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Insights into Medieval Grape Cultivation in Al-Andalus: Morphometric, Domestication, and Multivariate Analysis of *Vitis vinifera* Seed Types

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Abstract: Understanding the origins and evolution of modern grapevine varieties in the Iberian Peninsula and western Europe necessitates an examination of the proportions of *Vitis vinifera* cultivars, their relationships with wild grapevine populations, and the utilization of seedless cultivars in al-Andalus. Employing morphometric studies, domestication indices, multivariate analysis, and Bayesian hypothesis testing, this study investigates several distinct seed types identified in materials from Roman and medieval deposits. These seeds exhibit a spectrum from highly domesticated to purely wild. Our findings reveal the predominance of *Proles Occidentalis* Negrul, and the presence of feral-like grapevines associated with *Proles Euphratica*. Additionally, we observe the continuous presence of wild grapevines related to *Vitis sylvestris* CC Gmelin throughout the studied period. Seeds exhibiting intermediate characteristics are documented, alongside the identification of “stenosperms”, suggesting anomalies in seed formation. Notably, the presence of *Vitis vinifera* raisins “stenospermocarpics” of the sultana type is suggested, potentially elucidating the absence of table grapes and raisins of the *Proles Orientalis* Negrul in the archaeological record, despite frequent mentions by medieval agronomy writers from al-Andalus.

Keywords: grapevine; Bayesian methods; morphometrics; carpology; *Vitis*

1. Introduction

While grapevines feature in Iberian Peninsula prehistory records [1–3], initially as wild, Roman era viticulture, documented by Columella in 1548 [4], grapevine cultivation expanded significantly, emphasizing wine, raisins, and must. Medieval al-Andalus witnessed diverse viticulture with eastern table grapes and “sultana” raisins. Agricultural treatises spanning the tenth to fourteenth centuries CE, including *Kitāb fi Tartīb awqāt al-girāsa wa-l-magrūsāt* and *Al-Mugni’ fi l-filāḥa*, describe grapevine cultivation techniques and

varieties [5–8]. Varietal differentiation relied on traits like berry size, shape, color, flowering and ripening periods, cluster type, and sugar content [7,8]. Notably, *Almurjardal* and *Melar* grapes were prized for their flavor and raisin suitability, while the *Jalladi* variety was noted for its distinct traits [7,8]. Abū l-Jayr transferred rare bush species, and Ibn Baṣṣāl suggested grapevine transportation using seeds, hinting at an interaction in al-Andalus with native and exotic varieties, possibly resulting in hybrids in the post-Muslim conquest era.

The grapevine (*Vitis vinifera* L., Vitaceae), represents one of the oldest cultivated fruit plants [9]. The genus *Vitis* encompasses over 70 species, with *Vitis vinifera* L. boasting approximately 10,000 cultivars. Historically, some of these cultivars originated from Central Asia and the South Caucasus, spreading across western Europe and the Mediterranean basin [10].

The South Caucasus region is regarded as the birthplace of viticulture and wine-making [11–15]. Archaeological discoveries at sites within the Shulaveri group, such as Dangreuli Gora, Imiri Gora, and Gadachrili Gora, reveal a sophisticated level of grape cultivation and wine production in southern Georgia between the sixth and fourth millennia B.C. [14]. Furthermore, McGovern et al. [15] identified Georgia, located in the South Caucasus, as the probable point of origin for European winemaking.

Four theories on grapevine domestication exist. The monophyletic monospecific theory posits that cultivated grapevines (*V. vinifera*) originate from local wild populations (*V. sylvestris*) [16]. The monophyletic bispecific theory suggests that cultivated populations stem from a common ancestor, possibly extinct, shared with the wild species, implying present distinct species [17]. The polyphyletic multispecific theory proposes that regional cultivated grapevine populations derive from independent wild ancestors, each with its own group of wild relatives [18,19]. The hybrid theory [20] suggests cultivated grapevines originated from hybridization between wild species, particularly between dioecious European grapevines and hermaphrodites from Central Asia.

Wild grapevines (*Vitis sylvestris* CC Gmelin) and cultivated grapevines (*V. vinifera* L.) primarily differ in regard to their reproductive biology, with wild grapevines being dioecious and most cultivated grapevines being hermaphrodites [11]. Other distinctions arise from the domestication process, including differences in sugar content, berry and bunch dimensions, and blooming and ripening periods [21].

Vitis vinifera cultivars are grouped into three main types: wine grapes, table grapes, and dried fruits (raisins and sultanas) [22,23]. This classification aligns broadly with biogeographical groups of grape cultivars and exhibits a distinct allelic composition and frequencies [24–27].

Andrasovzsky [18] aimed to geographically classify grapevine varieties into five ecogeographic species: *Vitis mediterranea* (Mediterranean and Danube), *V. byzantina* (Caspian region), *V. alemannica* (Rhine Valley), *V. deliciosa* (Caucasus), and *V. antiquorum* (Central Asia). Negrul [24] introduced the term “Proles” to categorize major clusters of cultivated varieties, later refined by Gramotenko [28], Troshin et al. [26], and Troshin [29]. Each proles has characteristic distribution and morphology:

Proles Pontica Negrul (*V. mediterranea* András) spans the Danube Valley, Eastern Mediterranean, east of the Iberian Peninsula, western Caucasus, and Egypt, consisting of wine cultivars with dense clusters and small to medium berries, and comprises around 4000 to 5000 cultivars.

Proles Orientalis Negrul (Caspian region, Eastern Caucasus, Central Asia, western Mediterranean, Romania) encompasses table grapes and some ancient wine cultivars with thick, elongated berries. *Subproles Caspica* Negrul (*V. byzantina* András) includes around 300 cultivars, and *Subproles Antasiatica* Negrul (*V. antiquorum* András) about 1000.

Proles Occidentalis Negrul (*V. alemannica* András pp) covers the Rhine Valley, Italy, France, and part of the Iberian Peninsula, consisting of wine cultivars with small leaves and compact clusters, including between 1000 to 2000 cultivars.

Molecular evidence supports an east–west gradient. The chlorotype variation among *V. sylvestris* and *V. vinifera* suggests two significant origins for the cultivated germplasm:

one in the Near East and another in the western Mediterranean. Approximately 70% of Iberian Peninsula cultivars derive from western *V. sylvestris* populations [21]. Among the six haplotypes, half of western European varieties, especially Spanish accessions, share haplotype VI absent in Caucasian and Middle Eastern cultivars. Haplotype I prevalence declines from over 80% in South Caucasus and the Near East to under 20% in Spain, with intermediate values in central Europe [30]. Molecular analyses by Mercati et al. [31], confirmed significant east–west gene flow and identified five ancestral populations. The Portuguese germplasm is genetically closer to French varieties than those from Spain. The Maghreb region shows a connection to Spain, except for Tunisia, which ties to the Italian and Tyrrhenian ancestral group.

OIV [32,33] and IPGRI/UPOV/OIV [34] identified 128 morphological, physiological, and agronomic traits to describe grapevine diversity. Ampelographers prioritize lesser-known characters, which are crucial for defining groups, despite being less relevant to viticulturists. These characters remain integral to understanding the origins and characteristics of each group.

Vitis vinifera seeds exhibit a characteristic globose to obovoid shape, yet they display significant polymorphism and remain identifiable even in carbonized, mineralized, or fragmented states. Factors such as grape size, ripening degree, and seed quantity within each grape, contribute to the seed shape variability [35,36]. Ampelographic textbooks typically focus on a few seed characteristics for descriptive purposes. These include seed length and weight, which are categorized into distinct classes based on observations on dry seeds from well-developed bunches [32,33]. Additionally, the detection of transversal ridges distinguishes between *Vitis vinifera* and related species of section *Vitis* and those of section *Muscadinia* [32,33].

Biometric indices have proven to be valuable in the taxonomic study of *Vitis* since Stummer's pioneering work in 1911 [37]. Discrimination between wild and domesticated grapevine seeds based on morphometrics has been subject to ongoing review in ampelographic and archaeobotanical literature [38–41]. Furthermore, recent advancements include image analysis of the seed shape [42–45]. The application of distance-based trees for allocating archaeological grape seed samples is well established [45]. Similarly, Rivera et al. [46] tentatively assigned archaeological *Phoenix* seed samples using a method based on Ward's minimum variance algorithm.

The main aim of this study is to analyze medieval archaeological grapevine seeds morphometrically, comparing them with samples from other periods and with modern wild and cultivated grapevine populations. Our goal is to determine the identity and level of domestication of these medieval vines from al-Andalus, as well as their relationship with the broad groups of cultivated vines categorized by Negrul as proles. Additionally, we aim to distinguish raisin seed types from other grape types, based on morphology.

2. Materials and Methods

In this paper, we analyze nineteen grapevine seed samples from nine sites in Spain located in the southern Iberian Peninsula (Figure 1), which have been previously studied by our group [47–57]. We compare these samples with a diverse range of published archaeological seeds from the region [58–61], as well as with local modern cultivars.



Figure 1. Location of the analyzed sites.

2.1. Description of Sites Samples

The village of Huerta del Inglés (Badajoz) was excavated between 2022 and 2023, due to the installation of a photovoltaic solar plant. This revealed an Andalusi village active during the ninth to the early tenth century CE, possibly linked to a Visigoth farm from previous centuries at the same site. Around sixteen houses and more than eighty negative structures where grapevine seeds were found were identified, indicating a larger original settlement, inferred from associated *maqbara* findings [47]. These monocellular houses exploited the agricultural resources of the area, ideal for livestock and rainfed crops, possibly supplemented by a nearby spring for irrigation.

In 2021, as part of the project “Valorization, Conservation, and Maintenance of the Archaeological Sites of the Alcazaba de Badajoz”, an excavation was conducted in a section located at the northern end of the citadel. This area expanded towards the Guadiana River during the second half of the twelfth century under the Almohads, with no known previous occupation. The excavation revealed urban structures consisting of houses arranged around a central courtyard, along with other simple spaces, such as single or double-room structures with direct street access, likely serving as residences, artisan workshops, or stores. It is known that a blacksmith’s shop was located nearby. Following the conquest of the city in 1230 by Alfonso IX de León, this area was abandoned [48].

The site of La Graja, located north of Higuera, in the Cañada de Pajares valley, is identified as an Andalusi alquería spanning approximately 6.8 ha. Archaeological interventions, from 2020 to 2023, aimed to delve into the study of 11th century Islamic societies in Albacete province. These interventions revealed 46 structures on the site, with thirty being houses, consisting mainly of oblong bays where grapevine seeds were found,

surrounding a courtyard corral. Additionally, there are 8 small buildings with simple rectangular floor plans, situated in peripheral or central isolated areas, without other associated constructions [49].

The archaeological campaigns at the fortress of Isso (Hellín, Albacete, Spain) spanned from 2019 to 2022, with the aim of identifying its perimeter, much of which was lost due to the construction of a neighborhood of houses. The objectives also included dating the Andalusí fortress and understanding its various transformations. Through this work, it was revealed that the two large towers visible over the centuries represent only a fraction of a much larger quadrangular fortress, approximately 44 m on each side. Further analysis revealed that the wall and towers underwent at least three distinct phases of construction. Notably, significant chronological data were uncovered within the walls, where excavations reached unmodified rock, providing an excellent stratigraphic record. Analysis of the ceramic materials suggests that the medieval structures cannot predate the second half of the 12th century. If this hypothesis holds true, it implies state or king involvement in the construction, potentially serving military or storage purposes. Supporting evidence includes the discovery of storage structures in the northeastern corner, where grapevine seeds were found [50].

“Alcázar Menor” of Murcia: written sources and archaeological findings indicate the existence of a significant estate in the northern suburb of Murcia, situated approximately 100 m from the medina walls. This estate served dual purposes as a palatial residence and productive orchard, boasting residential, ceremonial, religious, and recreational structures, including baths, alongside extensive orchards, and gardens where grapevine seeds were found. Archaeological investigations at the site have revealed two superimposed palaces. The older palace, attributed to Amir *Abū ‘Abd Allāh Muhammad ibn Sa’d ibn Mardaniṣh* (1147–1172), is situated in the basement. It features a large transept garden, consisting of two platforms with a central gutter, crowned by a pavilion (*qubba*). The more recent palace, commonly associated with *Ibn Hud al-Mutawakkil* (1228–1238), was constructed atop the ruins of its predecessor. Portions of its remains still stand today, repurposed as walls within the present-day monastery [51].

Archaeological excavations conducted on the roof of the central nave of the 15th century church of Santa María in Alicante yielded numerous ceramic vessels, some containing remnants of plants, including grapevine seeds. The recovered remains reflect a diverse assortment of fruits, particularly dried fruits likely consumed by the workers. The presence of these fruits in the vessels is highly probable, given the distinctive distribution of the samples, all of which consist of monospecific samples [52].

The ancient settlement of Begastri, located at Cabezo de Roenas near Cehegín in Murcia, spans various historical periods. Initially an Iberian settlement, it later evolved into a Roman municipality and a Visigothic episcopal city. Minor Islamic occupation occurred during the Emirate/Caliphate period. The Roman–Visigoth phase saw the construction of fortified walls around the acropolis using large ashlar and masonry, incorporating ornamental materials like friezes and column bases. The city’s defensive perimeter stretched over 272 m, featuring quadrangular towers and a gate defended by towers and a barbican. Recent excavations in the western sector, where grapevine seeds were found, uncovered artifacts like belt buckles, glass fragments, and the tremis of Recaredo, suggesting an administrative or manorial area within the Visigothic city, affiliated with the kingdom of Toledo, and neighboring the Byzantine domain [53].

The Roman villa of Los Villaricos, situated in Arreaque, approximately 5 km east of Mula (Murcia), enjoys an ideal environment for agricultural activities. Its proximity to the river Mula and its strategic location along the Carthago Nova–Complutum road axis, via Yéchar towards Archena, highlights its significance. Since 1985, archaeological campaigns have revealed Los Villaricos to be one of the most remarkable Roman villa sites in the Iberian Peninsula. The excavations have unveiled distinct areas, including rustic sections dedicated to agricultural work and storage, notably for olive oil and wine production, evidenced by the discovery of two *torcularia* (winepresses). Additionally, the urban area

comprises a residential zone with a central courtyard and domestic spaces for the owner's family, along with a *balneum* area featuring baths with hot, warm, and cold water facilities. Carbon-14 analysis of the olive seed samples from the *torcularium* places the villa's peak period of expansion and operation during the 4th century CE. This era coincides with the height of the nearby civitas on La Almagra hill, ancient Mula. The final phase of the villa's occupation is marked by documented burials, indicating structural abandonment, reuse, and restructuring between the late 5th and early 7th centuries CE [54,55].

Located in the Los Baños district of Fortuna, the Roman health resort of Fortuna sits amidst an area known for its hyperthermal waters, shaping infrastructures dedicated to thermal activities across different epochs. The Roman era stands out as the pivotal period, witnessing the inception of the first spa facilities that influenced subsequent medieval and modern phases. The earliest constructions, dating back to the turn of the era, persisted through various reforms, including structural alterations, until the late 4th century CE [56]. In addition to the principal edifice housing the spring and pool, several ancillary structures complement the complex. These include an outdoor pond receiving surplus water from the spring, a pool, an outdoor *apodyterium* adjacent to one in the complex entrance, and a series of masonry rooms situated approximately 80 m away. The grapevine seeds were found in the rooms, which based on their layout and the recovered materials, likely served as essential hospitality facilities within the spa premises [57].

The territories from which the medieval samples analyzed originate, currently host notable viticultural activity, covered by the following five denominations of origin [62]:

1. Extremadura, known for white varieties such as "Alarije", "Borba", and "Jaén Blanco", and red varieties like "Bobal" and "Garnacha Tinta", grown on siliceous or chalky substrates, with precipitation between 400 and 600 mm, and average temperatures around 16.5 degrees Celsius (sites: Alcazaba de Badajoz and Huerta del Inglés);
2. Jumilla, cultivating varieties such as "Monastrell", "Garnacha Tintorera", and others for reds, and "Airén" for whites, on calcareous substrates at altitudes ranging from 300 to 900 m, with precipitation around 300 mm (site: Fortaleza de Issó);
3. Alicante, where "Monastrell" predominates among the red varieties, followed by "Garnacha Tintorera", while "Moscatel de Alejandría" is characteristic among the white varieties. The influence of maritime air, calcareous substrate, and precipitation between 300 and 500 mm are notable (site: Santa María de Alicante);
4. Bullas, cultivating "Monastrell", "Garnacha Tinta", and others for reds, and "Macabeo" for whites, on calcareous substrates at altitudes ranging from 500 to 1500 m, with precipitation around 365 mm, and average temperatures between 14.5 and 16 degrees Celsius (site: Begastri);
5. Almansa, known for "Garnacha Tintorera", "Monastrell", and other red varieties, and "Macabeo" or "Moscatel de Grano Menudo" for whites, grown on calcareous substrates at altitudes between 400 and 700 m, with precipitation around 300 mm, and average temperatures between 16 and 17 degrees Celsius (site: La Graja).

In the area near the city of Murcia, table grapes from cultivars "Aledo", "Dominga", and others are cultivated outside of the denominations of origin, in orchard areas irrigated with water from the Segura River or wells (sites: Los Villaricos, Alcazar Menor de Murcia, and Baños de Fortuna).

2.2. Sampling Methods and Criteria for Selection of the Materials

Archaeological samples were obtained during excavation, following specific methodologies outlined in the literature cited. A comprehensive flotation approach was used, and the seeds were retrieved using meshes with a minimum diameter of 0.5 mm. Individual seed isolation from the assemblage was conducted using a binocular microscope, at magnifications ranging from 10 to 40×, and stored in Eppendorf polymer tubes of various sizes.

The primary dataset comprises 4029 rows of analyzed single seeds from 783 seed samples (individuals), with 32 columns of observations. These columns include 13 quantitative

variables, 12 allometric indices, and 3 qualitative variables (divided into 11 categories). Additional columns contain information on sample provenance, taxonomic attribution, and other relevant data. To understand the *Vitis* species and cultivar diversity comprehensively, modern reference materials were utilized, providing a broad representation of cultivars, wild, and feral grapevines. Of the analyzed seeds, 3483 came from modern sources (481 samples), 399 from archaeological contexts (195 samples), primarily preserved in carbonized form, and 147 were fossilized (107 samples).

2.3. Morphometric Studies: Description of Measurements Taken, and Methods Used

An attempt was made to work with samples of ten seeds each for modern varieties and populations of wild vines, which were randomly selected for measurement from larger samples preserved in the seed collection at the University of Murcia. However, when including fossil samples and archaeological materials in the study, a significant number of the samples measured and analyzed consisted of fewer seeds or even just a single seed. Precisely for this reason, we preferred methods that allowed us to work with individual seeds, although the multivariate analysis and cluster creation were based on the parameters of each sample as a whole and not on the isolated values of each seed within it. On average, we worked with 5 seeds per sample, hence the total number of seeds and samples mentioned above. Medieval archaeological seeds underwent individual analysis based on 14 characteristics: 11 quantitative (notably total length, maximum breadth, and seed thickness, along with another 8 characteristics specified in Supplementary Table S1) and 3 qualitative (contour type, arrangement of fossettes, presence/absence of radial furrows) (Supplementary Table S2). Allometric variables (Supplementary Table S3) were reserved for interpreting results [36].

Digital scaled images were used for the analysis. Up to ten seeds from each sample were placed on a plasticine support with an integrated scale and photographed from dorsal, ventral, and lateral perspectives, using a Samsung A40 camera. Fiji 2.9.0 (14 September 2022) software was employed for image analysis, under consistent zoom conditions. Additionally, the scale images of fossilized and archaeological seeds from specialized literature aided the measurements. The data were recorded in an Excel spreadsheet, and the allometric relationships were automatically calculated.

The SEM analyses were conducted in the University of Murcia's Scientific and Technical Research Area. Specimens were mounted on aluminum stubs, coated with a 5.0 nm thin layer of platinum using a Leica EM ACE 600, and examined using an FE-SEM device (ApreoS Lovac IML Thermofisher, Waltham, MA, USA), with a selected voltage of 10 kV and a current of 0.20 nA for imaging.

2.4. Domestication Indices: Explanation of Indices Used and Their Significance

2.4.1. Primary Indices

Stummer [37] proposed an index based on the allometric relationship between the seed width and length, effectively distinguishing extreme forms, with intermediate values common in both wild and cultivated populations (Supplementary Table S4). Stummer's index values ranging from 0.44 to 0.53 are typically associated with cultivars, whereas values between 0.76 and 0.83 are specific to Austrian wild vines. However, values falling between 0.53 and 0.76 are observed in both cultivars and wild vines. Levadoux [38] demonstrated limited validity in regard to this index for distinguishing between wild and cultivated vines.

Facsar, Terpó, Facsar and Jerem, and Perret [39,63–65] introduced a novel index based on the allometric relationship between the length of the beak or column and the total length of the seed, providing effective differentiation between wild and cultivated populations, typically with the boundary between 18 and 19 (Supplementary Table S5).

Formulas devised by Mangafa and Kotsakis in 1996 [41] found successful application for local Greek samples, encompassing both modern seeds and archaeological remnants.

These formulas (Supplementary Table S6) rely on relationships and constants, involving variables like seed length (L), stalk length (LS), and chalaza position (PCH).

2.4.2. Derived Indices from Pre-Established Thresholds: Domestication and Wildness-Derived Indices

As the aforementioned indices aim to achieve the same objective of distinguishing between wild and domesticated forms, albeit yielding varying results, their collective utilization may enhance the ability to discriminate between seeds from wild and cultivated grapevines. The combined domestication/wild index is computed for each seed individually using the following formula (1), wherein NIT denotes indices surpassing, either above or below, the threshold value, and NI denotes the indices considered [Equation (1)]:

$$DW_i = \frac{\sum_{i=1}^n NIT_i}{\sum_{i=1}^n NI_i} \quad (1)$$

The threshold values for recognizing a seed as wild: Stummer > 75 , Perret < 19 , Mangafa and Kotsakis F1 < -0.2 , Mangafa and Kotsakis F2 < -0.2 , Mangafa and Kotsakis F3 < 0 , and Mangafa and Kotsakis F4 < -0.9 .

The wildness index (W_i) ranges from 0 to 1, with intermediary values of 0.17, 0.33, 0.5, 0.67, and 0.83. Seeds with wildness index values between (0.67) 0.83 and 1 are unequivocally phenotypically wild, while those between 0 and 0.17 (0.33) deemed domesticated. In this study, a value of 0.5 is considered merely intermediate, according to Rivera et al. [66], which suggests the presence of a hybrid swarm and introgression phenomena. Notably, the sum of the wildness index and its complement, the domestication index, always equals one.

2.5. Multivariate Analysis: Details of the Methods Employed

2.5.1. Variables

The data matrix comprises 783 samples and 231 columns or variables resulting from the analysis of each sample.

The quantitative and allometric variables are divided into intervals, and for each interval or category, the percentage of seeds from the sample that fall within it is calculated. For each sample, the ordered set of the 231 categories and their relative frequencies based on the observed values in the seeds of that sample constitute a descriptive spectrum, such that two exactly identical samples would present in the same spectrum (probability distributions), with identical frequencies and, therefore, the dissimilarity indices would have a value of zero. The spectrum of variables is structured as follows.

Quantitative continuous characteristics transformed into the following 137 categorical variables:

- Length (25 intervals or categories), width (21), thickness (9);
- Volume (12);
- Beak length (dorsal 9, ventral 9), width (at base 11, at junction 11), thickness (6);
- Chalaza length (18) and width (6).

Allometric continuous characteristics transformed into the following 83 categorical variables:

- Width/length (29), width/thickness (10);
- Beak length/seed length (16), beak width/length (9);
- Chalaza width/thickness (9), chalaza apex to seed apex distance (10);

Qualitative categorical characteristics, accounting for 11 variables, as follows:

- Outline (5);
- Fossettes (4);
- Dorsal radial grooves (2).

2.5.2. Data Analyses

This method was previously utilized for date palm seed classification by Rivera et al. [46]. The chi-square dissimilarity index was calculated following the methodologies outlined by Perrier et al. (2003) [67] and Perrier and Jacquemoud-Collet [68]. This index assesses the contribution of a value, x_{ik} , to the overall sum, x_i , across all the variables, serving as a comparison of unit profiles [Equation (2)].

$$d_{ij}^2 = \sum_{k=1}^K \left(\frac{x_{ik}}{x_i} - \frac{x_{jk}}{x_j} \right)^2 \left(\frac{x_{..}}{x_{.k}} \right) \quad (2)$$

for $j \neq i$.

Where d_{ij} is the dissimilarity between units i and j ; $i, j = 1, 2, \dots, N$ (samples, rows), $N = 783$; $k = 1, 2, \dots, K$ (variables, columns).

Where $d_{ij} = 1$ means varieties i, j differ in regard to all variables, and $d_{ij} = 0$ means varieties i, j are identical.

Pairwise dissimilarities are mapped onto a multidimensional space for analysis. To achieve a meaningful two-dimensional visualization of these relationships, cluster analysis is employed. Cluster analysis refers to a collection of numerical techniques aimed at categorizing study objects into distinct groups based on their characteristics [69]. Utilizing the minimum variance clustering, also known as Ward's method, the analysis focuses on minimizing variation within each cluster, resulting in distinct groupings [69]. Ward's method generates a single tree, where the goal is to minimize within-cluster variance.

For graphical representation, we employed Figtree software version 1.4.4. [70].

2.6. Bayesian Hypothesis Testing: Explanation of the Approach and Its Application

2.6.1. Bayes–Laplace Theorem

For archaeological seed interpretation, we employed a Bayesian approach to determine the conditional probability of an archaeological seed belonging to a specific *Vitis* taxon Θ_i . We sought to answer: What is the likelihood that an archaeological seed or sample is assigned to Θ_i given its domestication index value x_j and its cluster y_j ? Drawing upon a dataset of approximately 600 comparison samples, where the taxonomic identity is known a priori, both from seed morphology and grapevine plant studies, we constructed a discrete joint probability function $p(X, \Theta)$. This function assigns a posterior probability value to each combination of a *Vitis* taxon and a domestication index value or a *Vitis* taxon and a Ward's tree cluster.

Bayes' rule [Equation (3)] was employed to approximate the solution.

$$p(\theta|x) = p(x|\theta)p(\theta)/p(x) \quad (3)$$

where $p(\theta|x)$ is the posterior probability distribution for the parameter θ given a single observed value of the variable $X = x_j$, in our case the degree of domestication, which is represented by the domestication index value, which ranges from 0 (clearly wild) to 1 (cultivar with domesticated traits).

When considering the Bayes rule in terms of individual probabilities, formula [1] can be read as [Equation (4)]:

$$\text{posterior probability} = \frac{\text{likelihood} \times \text{prior probability}}{\text{marginal likelihood}} \quad (4)$$

For a given value of the data, for instance $X = x_4$ and a specific value for the parameter θ (*Vitis taxa*), such as, $\theta = \theta_3$, we get [Equation (5)].

$$p(\theta_3|x_4) = p(x_4|\theta_3)p(\theta_3)/p(x_4) \quad (5)$$

In [Equation (5)], both the likelihood $p(x_4 | \theta_3)$ and marginal likelihood $p(x_4)$ can be calculated based on the joint distribution derived from the comparison samples. The prior probability $p(\theta_3)$ is estimated using data on the regional prevalence of different taxa, from established sources of evidence.

2.6.2. Unveiling Medieval Seeds: Bayesian Analysis in Focus

In a Bayesian context, this framework selection serves as prior knowledge, establishing “a priori” probabilities that influence our results. Bayesian principles allow us to refine probabilities of hypotheses by integrating all available prior evidence, considering temporal and spatial constraints. In this study, we focused on the geographical variation in proportions of different *Vitis vinifera* “proles”, and the ratio *V. vinifera*/*V. sylvestris*. A meticulous formulation of “a priori” probability distributions, based on robust evidence, is as crucial as defining the hypotheses and relevant variables.

The “a priori” probabilities assume that during the 9th–13th centuries CE, 30% of vines were wild, while 70% were cultivated. Altering these proportions would affect the probabilities. Regarding cultivars, we anticipate a proportion similar to the contemporary western Mediterranean, given most variety introductions and translocations had occurred by then (Table 1).

Table 1. Alternative hypotheses and their respective priors and likelihoods ¹.

Groups	Prior	L1	L2
<i>Vitis vinifera</i> cultivars			
<i>Proles Orientalis</i> Negrul <i>Subproles Antasiatica</i>	0.14	0.07	0.042
<i>Proles Orientalis</i> Negrul <i>Subproles Caspica</i>	0.19	0.05	0.041
<i>Proles Pontica</i> Negrul	0.24	0.18	0.035
<i>Proles Occidentalis</i> Negrul	0.19	0.13	0.056
Varieties with intermediate characteristics	0.04	0.06	0.077
Wild grapevines in natural habitats			
<i>Vitis sylvestris</i> , autochthonous native western wild	0.21	0.39	0.104
Feral and colonial wild grapevines, descended from cultivated plants	0.05	0.06	0.068
Direct hybrids of wild Caucasian grapevines with cultivars *	0.01	0.01	0.038
Purely Caucasian feral *	0.01	0.01	0.041
Wild autochthonous native Caucasian grapevines *	0.01	0.02	0.068
Unlikely hypotheses			
American grapevine species *	0.0008	0.001	0.074
Eastern Asian grapevine species *	0.01	0.02	0.101
Fossils *	0.0001	0.0001	0.255

¹ L1, posterior probability combining prior, and the likelihood based on DI values. L2, normalized marginal likelihood considering the allocation to clusters of the ensemble of samples, as in Figure 2. * Wild grapevines from the Caucasus (*Vitis caucasica* Vavilov sensu auct), Asia and America, their probability is small, but we do not rule them out, as the extremely unlikely survival of a living fossil.

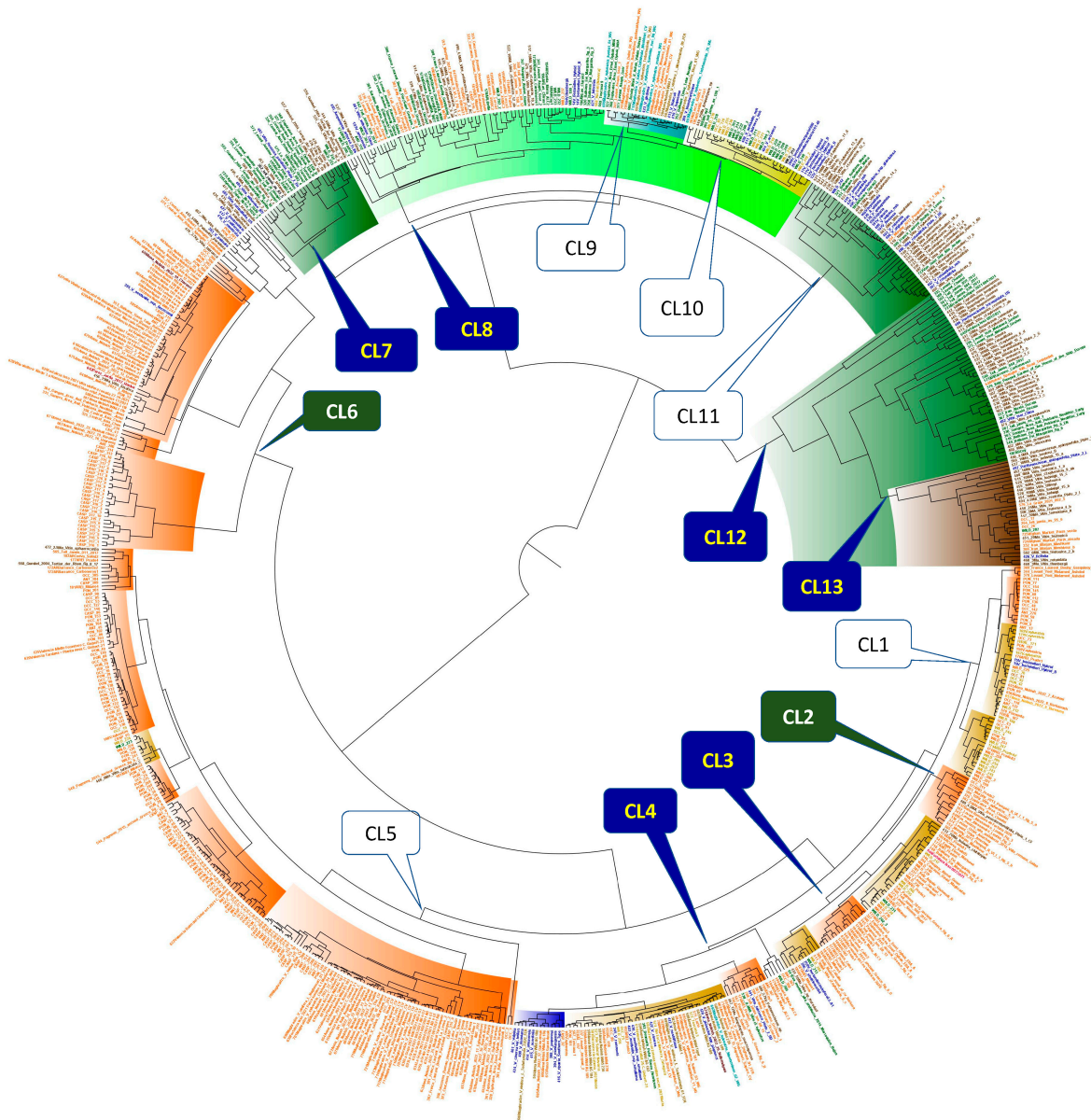


Figure 2. Ward's minimum variance tree. Cluster labels: Blue fill, yellow text for medieval seed clusters. Green fill, white text for earlier period clusters mentioned. White fill, black text for others. Color codes (RGB) for sample labels: *Vitis caucasica*: 0-153-153; *V. sylvestris*: 0-102-0; *V. vinifera*: 255-102-0; *V. vinifera* × *V. sylvestris*: 204-153-0; other wild *Vitis* species: 0-0-204; *Vitis* seeds fossil: 102-51-0; *V. vinifera* × *V. caucasica*: 153-102-0; *V. vinifera* × *V. amurensis*: 102-0-0. A higher resolution version of this graph is available in Supplementary Figure S2.

3. Results

3.1. Overview of Seed Types Identified in Roman and Medieval Deposits

Utilizing the Bayesian approach (Figure 2), we assessed the probability of archaeological seeds, described in Table 2, falling into distinct categories of wild, domesticated, and hybrid grapevines (Table 3, Figures 3–5).

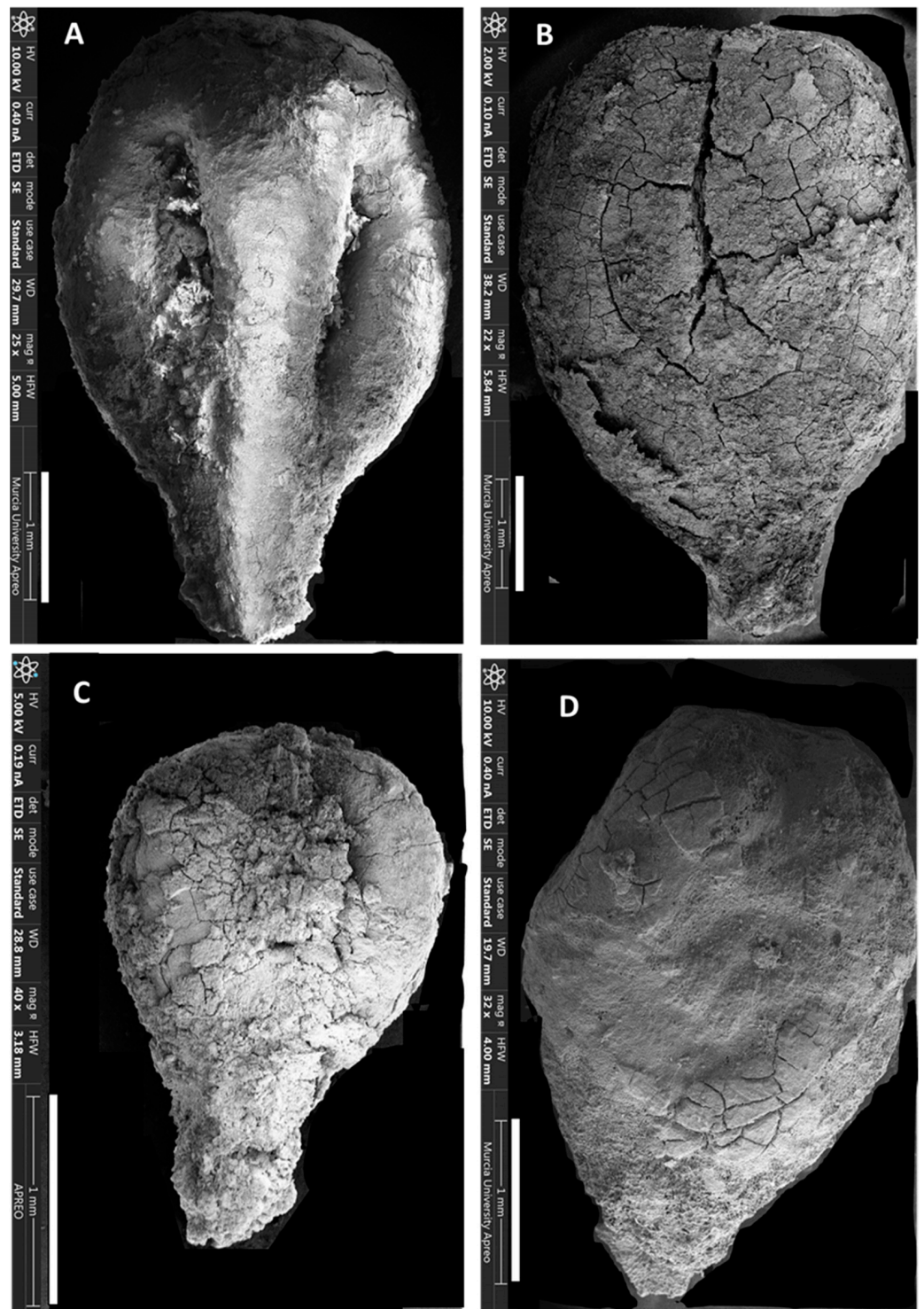


Figure 3. Archaeological medieval grapevine seeds from Spain: SEM images. (A) 646_Fortaleza_Isso_2021/7a. (B) 646_Fortaleza_Isso_2021/7_b. (C) Alcazaba_de_Badajoz_2022/4. (D) 575_La_Graja_(Higueruela,_Albacete,_Spain)_2021/2_4.

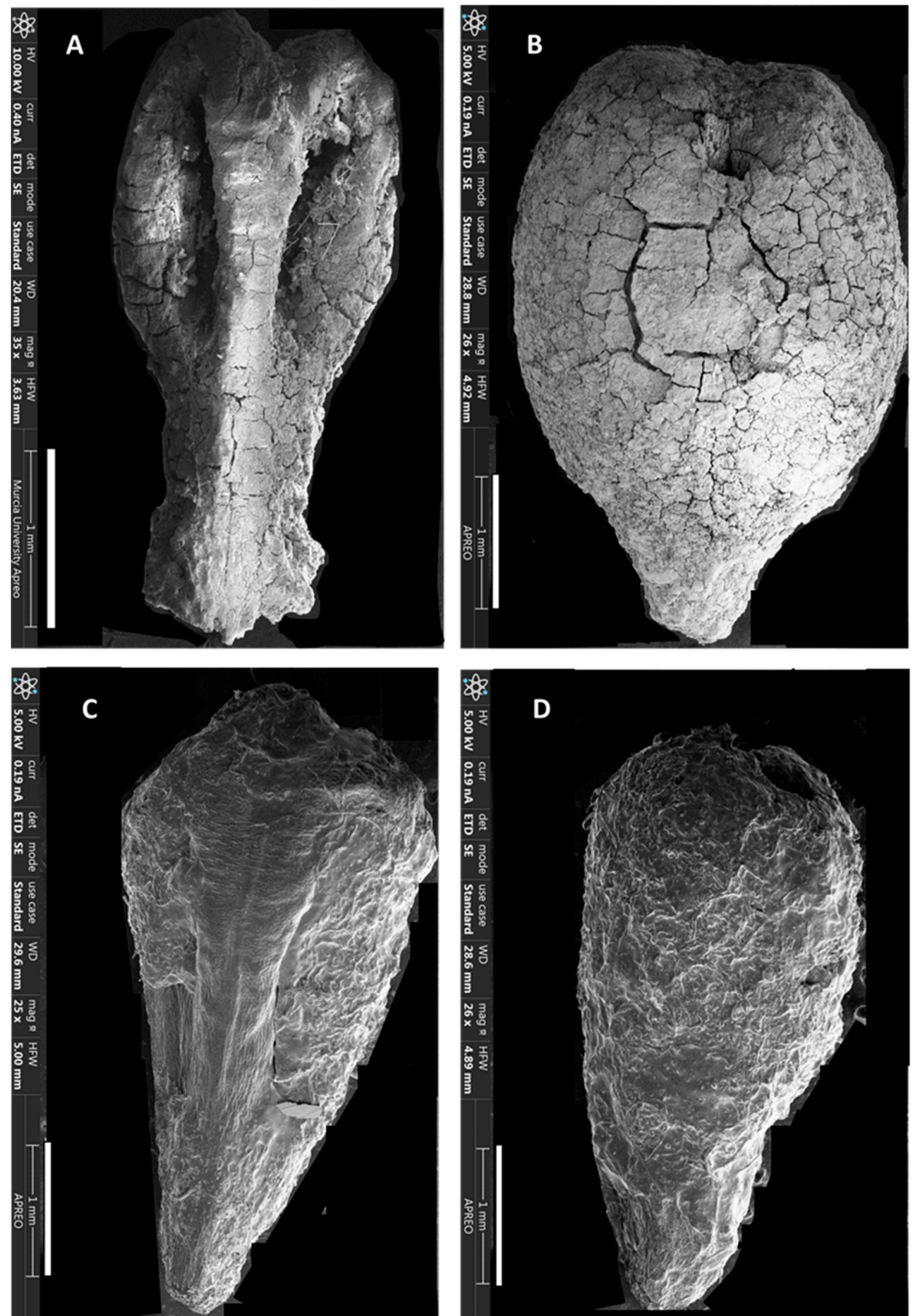


Figure 4. Archaeological medieval grapevine seeds from Spain and modern *Sultanina* SEM images. (A) 576_La_Graja_2021/2_5, recalling stenospermic *Sultanina* type. (B) 638_Begastri_2020. (C) Ventral and (D) dorsal: Afghan modern stenospermic seeds of *Sultanina*-type raisins.



Figure 5. Archaeological medieval grapevine seeds from Spain: (A) 196_Alcázar_Menor_(Murcia,_Spain)_2a, SEM image; (B) 194_AR_Santa María: 1—ALC1, 2—ALC2a, 3—ALC3, 4—ALC2b, 5—ALC4. Agfa Arcus 1200 scanner image.

Table 2. Values of the primary parameters identified and indexes of the individual seeds ¹.

Samples	DI	L (mm)	B (mm)	CL	SI	FP	M F1	M F2	M F3	M F4
637_Roman_Baths_of_Fortuna	1.00	5.5	3.1	2	57	21.36	−0.08	2.85	0.82	1.07
728_Huerta_del_Inglés_2023	1.00	5.0	3.4	8	68	23.41	0.02	0.79	0.82	0.70
576_La_Graja_2021/002_5a	0.67	3.9	1.9	13	47	30.56	−0.58	3.18	0.50	−1.14
646_Fortaleza_Isso_2021/007a	0.67	5.3	3.4	3	65	18.89	−1.01	1.88	0.23	0.72
194_AR_Santa_Maria_ALC2b	0.83	4.8	3.1	8	64	21.84	−0.56	2.28	0.23	0.07
647_Fortaleza_Isso_2021/009b	1.00	5.5	3.6	8	67	21.10	−0.10	2.92	0.89	1.20
196_AR_“Alcázar_Menor”_2a	0.50	4.4	3.1	8	71	21.85	−1.02	1.70	−0.34	−0.75
639_Visigothic_Los_Villaricos	0.67	5.7	3.7	3	66	16.87	−0.86	2.43	0.79	1.68
646_Fortaleza_Isso_2021/007b	1.00	6.1	3.9	3	66	20.18	0.42	4.04	1.92	2.96
194AR_Santa_Maria_ALC3	0.83	5.2	3.8	4	73	21.84	−0.27	2.56	0.51	0.53
194AR_Santa_Maria_ALC4	0.83	5.2	3.5	4	68	19.34	−0.68	2.23	0.40	0.70
575_La_Graja_2021/002_4	0.33	4.4	2.9	7	68	20.02	−1.53	0.92	−1.00	−1.31
194_AR_Santa_Maria_ALC2a	0.00	4.3	3.3	8	87	11.55	−1.96	0.04	−1.37	−1.28
196_AR_“Alcázar_Menor”_2b	0.00	4.2	3.7	8	79	18.51	−1.49	0.87	−0.85	−1.02
638_Begastri_2020	0.17	4.8	3.2	8	68	17.37	−1.77	0.49	−1.13	−1.08
194_AR_Santa_Maria_ALC1	0.50	5.4	3.4	3	63	14.38	−1.64	1.33	−0.01	0.83
196AR_“Alcázar_Menor”_1	0.33	4.3	2.8	8	64	21.82	−1.26	1.38	−0.69	−1.18
723Alcayaba_Badajoz_004/2021	0.33	2.9	1.8	12	62	31.18	−2.30	1.82	−0.47	−3.24
645_Fortaleza_Isso_001/2021	0.00	3.8	3.5	12	94	6.23	−2.83	−2.37	−3.09	−2.27

¹ Abbreviations: DI, domestication index value; L, length; B, breadth; BL, stalk length (mean of ventral and dorsal values); CL, cluster allocation; SI, Stummer’s index $100 \times B/L$ values; FP, Facsar-Perret’s Index $100 \times (Lb/Ls)$ vales; M, Mangafa and Kotsakis’ F1 to F4 indices.

We must note that although the classification obtained through the domestication index and that generated by multivariate cluster analysis typically coincide, there are occasions when they diverge, as do other domestication pointers.

Table 3. Allocation in terms of probabilities (0 to 1) of individual seeds to major groups ¹.

Sample	OR + PO	OC	HY	VS + AM + ASI	FER	CH + CF + CV	CL
Domesticated grapevines							
Domesticated or feral grapevines related to modern cultivars of <i>Proles Occidentalis</i>							
637_Roman_Baths_of_Fortuna_2020	0	1.00	0	0	0	0	2
728_Huerta_del_Inglés_2023	0	1.00	0	0	0	0	2
Domesticated grapevines with stenospermic seeds							
576_La_Graja_2021/2_5a	0.04	0.54	0	0.43	0	0	13
Feral grapevines							
Domesticated and feral grapevines related to modern cultivars and to Caucasian grapevines							
194AR_Santa_Maria_ALC3	0.26	0.11	0.11	0.03	0.30	0.19	4
194AR_Santa_Maria_ALC4	0.26	0.11	0.11	0.03	0.30	0.19	4
Intermediate grapevines							
Intermediate or primitive grapevines related to modern European hybrid and feral grapevines							
646_Fortaleza_Isso_2021/7b	0	0	0.26	0	0.74	0	3
639_Visigothic_Los_Villaricos	0	0	0.32	0.15	0.53	0	3
196_AR_“Alcázar_Menor”/2a	0	0	0.29	0.41	0.17	0.12	8
646_Fortaleza_Isso_2021/7a	0	0	0.32	0.15	0.53	0	3
647_Fortaleza_Isso_2021/9b	0.01	0	0.36	0.12	0.38	0.13	8
194_AR_Santa_Maria_ALC2b	0.01	0	0.36	0.12	0.38	0.13	8

Table 3. Cont.

Sample	OR + PO	OC	HY	VS + AM + ASI	FER	CH + CF + CV	CL
Wild grapevines							
Wild grapevines related to European wild grapevines							
575_La_Graja_2021/2_4	0	0	0.04	0.96	0	0	7
638_Begastri_2020	0	0	0.05	0.87	0	0.07	8
196AR_“Alcázar_Menor”1	0	0	0.08	0.80	0.01	0.11	8
194AR_Santa_Maria_ALC2a	0	0	0.08	0.80	0.01	0.11	8
196AR_“Alcázar_Menor”_2b	0	0	0.08	0.80	0.01	0.11	8
194AR_Santa_Maria_ALC1	0	0	0.21	0.75	0.04	0	3
Wild grapevines related to wild grapevines from East and Central Asia							
723Alcazaba_Badajoz_2021/4	0	0	0	1.00	0	0	12
645_Fortaleza_Isso_2021/1	0	0	0	1.00	0	0	12

¹ Abbreviations: OC, *Proles Occidentalis*; OR, *Proles Orientalis*; PO, *Proles Pontica*; HY, hybrids between “proles” or with wild western populations; VS, *Vitis sylvestris* wild grapevine of western and central Europe; AM, wild American species; ASI, wild Asian species; FER, feral grapevines escaped from cultivation; CH, hybrids from wild eastern populations; CF, feral grapevines originating from cultivation; CV, *Vitis caucasica* wild grapevine of South Caucasus; CL, cluster.

3.2. Identification of Hybrid Characteristics and Anomalies in Seed Formation

A significant proportion of the seeds exhibiting intermediate characteristics (Table 3), attributed to hybrids or colonial wild grapevines, is noteworthy. This observation raises two distinct possibilities: either these seeds were harvested from wild populations with a high degree of hybridization, or during that period, there were ongoing processes of introgression in cultivated populations derived from highly abundant wild populations and, somehow, the resulting grapevines from these crossings were conserved by cultivators.

Intermediate, Primitive, or Feral Grapevines with Wild Traits

Feral, subspontaneous, or colonial wild are grapevine populations that, despite growing in natural habitats, exhibit domesticated morphology [66]. In samples collected along riverbanks, it is straightforward to assign seeds with high or intermediate values of the domestication syndrome to these categories. However, for archaeological seeds whose precise origin is impossible to determine (whether from vineyards or natural habitats), cluster analysis allows for a more precise determination of their affinity with cultivars and feral grapevines. Seeds from Visigoth Los Villaricos, Fortaleza de Isso (Figure 3A,B), “Alcázar Menor” (Figure 5A), and Santa Maria (Figure 5B(4)), with domesticated traits (Table 2), appear linked to modern feral, colonial wild, and hybrid grapevines (Table 3), and are allocated to clusters 3 and 8 (Figure 2), along with Spanish feral grapevines from riparian forests along the Guadalquivir, Aragón, Erro, Esca, Biniés, Bidasoa, and Bullaque rivers. They also show connections to wild grapevines.

3.3. Proportions of *Vitis Vinifera* Cultivars and Their Relationships with Wild Grapevine Populations

3.3.1. Domesticated Grapevines Linked to *Proles Occidentalis* Negrul

The seeds of grapevines closely linked to modern *Proles Occidentalis* Negrul [25] (Table 3), exhibit a remarkably high domestication level and are from the Baths of Fortuna Roman site. Additionally, a seed originating from Huerta del Inglés exhibits similar characteristics, albeit slightly shorter and wider, potentially indicating a persistence of vine cultivation in the area since Visigoth times. These samples are categorized within cluster 2 (Figure 2), alongside seeds unearthed from a Roman Villa in Gabia (Granada) [58] and Pompeii [59].

3.3.2. Domesticated or Feral Grapevines Related to Proles Pontica Negrul

Two seeds from Santa Maria (Alicante, Spain) (Figure 5B(3 and 5)) exhibit a high domestication index and are allocated to cluster 4 (Figure 2), associated with numerous feral grapevines from Spain (riparian forests of Salazar, Esca, and Estena rivers) and Tuscany (Italy), modern cultivars of *Proles Pontica* like “Forcallat”, and to a lesser extent, *Occidentalis*, and are distantly related to hybrid grapevines (Table 3). This presents a notable case as their assignment to a specific prole is uncertain, making them intriguingly misplaced seeds.

3.3.3. European Wild Grapevines

Wild grapevine (*Vitis sylvestris* CC Gmel., the western European wild grapevine) (Table 3) seeds were recovered from La Graja (Figure 3D), Begastri (Figure 4B), Santa Maria (Figure 5B(1 and 2)), and “Alcázar Menor”. It is important to note that, given the significance of stalk length in assigning seeds to the wild group, we should not dismiss the possibility that some seeds with partial stalk breakage might have been improperly assigned to this group [2,36,37].

The small seeds are allocated to clusters 3, 7, and 8 (Figure 2), along with seeds from various wild grapevines (autochthonous or colonial feral) in Spain, found in the riparian forests of Bidasoa, Guadiana, Bullaque, Borosa rivers, as well as in Tuscany (Italy) [66]. Similar seeds have been discovered at the Marroquíes Bajos site in upper Andalusia [58] and as desiccated seeds from the medieval town of Madīnat Ilbīra [60].

3.3.4. Wild Grapevines Related to Ampelopsis

Grapevine seeds from Alcazaba of Badajoz (Figure 3C) and Fortaleza de Isso, with a low domestication index, are associated with wild *Vitaceae*, particularly those of the genus *Ampelopsis*, from East and Central Asia ($p = 0.92$). These grapevines exhibit peculiarly small seeds allocated to cluster 12 (Figure 2), along with archaeological materials from the garden of the House of the Ship Europa at Pompeii, Italy [61], and several Ypresian Eocene *Vitaceae* fossils from London clay ($DI = 0$) [71].

3.4. Presence of Seedless Cultivars and Their Implications for Grapevine Evolution

The presence of a seed with stenospermic traits from Alquería de La Graja (Table 3) suggests the utilization of *Sultanina*-type grapevines, intended for raisin production, which largely bear seedless grapes but, in some berries, exhibit very narrow anomalous seeds (Figure 4A) comparable to those of present-day ‘sultanas’ from Iran and Afghanistan (Figure 4C,D). The seed was allocated to cluster 13 (Figure 3) alongside modern cultivars like *Korinthiaki*, as well as stenosperms of Afghan raisins of the *Sultanina* type (*Proles Orientalis* Negrul). Samples exhibiting the “stenospermic” type were also observed in the ancient Near East [72,73].

4. Discussion

4.1. Interpretation of Findings in the Context of Medieval Grape Cultivation Practices

We observe, among the analyzed seeds, the consistent presence of seeds resembling wild and intermediate types (Tables 3 and 4), which could indicate ongoing gathering from natural habitats, deliberate cultivation in orchards, or the persistence of cultivars with primitive traits. Certain characteristics of wild grapevines are also evident in cultivars, such as *Riesling*, *Pinot*, *Verdot*, and *Mansengou*, referred to as archaic due to their primitive traits. These cultivars often boast a high oenological value and a berry flavor reminiscent of lambruscae. Key traits of primitive cultivars include [38,44]: the prevalence of androecium flowers with reduced and non-functional gynoecium, seeds like those of wild vines in size and shape, with high germination rates, small clusters, bearing round, robust berries.

Table 4. Proportion of domesticated and wild grapevines in the samples.

Main Group	Percentage of Samples (%)	Only Andalusi (Excluding Roman and Visigothic Samples) (%)
Domesticated	17	13
Hybrids and feral (colonial wild)	39	40
Wild	33	33
Stenospermocarpic	11	13

Data from Table 4. Domesticated: OC, *Proles Occidentalis*; OR, *Proles Orientalis*; PO, *Proles Pontica*. Hybrid and Feral: HY, hybrids between “proles” or with wild western populations; FER, feral grapevines escaped from cultivation; CH, hybrids with wild eastern populations; CF, feral grapevines originating from cultivation. Wild: VS, *Vitis sylvestris* wild grapevine of western and central Europe; AM, wild American species; ASI, wild Asian species; CV, *Vitis caucasica* wild grapevine of South Caucasus. Stenospermocarpic: two samples.

4.2. Comparison with Historical and Archaeological Evidence from Al-Andalus

According to the literature (Table 5), grapevines thrived in medieval Andalusian territories (Table 5). The allocation to proles (*Orientalis*, *Occidentalis*, or *Pontica*) is tentative, based on the available information on morphology and uses. *Proles Pontica* predominates (c. 50%), followed by *Orientalis* (c. 45%), with *Occidentalis* represented minimally (c. 10%).

Table 5. Domesticated grapevines in Andalusi agricultural texts.

Proles ¹	Names	Description	Authors	Refs.
OC	(Compact)	Clustered tightly	Al-Ṭignarī	[8]
OR	‘Adara	Elongated black grapes, known as maiden grapes	Ibn al-‘Awwām	[8]
OR	<i>Al-ahmar</i> (the red)	Red date grapes, sharp at both ends, resembling dates in size	Ibn al-‘Awwām	[8]
OR	<i>Asabi al-adara</i> (fingers), ‘ <i>Abqari</i> (superior)	Maiden’s finger grapes, black	Ibn al-‘Awwām, ‘ <i>Umda</i>	[8]
OR	<i>Asabi al-adara</i> , <i>Asabi al-fatayat</i> , <i>Asabi al-qaynat</i> (fingers)	Maiden’s finger grapes, red, akin to the color of henna	Abū l-Jayr, ‘ <i>Umda</i>	[8,74]
OR	Buyun, Bayan	Grapes the size of broad beans, with a reddish tint akin to poppy juice	Abū l-Jayr, ‘ <i>Umda</i>	[8,74]
OR	<i>Futuhi</i>	Reddish–yellow grapes ripening late in autumn, larger than idari grapes with a firm skin	Ibn al-‘Awwām, ‘ <i>Umda</i>	[8]
OR	Idari, <i>Al-Bayut</i> (acorn)	Grapes similar in length to acorns, boasting robust skin	Abū l-Jayr, ‘ <i>Umda</i>	[8,74]
OR	Sutfunus/Sutkunus, <i>Melar negra</i> , al-‘Ashali (lizard’s grapes)	Honey grapes, characterized by a red-tinted hue on black grapes	Abū l-Jayr, Al-Ṭignarī	[5–8,74]
PO	<i>Al-asar</i> (families?)	With a light-yellow tone on early white grapes	Al-Ṭignarī, Ibn al-‘Awwām	[8]
PO	<i>Almujuardal</i> (the instigator?)	Grapes with petite berries, akin to mustard seeds, boasting a superior taste, sweetness, and clear juice; they blossom early with a gradual setting	Ibn Baṣṣāl	[5–8,74]
PO	<i>Jallādī/Jalāwī</i> (sweet) or <i>Yayyani</i>	Jaén grapes, small and flattened with sturdy seeds	Al-Ṭignarī, Ibn al-‘Awwām	[5–8,74]

Table 5. Cont.

Proles ¹	Names	Description	Authors	Refs.
PO	Jarūfi, Fijar	“Cabrito” grapes, resembling the shape of baby goat hearts, mainly used for sultana production	Al-Ṭignarī, Ibn al-ʿAwwām	[5–8]
PO	Jinziri	Grapes with berries the size of small black plums and a thick skin, which ripen in autumn	Abū l-Jayr, ʿUmda	[8,74]
PO	Lanat (wooly)	Grapes with large, spherical, deep black berries, coated in a greyish hue	Abū l-Jayr, ʿUmda	[8,74]
PO	Quraysi	Grapes akin to woolly grapes (Lanat), featuring smaller berries and intense sweetness	Abū l-Jayr, ʿUmda	[8,74]
PO or OC	Al-aswad (the black)	Medium-sized black berries	Al-Ṭignarī, Ibn al-ʿAwwām	[8]
PO or OC	Al-mudhari (urban?)	Round black berries	Ibn al-ʿAwwām	[8]

¹ Abbreviations: OC, *Occidentalis*; OR, *Orientalis*; PO, *Pontica*.

The treatises provide insights into vine cultivation techniques, indicating a shift towards intensive farming on small, irrigated properties during the Andalusi period, diverging from practices in classical antiquity and the early High Middle Ages. While the treatises suggest a focus on table grapes during this period, further study of archaeological seeds from medieval sites is needed for a comprehensive understanding.

The analysis of medieval seeds reveals a prevalence of wild or hybrid vines, instead of selected *Proles Orientalis* Negrul. This suggests a continuation from the Roman period or a resurgence of wild vine predominance. More selected grapevine forms are characterized by greater fertility, larger clusters, and berries with appealing shapes, tastes, sizes, and colors. Despite their attractiveness, they have reduced vitality. Some, like the “sultana”, are stenospermocarpic or even seedless.

The presence of “stenospermic” seeds could elucidate the anomaly between textual sources and archaeological findings. These seeds are associated with the selection process of seedless grape varieties, known as “stenospermocarpy”, alongside parthenocarpy. It is likely that the elongated grapes of *Proles Orientalis* (Table 5) lacked seeds or had vestigial ones, leaving little trace in the archaeological record.

Stenospermocarpy in *Vitaceae* often results from anomalies in seed development due to complex interactions from cross-pollination between genetically distant individuals. This phenomenon is common when obtaining seedless table grapevine cultivars and raisins. Raisins, being durable in dried form, are more likely to appear in the archaeological record [75].

Raisins were then, as they are now, the object of long-distance commerce, but in parallel, local production of raisins is well documented. Bleaching and drying of grape berries are described by Columella as methods of preparing raisins, while Andalusian writers, such as Abū al-Jayr and Ibn al-ʿAwwām, recommend natural drying on the vine, after twisting the cluster peduncles, or a preliminary brining of unripe berries before proceeding to dry them. Different bleaching techniques are mentioned by Ibn al-ʿAwwām and Ibn Luyūn [76].

4.3. Implications for Understanding the Origins and Evolution of Grapevine Varieties in the Iberian Peninsula and Western Europe

Vitis sylvestris is found in medieval layers across various Spanish sites, sometimes alongside intermediate seed types and cultivars. Mentions of these wild grapevines also appear in al-Andalus agricultural texts (Table 6).

Table 6. Wild grapevines in texts from al-Andalus.

Names	Description	Authors	Refs.
<i>Nigrir</i>	Poor-quality grapes, with berries the size of chickpeas, with many seeds, astringent taste and indigestible	‘Umda	[74]
<i>Sawu</i> (smooth?)	Grapes the size of a bitter vetch, very small, very astringent grapes; plants that grow in riparian forests	‘Umda	[74]
<i>Karm barri</i> (generous wild)	Wild vines (male), not fruiting	‘Umda	[74]
<i>Karm barri</i> (generous wild)	Wild grapevines (female), bearing fruit	‘Umda	[74]

Vineyards in al-Andalus likely experienced cycles of abandonment and revival, particularly wine grapes, in response to changes in tolerance levels for wine production and consumption. During restriction periods, vineyards may have been abandoned and later reintroduced, leading to hybridization with wild vines in riparian forests. This could explain the presence of intermediate seed types and grape varieties.

The coexistence of wild and domesticated vines dates back to ancient times, implying the potential for introgressions and hybridization zones. At the Nuragic culture settlement in Sa Osa (Sardinia, Italy), uncharred grape pips from waterlogged pits dating back to the Middle and Late Bronze Age (ca. 1350–1150 B.C.) were analyzed. The archaeological findings revealed a predominance of *V. vinifera* in pit N, an equal distribution of *V. vinifera* and *V. sylvestris* in pit U, and a majority of *V. sylvestris* in pit V [77]. In the late 18th and early 19th centuries, Clemente [78–80] identified three wild types in Algaida (Sanlúcar de Barrameda, Spain): Garabatona, Virgiliana, and Mantuo savage. These types exhibited distinctive characteristics resembling cultivars found along the Danube River and certain *Proles Occidentalis* cultivars. A recent study by Rivera et al. [66] observed the cohabitation of wild, feral, and hybrid grapevine individuals in the same area in modern times. Planchon [81] documented numerous wild grapevine populations with diverse morphologies thriving in France, while Campostrini et al. [82] noted similar populations in Italy during the 19th century, although many have since declined due to phylloxera infestations or habitat destruction.

Limited sample sizes, often comprising one single seed and always fewer than 100 seeds, hinder a comprehensive analysis of intra-sample or within-site heterogeneity. Stalk length, a significant variable, may occur damaged in archaeological samples, posing challenges for the interpretive model.

5. Conclusions

In our analysis of medieval grapevine seeds, we observed the presence of *Proles Orientalis* (mostly stenospemic) and *Proles Pontica*, while those from the Roman period closely resemble *Proles Occidentalis*. Additionally, some seeds exhibit domestication traits, but cannot be confidently assigned to any known modern proles. Finally, we should highlight the numerous seeds with intermediate traits, suggesting introgression, allocated within modern colonial feral populations, as well as other seeds that were distinctly wild. This study holds significance as it highlights the extensive exchange of the grapevine germplasm across major grape-growing regions and the exchange with local autochthonous wild grapevine populations.

For future research, we recommend systematically and widely collecting plant remains in medieval excavation sites, with particular attention to anomalies like stenospemic or tiny grape seeds. This approach could provide further insights into the historical cultivation practices and genetic diversity of grapevines.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/horticulturae10050530/s1>, Table S1: Quantitative characters. Table S2: Qualitative characters. Table S3: Allometric characters. Table S4: Stummer’s index for wild and domesticated grapevine seeds.; Table S5: Facsar–Perret index for wild and domesticated

grapevine seeds; Table S6: Mangafa and Kotsakis indexes for wild and domesticated grapevine seeds. Figure S1. Qualitative and quantitative characters analysed in grapevine seeds. Figure S2: Expanded version of Figure 2.

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