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# COMPOSITIONAL STUDY OF GOLD COINS HOARD FROM ORDONA (SOUTH ITALY) USING ED-XRF

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***Abstract***

*This work shows the study of a valuable hoard of gold coins found in 1965 in the archaeological site of Ordona, ancient Roman city of Herdonia (Apulia, Southern Italy). This precious treasure, preserved in the MArTA museum of Taranto (Southern Italy), consists of a Byzantine solid (nomisma) and 147 Arab-type gold tarì. All coins were analysed using energy dispersive X-ray fluorescence (ED-XRF) in order to determine their chemical composition. The experimental results were processed using multivariate statistical techniques, such as principal component analysis (PCA) and hierarchical clustering analysis (HCA), to highlight similarities or differences among the various samples.*

***Keywords***: *Ordona (South Italy); MArTA museum (South Italy); ED-XRF; Coins; Gold; Statistical analysis*

## Introduction

Ordona is a famous Apulian archaeological site twenty kilometers south of Foggia (Apulia, South Italy). Ordona has a long history of systematic excavations initiated in 1962 by a Belgian mission [1, 2].

The research has brought to light more than two hundred tombs, ranging from the Early Iron Age to the early 3rd century BCE, with further remains from the ancient Roman city of Herdonia [3, 4].

Between 1965 and 1966, the Belgian mission discovered the Ordona hoard. It was kept inside a clay vase (found in fragments), hidden not very deep in the filling layer of the southern entrance of the Roman amphitheater [5].

The valuable hoard is currently being studied by Sarcinelli [6, 7] and it consists of a Byzantine solidus (*nomisma*) (Fig. 1) and 147 Arab-type gold tarì, imitations of Sicilian gold dinar quarters [8-10]. Figure 2 and 3 show the photos of some of the analyzed coins. In particular, figure 3 shows the photos of the coin n. 167127, which is shattered into two parts (labeled with a and b).

The gold coin hoard from Ordona is kept in the museum MArTA in Taranto (South Italy) with inventory numbers from 167064 to 167211 [11]. Fortunately, this treasure has been recovered and can be admired and studied in the museum. In fact, the need to preserve ancient artifacts of cultural heritage is of fundamental importance so that they can be safeguarded and passed down to future generations [12].

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**Fig. 1.** Photo of the Byzantine solid (inventory number 167064; diameter equal to 26.2mm)


**Fig. 2.** Photo of three coins: (a) n. 167066 (diameter of 19.55mm), (b) 167102 (diameter of 21.1mm), and (c) 1637115 (diameter of 15.7mm)

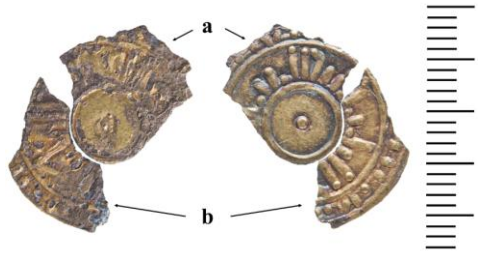


**Fig. 3.** Photo of the coin n. 167127

Its burial was dated by the discoverers to between 976 and 999 and this chronology was considered the terminus ante quem for the complete destruction of the amphitheater, with the filling in of the gaps and access ramps with debris [5].

The first studies hypothesized that the Ordona hoard must have been buried not before 1020 but more probably around the middle or third quarter of the century. Travaini in 1995 [13] indicated a date of around 1025 for the burial of the Ordona hoard and emphasized the presence of the only Byzantine histamenon: solids of this type seem to be the last to be hoarded in Italy, a fact that led the scholar to also consider the possibility of a more recent date of burial, between 1030 and 1040. Recently Sarcinelli [6] has proposed a burial date of the treasure to be around the middle of the 11$^{th}$ century or shortly after.

The entire hoard from Ordona was analyzed using energy dispersive X-ray fluorescence (ED-XRF) in order to determine the chemical composition of the coins [14, 15].

Reliability, validity, uncertainties and errors in ED-XRF analysis of ancient gold-alloy coins depend on several factors, such as the composition and conditions of the artifact itself, the calibration samples, the instrument and the experience of the technical staff [16-20]. In particular, numerous questions related to the ED-XRF analysis of gold alloy coins must be evaluated for correct final concentration values [21]. For these reasons, in the present work important precautions were followed to obtain reliable experimental results. First of all, each coin was analyzed in different areas and the reported concentration is the mean value. The differences among the various points give a reasonable idea about the error associated with the measurements. Secondly, variations due to curvature or roughness of the samples are reduced.

Finally, the experimental results were processed using multivariate statistical techniques in order to better understand the differences and/or similarities among the coins analyzed.

## Experimental part

### *Description of the coins*

The Byzantine nomisma belongs to the issues of the Byzantine emperor Basil II "*Bulgaroktonos*" together with his brother Constantine VIII (976-1025).

The gold taris are imitations of the dinar quarters of Caliph Fatimid al-Mu'izz li-dīn Allā (341-365 AH / 953-975 AD) [22].

The standard gold coin in Islamic dominions was the dīnār, weighing about 4.25 grams. In Arab Sicily, however, only the quarter dīnār or rubā'ī, weighing about 1 gram, was produced. The quarter dinar was the most widespread Muslim circulating coin in Southern Italy, reaching as far as Campania dīnār, the Tyrrhenian coast. It is called by texts "*tarì*" or "*tarenus,"* a denomination originated from the Arabic term ṭarī, i.e., "*fresh,"* and therefore "*freshly minted*" [23].

It first spread in western regions (in Calabria, the principality of Salerno and the duchies of Amalfi and Naples), while in the Catepanate of Italy and in Benevento the Byzantine coinage circulated predominantly.

The most widespread Arab coins were the Fatimid coins of the mid-10$^{th}$ century, renowned for their extremely pure gold content [13] and also the most imitated, especially those of the caliph al-Mu'izz (952-975). In Amalfi and Salerno, documents refer to "*tarì cassimini*" (from Abu'l Qasim, title of Caliph al'Qa'im, 934-946) and "*tarì buttumini boni*" (from Abu Tamin, title of Caliph al-Mu'izz, 952-975). To the latter we owe the mutation of the types, which replaced the traditional horizontal legend with a concentric one.

In fact, the Sicilian taris themselves, originally struck with a title of 16 1/3 carats (between 69% and 71% of gold), already underwent a reduction of this title during the years of Arab rule in Sicily: from 73% (17 carats) on some series issued by al-Mustanṣir billāh (427-487AH/AD 1036-1094) to values oscillating between 71% and 15% on some quarter dinars

from the Cassibile hoard, issues immediately preceding or contemporary with the conquest of Palermo by the Normans [13].

The taris of the Ordona hoard were minted in the mint of Salerno, which opened under the Lombards by Siconolfo (839-849). The first document that speaks of Salerno taris is dated 1012: "*septem auri tari bonipensanti et medium tari moneta salernitana"*.

The main question is whether these Salerno issues were produced in a good gold alloy, on a par with the Sicilian mint gold Arab taris that they imitated. In the early stages, the Salerno taris do not seem to differ much, in terms of gold content, from the Sicilian ones. Over time, however, they became much wider and thinner and the percentage of gold became gradually inferior [13].

***ED-XRF analysis***

The entire hoard from Ordona was analyzed by energy dispersive X-ray fluorescence (ED-XRF). In particular, a portable X-ray microfluorescence spectrometer produced by Unisantis S.A.®, model XMF-104, was used to carry out the measurements.

The instrument consists of an X-ray tube with a molybdenum anode operating at 4-50kV voltage and 0.1-1mA current, Kumakhov's polycapillary lens for beam collimation and a Si–PIN detector.

The X-ray focal spot of the instrument is a circle with a 100µm diameter and it allows reaching minimal areas and analyzing interesting details.

The detector has a resolution of 150eV at 5.9keV and a beryllium window thickness of 12.5µm, thermoelectrically cooled. The measurement system is completed by a multi-channel board produced by AMPTEK®, model MCA8000A, interfaced with a laptop.

All coins were analyzed with a voltage of 20kV and a current of 0.5mA for an acquisition time of 60 seconds, analyzing five different regions for each coin. The analysis of the metal alloy was performed on regions without surface deposits.

Seven standards containing known concentrations (%wt) of gold, silver and copper were used for the calibration and for the quantitative determination of chemical composition.

The chemical composition of each standard was chosen according to the composition of the studied alloy.

All chemical compounds were analytical grade and purchased from Sigma-Aldrich®.

Each standard was prepared by mixing the elements in different weight percentages. In particular, the chemical elements were weighed using an analytical balance KERN® model ABT 100–5M, subsequently mixed and homogenized in an agate mortar for ten minutes and finally melted in a crucible of graphite.

The homogeneity of elements in the standards was verified by analyzing the standards in different regions. The standards were analyzed in the same operating conditions as the coins. Moreover, the samples analyzed are assumed to have "*infinite thickness*" [24-28] and the quantitative results are expressed in terms of weight percentage (%wt).

Table 1 shows the chemical composition of seven standards used for the calibration of ED-XRF analysis.

**Table 1.** Chemical composition of the standards used for calibration in ED-XRF

| Standards | Au | Ag | Cu |
|---|---|---|---|
| | (% wt) | | |
| 1 | 92.4 | 3.3 | 4.3 |
| 2 | 90.4 | 2.4 | 7.2 |
| 3 | 86.6 | 0 | 13.4 |
| 4 | 100.0 | 0 | 0 |
| 5 | 80.7 | 13.5 | 5.8 |
| 6 | 88.2 | 8.2 | 3.5 |
| 7 | 69.8 | 21.2 | 9.1 |

***Statistical analysis***

Experimental results obtained by ED-XRF analysis have been elaborated with multivariate statistical analysis [29, 30] in order to identify possible correlations and/or differences existing among the coins analyzed. In particular, the Statistica version 10 software package (StatSoft® Inc., Tulsa, OK, USA) was used by applying the method of the Hierarchical Cluster Analysis (HCA) and of the principal component analysis (PCA).

The HCA method is a statistical treatment designed to reveal groupings (or clusters) within a data set that sometimes would not be apparent by the reading of a data table. The purpose of this analysis is to join together samples into successively larger clusters by using some measure of similarity or dissimilarity.

Distance is the basic criterion for any clustering and probably the most straightforward way of computing the distances among objects in a multidimensional space is to compute Euclidean distances. Objects that are near each other should belong to the same cluster and objects that are far from each other should belong to different clusters.

The dendrogram is the graphical summary of the cluster analysis. The cases or the variables are listed along the horizontal axis, while the distance among the clusters is shown along the vertical axis.

The PCA method calculates the orthogonal linear combinations of the autoscaled variables by employing a correlation matrix based on the maximum variance criterion. Such linear combinations are called principal component scores and the coefficients of the linear combinations are called loadings. The numerical loading value, for each variable of a given principal component, shows how much the variable has in common with that component.

Principal component analysis can provide important information on the similarity or discrimination of the studied samples.

**Results and discussion**

Table 2 summarizes the weight, the diameter and the chemical composition for each coin.

The coins have different diameters, varying between approximately 15mm and 22mm. The analyses do not show compositional variations as a function of the diameter of the coins.

**Table 2.** Weight, diameter and chemical composition of the analyzed coins

| Inventory number | Weight (g) | Diameter (mm) | Au | Ag | Cu | *Note* |
|---|---|---|---|---|---|---|
| | | | (% wt) | | | |
| 167064 | 4.38 | 26.2 | 91.5 | 2.0 | 0.2 | *trace of Fe* |
| 167065 | 1.00 | 17.5 | 88.5 | 3.5 | 0.3 | |
| 167066 | 0.92 | 19.55 | 76.5 | 14.5 | 0.4 | *trace of Fe* |
| 167067 | 1.02 | 20.25 | 90.5 | 2.5 | <0.2 | |
| 167068 | 1.03 | 19.2 | 89.5 | 4.0 | 0.5 | |
| 167069 | 1.01 | 21,3 | 89.0 | 5.0 | 0.4 | |
| 167070 | 1.01 | 21.2 | 93.5 | 3.0 | 0.4 | |
| 167071 | 0.98 | 20.7 | 88.0 | 5.0 | 0.5 | |
| 167072 | 1.01 | 19.9 | 91.5 | 3.5 | 0.2 | *trace of Fe* |
| 167073 | 1.00 | 21.4 | 91.5 | 4.5 | 0.6 | |
| 167074 | 1.03 | 18.1 | 91.5 | 5.5 | 0.5 | |
| 167075 | 0.97 | 20.8 | 89.5 | 3.0 | 0.8 | |
| 167076 | 0.98 | 20.2 | 91.0 | 4.0 | 0.3 | |
| 167077 | 1.00 | 17.1 | 95.0 | 4.5 | 0.5 | |
| 167078 | 1.02 | 20.3 | 94.0 | 3.5 | 0.4 | |
| 167079 | 0.99 | 16.9 | 92.5 | 4.0 | 0.7 | |
| 167080 | 0.96 | 20.7 | 92.5 | 5.0 | 0.3 | |
| 167081 | 1.01 | 17 | 92.0 | 4.5 | 0.3 | |
| 167082 | 1.02 | 20 | 90.5 | 4.0 | 0.4 | |
| 167083 | 0.88 | 17.7 | 90.0 | 4.5 | 1.4 | |
| 167084 | 1.00 | 18.1 | 90.5 | 5.5 | 0.6 | |
| 167085 | 0.96 | 16.7 | 92.0 | 3.5 | 0.4 | |
| 167086 | 1.01 | 20.5 | 92.0 | 4.0 | 0.4 | |
| 167087 | 1.03 | 20.8 | 91.5 | 4.0 | 1.0 | |
| 167088 | 1.05 | 17 | 90.5 | 6.0 | 0.4 | |
| 167089 | 1.00 | 19.6 | 92.5 | 4.0 | 0.5 | |

| Inventory number | Weight (g) | Diameter (mm) | Au | Ag | Cu | *Note* |
|---|---|---|---|---|---|---|
| | | | | (% wt) | | |
| 167090 | 1.03 | 18.3 | 92.0 | 4.0 | 0.7 | |
| 167091 | 1.01 | 19.5 | 93.5 | 4.0 | <0.2 | |
| 167092 | 0.99 | 16.2 | 92.5 | 5.0 | 0.7 | |
| 167093 | 1.02 | 18.2 | 91.5 | 4.0 | 0.7 | *trace of Fe* |
| 167094 | 1.02 | 17 | 89.5 | 5.5 | 0.8 | *trace of Fe* |
| 167095 | 1.02 | 21.1 | 90.5 | 4.0 | 0.8 | |
| 167096 | 1.02 | 16.2 | 91.5 | 3.0 | 0.4 | |
| 167097 | 1.01 | 21.3 | 91.0 | 3.5 | 0.9 | |
| 167098 | 0.98 | 20.5 | 89.5 | 6.5 | 0.4 | |
| 167099 | 1.04 | 19.9 | 93.0 | 3.5 | 0.4 | |
| 167100 | 1.03 | 15.7 | 90.5 | 5.0 | 0.5 | |
| 167101 | 1.01 | 19.3 | 90.0 | 4.5 | 1.0 | *trace of Fe* |
| 167102 | 1.01 | 21.1 | 89.0 | 6.0 | 1.3 | |
| 167103 | 1.02 | 20.5 | 89.5 | 6.5 | 0.5 | *trace of Fe* |
| 167104 | 1.03 | 17.8 | 89.0 | 7.0 | 0.5 | |
| 167105 | 1.00 | 15.9 | 88.5 | 5.0 | 0.5 | |
| 167106 | 1.03 | 21.9 | 90.5 | 5.5 | 0.6 | |
| 167107 | 1.03 | 19 | 91.5 | 4.0 | 0.9 | |
| 167108 | 1.01 | 18.9 | 89.0 | 3.5 | 0.3 | *dark area with Ag. Fe and Ca* |
| 167109 | 1.01 | 21 | 90.0 | 3.5 | 0.7 | |
| 167110 | 1.02 | 20.8 | 92.0 | 5.0 | 0.5 | |
| 167111 | 1.00 | 16.8 | 90.5 | 6.0 | 0.5 | |
| 167112 | 0.99 | 19.8 | 90.5 | 3.0 | 0.8 | |
| 167113 | 1.03 | 19.1 | 91.5 | 4.5 | 0.6 | |
| 167114 | 1.02 | 20.9 | 91.5 | 3.5 | 0.6 | |
| 167115 | 1.03 | 15.7 | 90.0 | 5.5 | 1.2 | |
| 167116 | 1.00 | 20.8 | 92.0 | 3.0 | 0.5 | |
| 167117 | 1.02 | 20.7 | 91.0 | 4.0 | 1.0 | *dark area with Ag, Fe and Ca* |
| 167118 | 1.01 | 20.8 | 89.5 | 6.0 | 0.6 | |
| 167119 | 1.01 | 16.2 | 93.0 | 3.0 | 0.3 | |
| 167120 | 1.02 | 20.9 | 88.0 | 6.0 | 0.6 | |
| 167121 | 1.03 | 17.8 | 91.0 | 4.0 | 0.6 | |
| 167122 | 1.03 | 20.5 | 91.0 | 3.0 | 0.4 | |
| 167123 | 0.99 | 20.5 | 93.5 | 3.0 | 0.4 | |
| 167124 | 0.99 | 17.1 | 92.0 | 3.5 | 1.0 | |
| 167125 | 1.01 | 21.7 | 91.0 | 4.0 | 0.6 | |
| 167126 | 0.99 | 20.9 | 94.0 | 2.5 | 0.3 | |
| 167127a | 0.47 | | 89.0 | 9.0 | <0.2 | *deposit of Ca and Fe* |
| 167127b | | | 60.0 | 25.5 | 1.5 | *deposit of Ca and Fe* |
| 167128 | 1.01 | 21.55 | 89.5 | 3.5 | 0.8 | |
| 167129 | 1.00 | 20.3 | 90.5 | 3.0 | <0.2 | |
| 167130 | 0.92 | 16.9 | 71.5 | 23.0 | 1.2 | |
| 167131 | 1.04 | 20.8 | 90.5 | 4.5 | 0.3 | |
| 167132 | 1.04 | 19.2 | 88.5 | 5.0 | 0.6 | |
| 167133 | 1.02 | 16.1 | 80.5 | 5.5 | 0.4 | |
| 167134 | 0.96 | 20.1 | 83.0 | 1.2 | 0.6 | *trace of Fe and Mn* |
| 167135 | 1.05 | 17.1 | 90.5 | 2.5 | 0.7 | |
| 167136 | 1.03 | 21.2 | 95.0 | <2.0 | 0.3 | |
| 167137 | 1.02 | 18.9 | 84.5 | 2.0 | 0.4 | *trace of Fe* |
| 167138 | 1.03 | 20.9 | 90.5 | 2.5 | 0.5 | |
| 167139 | 1.01 | 20.6 | 90.0 | 2.5 | 0.7 | |
| 167140 | 1.05 | 20.7 | 91.0 | 3.0 | 0.6 | |
| 167141 | 1.00 | 19.2 | 89.5 | 3.5 | 1.0 | |
| 167142 | 1.01 | 19.9 | 89.5 | 3.5 | 1.0 | |
| 167143 | 0.99 | 17.25 | 90.5 | <2.0 | 0.6 | *presence of deposits* |
| 167144 | 1.01 | 20.6 | 83.5 | 7.5 | 0.6 | *presence of deposits* |
| 167145 | 0.96 | 21.3 | 87.0 | 4.5 | 1.5 | |
| 167146 | 1.02 | 21.35 | 92.5 | 2.0 | 0.3 | |
| 167147 | 0.98 | 21.1 | 89.0 | <2.0 | <0.2 | |
| 167148 | 1.00 | 20.9 | 89.5 | 3.5 | 0.7 | |
| 167149 | 0.98 | 18.8 | 90.5 | 3.0 | 0.5 | |
| 167150 | 1.01 | 16.9 | 91.5 | 4.5 | 0.5 | |
| 167151 | 1.01 | 19.7 | 92.0 | 3.5 | 0.5 | |
| 167152 | 0.98 | 20.6 | 92.5 | 2.0 | 0.4 | |
| 167153 | 0.98 | 20.8 | 91.0 | 5.5 | <0.2 | |
| 167154 | 1.02 | 17.7 | 88.5 | 4.0 | 0.7 | |
| 167155 | 1.02 | 20.9 | 90.5 | 2.0 | 0.5 | |
| 167156 | 0.93 | 17.5 | 89.0 | 3.0 | 0.4 | |
| 167157 | 1.02 | 21 | 89.5 | 4.0 | 0.4 | |

| Inventory number | Weight (g) | Diameter (mm) | Au | Ag | Cu | *Note* |
|---|---|---|---|---|---|---|
| | | | | (% wt) | | |
| 167158 | 1.00 | 21.2 | 89.0 | <2.0 | 0.4 | |
| 167159 | 1.02 | 19.8 | 91.0 | <2.0 | 0.6 | |
| 167160 | 0.96 | 20.9 | 90.0 | 3.5 | 0.6 | |
| 167161 | 1.06 | 21 | 88.5 | 3.0 | 0.7 | |
| 167162 | 0.98 | 18.4 | 89.0 | 4.0 | 0.7 | |
| 167163 | 1.04 | 17.9 | 88.0 | 3.0 | 0.5 | |
| 167164 | 0.98 | 20.9 | 87.5 | 6.0 | 0.9 | |
| 167165 | 1.00 | 20.7 | 88.0 | 3.0 | 0.2 | |
| 167166 | 1.01 | 20.6 | 90.0 | 4.0 | 0.5 | |
| 167167 | 1.02 | 20.7 | 89.5 | 2.5 | 0.5 | |
| 167168 | 1.03 | 19.4 | 90.5 | 4.0 | 0.7 | |
| 167169 | 0.99 | 21.1 | 92.5 | 2.2 | 0.5 | |
| 167170 | 1.00 | 20.5 | 90.0 | 3.5 | 0.4 | |
| 167171 | 1.02 | 19.65 | 89.5 | <2.0 | <0.2 | |
| 167172 | 0.98 | 21 | 91.5 | 4.0 | 0.4 | |
| 167173 | 1.01 | 20.5 | 92.0 | 3.5 | 0.6 | |
| 167174 | 0.76 | 16.7 | 80.0 | 17.0 | 0.4 | |
| 167175 | 1.02 | 17.9 | 90.0 | 4.5 | 0.9 | |
| 167176 | 1.03 | 16.6 | 92.5 | 3.5 | 0.6 | |
| 167177 | 1.02 | 17 | 87.5 | 3.5 | 0.4 | |
| 167178 | 1.03 | 19.8 | 88.0 | 4.0 | 0.5 | |
| 167179 | 1.02 | 20.9 | 87.5 | 4.0 | 0.3 | |
| 167180 | 1.01 | 20.3 | 85.5 | <2.0 | 0.6 | |
| 167181 | 0.99 | 18.6 | 87.0 | 5.5 | 0.8 | |
| 167182 | 0.99 | 21.1 | 90.0 | 3.5 | 0.8 | |
| 167183 | 0.97 | 20.7 | 89.5 | 2.0 | 0.4 | |
| 167184 | 1.02 | 20.6 | 91.5 | 2.0 | 0.2 | |
| 167185 | 1.02 | 17.9 | 89.5 | 2.0 | 0.2 | |
| 167186 | 1.02 | 16.6 | 89.0 | 3.0 | 0.4 | |
| 167187 | 1.02 | 20.5 | 90.5 | 3.5 | 1.2 | |
| 167188 | 0.99 | 17.2 | 84.5 | 6.0 | 0.4 | |
| 167189 | 1.03 | 19.1 | 87.5 | 3.5 | 0.8 | |
| 167190 | 0.98 | 18.4 | 90.0 | 2.0 | 0.4 | |
| 167191 | 1.02 | 19.3 | 89.5 | 2.0 | 0.5 | |
| 167192 | 0.96 | 18 | 89.0 | 2.5 | 0.6 | |
| 167193 | 1.00 | 20.9 | 90.0 | 3.0 | 0.3 | |
| 167194 | 1.04 | 17.1 | 88.5 | 3.0 | 0.4 | |
| 167195 | 0.99 | 18.1 | 88.5 | 2.5 | 0.5 | |
| 167196 | 1.02 | 21.2 | 89.5 | 3.0 | 0.7 | |
| 167197 | 0.99 | 20.3 | 91.5 | 3.0 | 0.7 | |
| 167198 | 1.03 | 19.8 | 89.5 | 4.0 | 0.3 | |
| 167199 | 1.03 | 20.7 | 92.0 | <2.0 | <0.2 | |
| 167200 | 0.99 | 20.1 | 91.5 | 4.0 | 0.3 | |
| 167201 | 1.00 | 21.6 | 90.5 | 3.0 | 0.8 | |
| 167202 | 1.02 | 19.7 | 88.5 | 3.0 | 0.8 | |
| 167203 | 1.03 | 19.2 | 89.5 | 4.0 | 0.6 | |
| 167204 | 0.97 | 17.6 | 89.0 | 4.0 | 0.4 | |
| 167205 | 1.02 | 21.3 | 89.0 | 3.0 | 0.2 | |
| 167206 | 1.01 | 20.1 | 89.5 | 4.5 | 0.3 | |
| 167207 | 1.02 | 20.8 | 90.5 | 3.5 | 0.8 | |
| 167208 | 1.03 | 16.3 | 89.5 | 2.0 | 0.3 | |
| 167209 | 1.04 | 15.6 | 91.5 | 2.0 | 0.5 | |
| 167210 | 0.98 | 17.1 | 88.5 | 4.5 | 0.4 | |
| 167211 | 1.00 | 21.8 | 89.5 | 2.5 | 0.6 | |
| | | *Standard deviation* | *1.0* | *0.5* | *0.1* | |
| | | *Detection limit* | *0.5* | *0.8* | *0.2* | |

By carrying out the average and standard deviation of the concentrations of the elements investigated on the entire treasure, the following values are obtained: gold (90±4) %wt, silver (4±3) %wt and copper (0.6±0.3) %wt.

The Byzantine solid (n. 167064) has a chemical composition equal to (91.5±1.0) %wt of gold, (2.0±0.1) %wt of silver and (0.2±0.1) %wt of copper.

Therefore, analyses demonstrate that the investigated Salerno taris contained a significantly higher percentage of gold than the Sicilian quarter dīnār they imitated.

Figure 4 shows how the composition of the coins is quite homogeneous with the exception of four coins (167066, 167127b, 167130 and 167174), which show gold concentrations lower than 80 % wt and silver concentrations higher than 14.5%wt. The remaining coins contain higher concentrations of gold and silver concentrations lower than 8%wt.

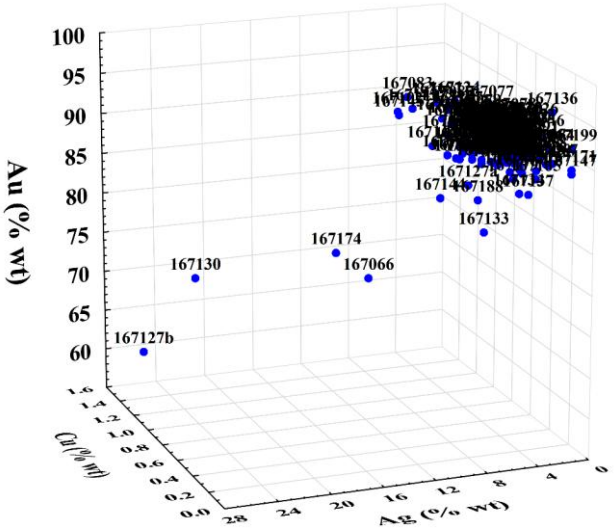


**Fig. 4**. Gold-copper-silver concentrations of the analyzed coins

In particular, the coin with inventory number 167127b shows a non-homogeneous surface composition with the presence of deposits containing calcium and iron. The average percentage of silver is equal to 25.5%wt with a consequent reduction in the gold content (60.0%wt) and higher copper concentration (1.5%wt). Moreover, the coin n. 167127 shows a different chemical composition in the two fragments (a and b): this different chemical composition determined the fragmentation of the coin itself into two pieces and its current poor state of conservation. This may lead one to believe that the coin is a fake.

The coin with inventory number 167130, in contrast to the previous one, shows a composition with average values equal to 71.5±1.0%wt of gold, 23.0±0.5%wt of silver and 1.2±0.1 %wt of copper.

The coins n. 167066 and n. 167174 are also characterized by relatively high concentrations of silver, equal to 14.5±0.5%wt and 17.0±0.5%wt, respectively.

The remaining 143 coins show a similar composition and, with a significantly lower standard deviation, the average values are equal to 90±2%wt of gold, 0.5±0.3%wt of copper and 3.7±1.3% wt of silver.

Experimental results obtained by ED-XRF analysis have been elaborated subsequently with the multivariate statistical treatment by using the method of the hierarchical clustering analysis (HCA) and of the principal component analysis (PCA) applied on a data set of 148 cases (coins) and three variables (the concentration of gold, silver and copper).

Principal component analysis is concerned; two principal components were extracted, covering 92.4% of the cumulative variance. The loading of the variables on the first two principal components (Fig. 5) shows that silver and copper are the dominant variables for the positive values of the first principal component, while gold is the dominant variable for the negative values of the first principal component. Moreover, gold and copper are the dominant variables for the positive values of the second principal component, while silver is the dominant variable for the negative values of the second principal component.

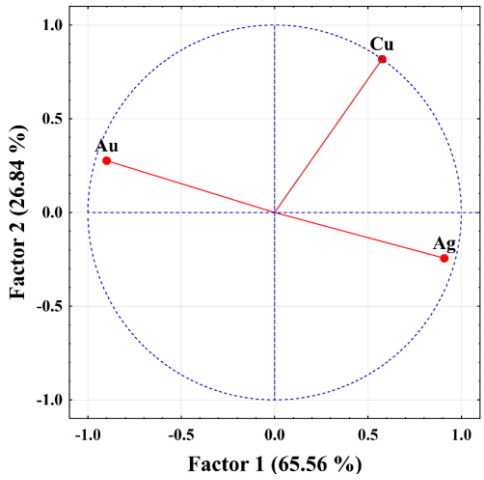


**Fig. 5**. Loading of the variables (Au, Ag and Cu) on the first two principal components

The scatter plot of the scores for the first two principal components, PC1 and PC2 (Fig. 6) shows that most of the coins form a big cluster, but it is possible to discriminate four coins (167066, 167127b, 167130 and 167174) since they have positive values of the first principal component and negative values of the second principal component. This is because these coins contain more silver and a lower concentration of gold.

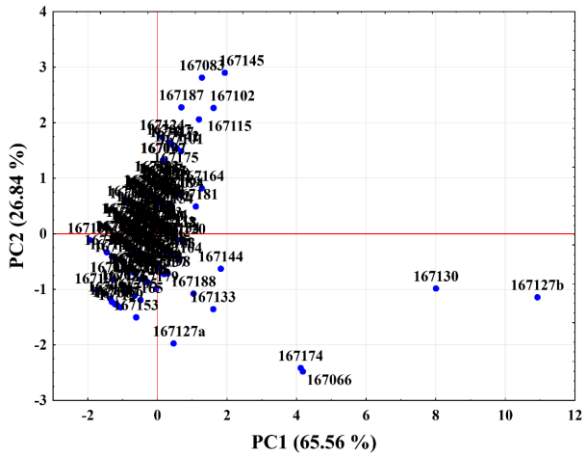


**Fig. 6**. Scatter plot of the scores for the first two principal components

Hierarchical clustering analysis was carried out by using Complete Linkage procedure applied on the Euclidean distances and the dendrogram of the samples (Fig. 7) shows the coins divided into two main clusters, confirming the results obtained by the PCA analysis. A zoom of the graph is shown in order to better highlight the discrimination of the four coins.

Moreover, in the second large group it is possible to highlight a further cluster that includes six coins (with inventory numbers 167180, 167137, 167134, 167188, 167144 and 167133). These six coins are characterized by a gold concentration between 80.5 and 85.5%wt and a silver concentration lower than 7.5%wt.

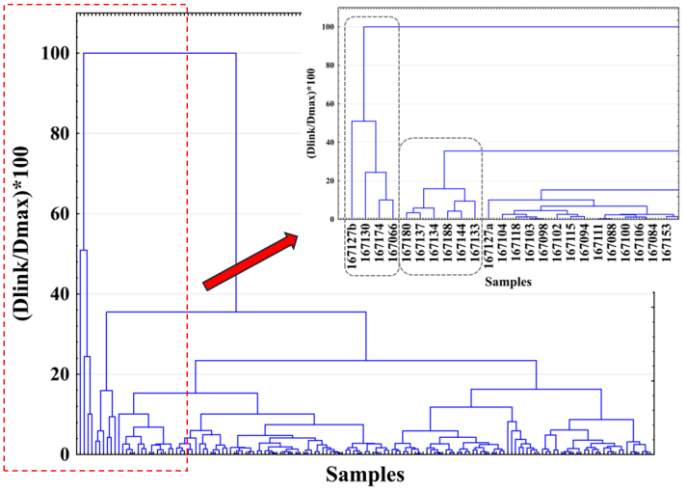


**Fig. 7**. Dendrogram of the coins

Therefore, once again, the statistical treatment of the experimental results allowed us to highlight differences and similarities among the analyzed samples.

## Conclusions

The investigated precious hoard from Ordona, the ancient Roman city of Herdonia (Apulia, Southern Italy), showed coins with high gold content and very similar chemical composition.

With the exception of four specimens with a lower gold content, the concentration of gold is around 90±2%wt, which does not vary with the diameter and mass of the coins.

The alloy has a silver content of around 4%wt as a secondary element, while the low presence of copper can be considered more an impurity than the result of an intentional addition to the alloy.

In particular, the coin with inventory number 167127 shows nonuniform surface chemical composition in the two fragments, the presence of deposits containing calcium and iron, a poor conservation state and lower gold content. For these reasons, it is possible to hypothesize that this specimen is a fake.

Moreover, non-destructive analyzes performed demonstrate that the Salerno taris, imitating Sicilian quarters dīnār, contained a significantly higher percentage of gold than the Sicilian coins they imitated.

In conclusion, this study provides conservators and conservation scientists information on the chemical composition of the analyzed coins.

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