). Si tratta di una serie di produzioni realizzate nel sud della Penisola Iberica durante la prima età moderna. La metodologia impiegata muove dall’identificazione delle caratteristiche morfologiche di ciascun recipiente considerando una serie di variabili quantitative. Si procede quindi con il test diverifica della normalità e viene calcolato il coefficiente di correlazione lineare. Successivamente, tramite il clustering, si identificano i gruppi di anfore spagnole da olio. L’analisi delle componenti principali fornisce ulteriori informazioni che permettono di comprendere in maniera più approfondita i gruppi così ottenuti. Come passo finale, il calcolo del coefficiente di variabilità ci permette di conoscere il livello di standardizzazione di ciascuna variabile. Per concludere, quando tutti questi valori sono noti, è possibile individuare su quali unità di misura si basasse il sistema di produzione delle anfore spagnole da olio.

ZUSAMMENFASSUNG
Standardisierung und Maßeinheiten in der Keramikproduktion. Der Fall des Nach-mittelalterlichen Botijuela oder der spanische Oliven Tiegel gemacht in Sevilla

Das Ziel dieses Artikels ist, den Grad der Standardisierung für die Keramikproduktion und die Maßeinheiten zu bestimmen, die ihre Produktion regelt. Die Gruppe, die ausgewählt wurde, diese Methode zu testen, ist bekannt unter dem Namen ‘das spanische Olivenglas’. Eine Reihe von Produkten sind im Süden der iberischen Halbinsel während der Frühneuzeit hergestellt wurden. Die Methode beginnt mit der morphometrischen Charakterisierung der einzelnen Schiffe, um eine Reihe von quantitativen Variablen zu erstellen. Dann wird der Test auf Normalverteilung ausgeführt, und der Produkt-Moment-Korrelationskoeffizient berechnet. Sobald diese Daten bekannt sind, können schließlich die möglichen Maßeinheiten, die das Produktionsystem des spanischen Oliven Glases bestimmt, anerkannten. Anschließend identifiziert eine Clusteranalyse verschiedene Gruppen von spanischen Oliven Gläser. Die Hauptkomponenten-Analyse enthält zusätzliche Informationen, die ein tieferes Verständnis der Gruppen enthalten kann. Als letzter Schritt, Berechnung des Koeffizienten der Variations, ermöglicht es uns, den Grad der Standardisierung der einzelnen Variablen zu erkennen. Schließlich, sobald diese Daten bekannt sind, können die möglichen Maßeinheiten für das System der spanischen Oliven Tiegel erkannten werden.

RESUMEN
Estandarización y unidades de medida utilizadas en la producción de cerámica: el caso de la botijuela post-medieval u olive jar hecha en Sevilla

El objetivo de este trabajo es determinar el grado de estandarización de una producción cerámica y las unidades de medida que regulan su producción. El grupo elegido para probar esta metodología se conoce como Spanish olive jar o botijuela, fabricada en el sur de la Península Ibérica a lo largo del periodo moderno temprano. La metodología hace una caracterización morfométrica de cada vasija usando varias variables cuantitativas. Después se realiza la ‘prueba de normalidad’, y se calcula el coeficiente de ‘correlación producto momento’; a éste sigue un análisis de grupos de las diversas botijuelas. El análisis de componentes principales identifica además diversos grupos de botijuelas, mientras el análisis de componentes principales ayuda a entender mejor dichos grupos. También se calcula el coeficiente de variación para identificar el grado de estandarización de cada variable. Finalmente, con todos estos datos se pueden identificar las posibles unidades de medida que regían el sistema de producción de estas botijuelas.

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