Article

Volcanic Terroirs: Exploring Minerals in Canary Red Wine

Jesus Heras-Roger * , Carlos Díaz-Romero , Javier Darias-Rosales , Jacinto Darias-Martín

Posted Date: 5 November 2024

doi: 10.20944/preprints202411.0270.v1

Keywords: mineral; red wine; authenticity; classification; geographical origine; Canary; volcanic

Article

Volcanic Terroirs: Exploring Minerals in Canary Red Wine

Jesus Heras-Roger [1,2,*], Carlos Díaz -Romero [1], Javier Darias-Rosales [3] and Jacinto Darias-Martín [1]

[1] Departamento de Ingeniería Química y Tecnología Farmacéutica, Universidad de La Laguna, 38201, Spain
[2] Cátedra de Agroturismo y Enoturismo de Canarias ICCA-ULL, Spain
[3] Departamento de Toxicología, Universidad de La Laguna, 38071, Spain
* Correspondence: jherasro@ull.edu.es

Abstract: The mineral composition of monovarietal red wines from the Canary Islands was analyzed to evaluate the potential of mineral content as a marker for wine authenticity by geographical origin. Key minerals—K, Na, Mg, Mn, Fe, Cu, and Co—were quantified in 190 wine samples using flame absorption spectrometry. The study revealed slight mineral profile differences between recently introduced international grape cultivars and traditional ungrafted varieties. A significant correlation was found between K and Mg, highlighting their roles in vine physiology. Results indicated that Tenerife wines had elevated Fe and Mn, Lanzarote wines showed higher Na (likely from marine aerosols), and La Gomera wines had significantly high Mn. Linear Discriminant Analysis demonstrated that Mn, Mg, and Na differentiated wines by island, with 85% classification accuracy, while Cu and Fe correlated with wine aging. These findings emphasize the influence of volcanic soils and microclimate on mineral profiles, supporting mineral analysis as a cost-effective tool for classifying red wines by origin. This study offers insights into how terroir, grape cultivar, and winemaking practices define the unique characteristics of Canary Island wines.

Keywords: mineral; red wine; authenticity; classification; geographical origine; Canary; volcanic

1. Introduction

The origins of minerals found in wine are diverse, arising from various sources such as vineyard soil, use of pesticide sprays, fining agents, and winemaking practices [1]. The predominant source of each element can differ significantly; for instance, in some cases, their concentrations theoretically correlate strongly with soil type and geological factors (e.g., Mn or Co), while in others, it may additionally be influenced by winemaking techniques (e.g., K, Na, Ca, Fe or Cu) [2]. Consequently, mineral concentrations have garnered global attention as potential markers of authenticity, particularly in studies investigating their association with geographical origin. The mineral composition of soils in the Canary Islands is notably heterogeneous, influenced by variations in volcanic activity and soil age, which precludes a standardized mineral profile for all vineyards across the archipelago. Previous studies have highlighted some elements that have often been related to the ways of authenticating wines such as K, Na, Fe, Ca, Cu, Co, Sb, Cs, Cr, Mn, Al, Ba, Mg and Sr [3].

Advanced research in this subject involves the analysis of trace element content and stable isotope ratios as indicators of the origin of food industry products [4]. However, quantifying trace elements and stable isotope ratios requires access to a costly infrastructure and skilled technicians [5]. In contrast, flame absorption and emission techniques are relatively simple, low cost-effective, and readily accessible methods useful for most of the concentrated minerals [6]. Moreover, their analytical methods for wine have been already worldwide standardized by the International Organisation of Vine and Wine (OIV) [7].

In this context, researchers from diverse winemaking regions have attempted to identify the most discriminant elements for distinguishing wines from their respective areas. For example, Li and K were proposed in Italy [8], while Mn, Sr, Ag, Co, and Cr have been utilized in Romania [9], and Al,

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

Be, Ba, Ni, Ca, Na, and Mg in Serbia [10]. A cross-continental study, encompassing wines from four countries, revealed that only K, B, and Na were sufficient to differentiate the analyzed wine samples according to their country of origin [11]. In a more comprehensive trial, examining over 1000 wines from Australia, it was concluded that the mineral composition of wines can indeed serve to classify them by country of origin, and even by region, with the most indicative minerals including Li, Na, Mg, Si, P, K, Ca, Mn, Fe, Ni, Zn, Rb, Sr, Cs, and Ba [12]. Nevertheless, while the mineral content seems to be suitable to differentiate with great accuracy wines according to the geographical origin, the stable isotope ratios could be considered as the most useful indicator to differentiate, above all, the year of production [13].

The Canary Islands have a rich history of viticulture that extends over several centuries. Situated off the coast of northwestern Africa, the archipelago's distinct terroir is shaped by its volcanic origins, varying altitudes, and microclimates, which give rise to a remarkable diversity of wines. Each island, and even each vineyard slope, possesses differential characteristics due to differences in volcanic soil composition, altitude, orientation, and climate. One of the most notable features of Canary Island viticulture is the absence of rootstock grafting, which was possible by the islands' isolation from the phylloxera plague. Today, there are 11 distinct wine Denominations of Origin in the Canary Islands, ranging from the arid landscapes of Lanzarote to the verdant valleys of Tenerife. Given the heterogeneity of conditions, and particularly volcanic soils across the Canary Islands, this archipelago was one of the first geographical areas to apply mineral discrimination. Canary Islands wines have extensively been considered for studying the mineral content as a potential mean for origin classification [14–25]. Most of these studies concluded by achieving thorough discrimination based on the trace elements concentrations.

The purpose of this research was to establish the potential use of minerals with high concentrations, which are easily quantifiable by absorption spectrometry, for contributing to a relatively fast and non-expensive determination of the origin discrimination in Canary Islands wines. Generally, red wines exhibit higher mineral content than white and rosé wines due to their prolonged skin contact [1]. Therefore, for this research, we have selected Canary single-varietal red wines from six different islands, enhancing heterogeneity between areas by considering various cultivars and vintages. Although red wines were chosen for their higher mineral concentration, it could be interesting in a second phase to explore the mineral content in white and rosé wines, as they may offer additional insights for origin discrimination and other analytical purposes.

To the best of our knowledge this is the first mineral study strictly focused on monovarietal red wines, including a high number of wine samples from different volcanic soils. Correlation study and lineal discriminant analysis were applied in order to find out relations between the analyzed minerals and classify the single-varietal red wines according to grape cultivar, precedence island and Denomination of Origin, and wine ageing.

2. Materials and Methods

2.1. Wine Samples

190 bottled monovarietal red wines were selected from the Canary Islands (Spain) including ten cultivars, six islands and six vintages. The distribution of red wine samples according to the island of origin was designed to represent the quantity of red wine produced in each area, considering that some islands mainly produce white wines. Thus, Tenerife island was the most represented (n=130), as it contains five Denominations of Origin, which were distributed in our research as follows: Tacoronte-Acentejo (n=48), Abona (n=41), Valle de la Orotava (n=19), Ycoden-Daute-Isora (n=14), Valle de Güímar (n=8). Following Tenerife Island, the rest of the selected wines come from the following islands: La Palma (n=16), El Hierro (n=15), Gran Canaria (n=12), La Gomera (n=9), Lanzarote (n=8). For a more detailed understanding of the geographical location of the Canary Islands' Denominations of Origin, as well as the sample distribution in terms of ageing and cultivar, please refer to Table 1 and Figure 1

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

Table 1. Wine Samples distribution according to Cultivar and Wine ageing.

	Information	Samples (n)
CULTIVAR		
Listán Negro	Autochthonous	77
Baboso	also known as Alfrocheiro	24
Negramoll	also known as Mollar Cano	15
Vijariego	also known as Sumoll	15
Listán Prieto	also known as Mission grape	15
Tintilla	also known as Trousseau	11
Castellana	also known as Tinta Cão	10
Syrah	International	10
Merlot	International	7
Ruby Cab.	International	6
WINE AGEING (years)		
Young (≤2)	Most Canary wines	103
Medium (3-5)	Minor proportion in the market	75
Old (≥6)	Rarely elaborated	12

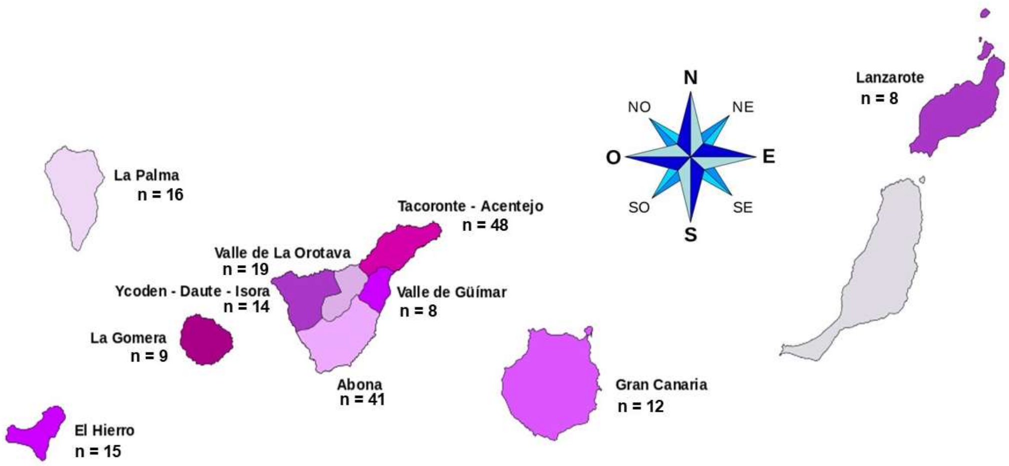

Figure 1. Canary Islands with samples distribution according to Denomination of Origin.

2.2. Analytical Methods

The minerals considered for differentiation were K, Na, Mg, Mn, Fe, Cu, and Co. These minerals were selected based on their ease of quantification, and generally based on their presumed high concentrations and previous mentions in the scientific literature as potential markers. Mineral concentrations were determined through atomic absorption spectrometry using air/acetylene flame, except for magnesium, which required an acetylene/nitrous oxide flame. No additional microelements or radioactive elements were analyzed, as they would require advanced instrumentation beyond the usual wine laboratory capacities. No digestion procedures were applied but all samples were filtered (0.45 µm) before assessment. For the Fe, Cu, and Mn determination, ethanol was previously removed by heating (T ~ 60 °C, t ~ 24 h) in accordance with OIV standards [7]. Instrumental measurements were made with a Varian SpectrAA atomic absorption spectrophotometer equipped with a deuterium lamp for background correction and hollow-cathode lamps for each of the elements studied. The determination of Na and K is confounded by ionization interferences that entail the use of some suppressor; thus, the samples used to determine Na were supplied with KCl, and those used to determine K with NaCl.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

Standard stock solutions of the different metal ions at a 1000 μg/ml concentration were prepared from atomic absorption spectroscopic grade chemicals (Panreac, Spain) and used to make working solutions by appropriate dilution. Reagent-grade nitric acid, ultrapure de-ionized Milli-Q water (Millipore, USA) and the surfactant Extran (Merck, Germany) were used. The detection limits were determined based on the standard method of calculating three times the standard deviation of the baseline (zero) instrumental signal. The detection limits obtained for the mineral analysed were the following (expressed in mg/l): K, 0.2; Na, 0.2; Mg, 0.01; Fe, 0.1; Cu, 0.03; Mn, 0.05; Co, 0.01.

2.3. Statistical Analysis

Statistical analyses were performed using SPSS v.18. To evaluate significant differences between groups, one-way ANOVA was conducted. A p-value threshold of <0.05 was accepted to determine statistical significance. Post-hoc comparisons were carried out using Duncan's multiple range test to identify specific group differences. Bivariate correlations were assessed using the Pearson correlation coefficient, highlighting any positive or negative associations. For linear discriminant analysis, a stepwise approach was employed to identify the most significant variables contributing to group separation. Additionally, all variables were included in the analysis to explore potential interactions and relationships among factors. Potential probabilities were calculated based on the sample size of each population and utilizing an intra-groups variance matrix. This approach allowed for a comprehensive evaluation of group differences and the identification of key variables influencing classification.

3. Results

3.1. Overall Mineral Content

The overall mineral content is detailed in Table 2. As expected, K was most concentrated mineral, followed by Mg, Na, Fe, Mn, Cu, and finally Co, largely in accordance with global wine literature [26] and Canary Islands previous mineral studies [14–25]. K, Na, and Mg are typically classified as macroelements in vines, as they can constitute between 1% and 3% of the dry extract. In contrast, minerals present at concentrations below 1,000 mg/kg in vines dry samples are considered trace elements, despite their critical role in plant growth and development. Examples of such trace elements include Cu, Fe, Mn, and Co [5]. It is notable that the coefficient of variation (CV) for Cu was abnormally high, reaching 220%, which was significantly greater than the CVs observed for the other minerals analysed, which varied between 20% and 60% In this sense, approximately 80% of the wines showed a Cu concentration lower than 0.2 mg/l.

Table 2. Mineral concentrations (mg/l) in monovarietal red wines from the Canary Islands.

	Mean ± Standard Deviation	Range (Min-Max)	Quartiles Q25–Q50–Q75
Fe	1.64 ± 1.00	0.30–7.33	1.00–1.46–1.98
Cu	0.22 ±0.49	0.03–6.70	0.04–0.09–0.17
Co	0.02 ±0.01	0.01–0.05	0.02–0.03–0.03
Mn	1.35 ± 0.69	0.05–5.07	0.95–1.19–1.63
K	1248 ± 459	531–3727	1103–1357–1683
Mg	128.0 ± 26.6	65.0–263.1	109.1–124.5- 144.6
Na	97.1± 55.0	19.0–351.2	62.3–92.8- 117.5

3.2. Mineral Concentration According to Several Factors

Table 3 presents the detailed mineral concentrations of the samples, categorized by various grouping factor, such as grape cultivar, as indicated on the label; island of origin; and wine ageing time. Results of variance analysis are also included in that table, highlighting the statistically significant differences observed through ANOVA ($p < 0.05$) for each of these grouping variables.

 doi:10.20944/preprints202411.0270.v1

Table 3. Mineral concentration (mg/l) according to grape cultivar, island and wine ageing.

CULTIVAR	**Fe**	**Cu**	**Co**	**Mn**	**K**	**Mg**	**Na**
Listán Negro	1.68^{ab} ± 0.75	0.25^{ab} ± 0.61	0.03^{b} ± 0.01	1.57^{a} ± 0.79	1285^{ab} ± 332	118.3^{abc} ± 19.8	94.6^{abc} ± 41.6
Negramoll	1.56^{ab} ±0.57	0.23^{ab} ± 0.24	0.03^{ab} ± 0.01	1.02^{a} ± 0.98	1346^{ab} ± 417	107.5^{a} ± 19.2	85.1^{abc} ± 47.9
Baboso	1.55^{ab} ±1.10	0.10^{a} ± 0.08	0.02^{ab} ± 0.01	1.27^{a} ± 0.51	1631^{b} ± 350	145.4^{d} ± 30.1	121.2^{bc} ± 68.7
Listán Prieto	2.14^{b} ± 1.88	0.66^{b} ± 0.57	0.03^{ab} ± 0.01	1.29^{a} ± 0.51	1186^{a} ± 414	114.0^{ab} ± 23.1	72.5^{ab} ± 54.0
Tintilla	1.09^{a} ± 0.60	0.09^{a} ± 0.11	0.02^{ab} ± 0.01	1.12^{a} ± 0.35	1582^{ab} ± 471	131.1^{bcd} ± 18.6	63.4^{a} ± 36.2
Castellana	0.94^{a} ± 0.26	0.13^{a} ± 0.09	0.01^{a} ± 0.01	1.02^{a} ± 0.14	2278^{c} ± 1041	138.0^{cd} ± 30.1	60.7^{a} ± 38.7
Vijariego	1.80^{ab} ± 1.35	0.11^{a} ± 0.10	0.03^{b} ± 0.01	1.20^{a} ± 0.46	1394^{ab} ± 287	146.5^{d} ± 24.0	87.6^{abc} ± 41.7
Ruby Cab.	1.06^{a} ± 0.32	0.11^{a} ± 0.10	0.03^{b} ± 0.01	1.25^{a} ± 0.46	1723^{b} ± 241	142.6^{d} ± 33.9	100.5^{abc} ± 59.6
Merlot	1.32^{ab} ± 0.27	0.06^{a} ± 0.01	0.04^{b} ± 0.01	0.94^{a} ± 0.23	1522^{ab} ± 570	155.3^{d} ± 29.8	181.3^{d} ± 102.1
Syrah	1.77^{ab} ± 1.01	0.11^{a} ± 0.08	0.03^{b} ± 0.01	1.29^{a} ± 0.44	1536^{ab} ± 493	150.1^{d} ± 21.6	128.9^{c} ± 74.3
ISLAND	Fe	Cu	Co	Mn	K	Mg	Na
Tenerife	1.51^{a} ± 0.99	0.24^{a} ± 0.58	0.02^{ab} ± 0.01	1.41^{b} ± 0.59	1427^{a} ± 505	128.2^{ab} ± 27.9	98.9^{a} ± 56.1
La Palma	1.65^{a} ± 0.59	0.20^{a} ± 0.23	0.03^{ab} ± 0.01	0.60^{a} ± 0.14	1418^{a} ± 297	109.4^{a} ± 22.7	82.0^{a} ± 50.0
El Hierro	2.10^{ab} ± 1.18	0.12^{a} ± 0.10	0.03^{ab} ± 0.01	1.17^{b} ± 0.46	1624^{a} ± 256	144.1^{b} ± 17.0	106.5^{a} ± 20.6
Gran Canaria	1.41^{a} ± 0.67	0.17^{a} ± 0.13	0.01^{a} ± 0.01	1.12^{b} ± 0.29	1359^{a} ±424	132.6^{ab} ± 20.2	64.8^{a} ± 50.1
La Gomera	2.55^{b} ± 0.71	0.10^{a} ± 0.07	0.03^{ab} ± 0.01	2.93^{c} ± 1.47	1292^{a} ± 175	123.7^{ab} ± 16.6	77.0^{a} ± 23.5
Lanzarote	2.95^{b} ± 1.15	0.08^{a} ± 0.05	0.04^{b} ± 0.01	1.15^{b} ± 0.41	1207^{a} ± 166	122.6^{ab} ± 18.0	167.2^{b} ± 85.9
AGEING	Fe	Cu	Co	Mn	K	Mg	Na
Young (≤2)	1.79^{ab} ± 1.16	0.29^{a} ± 0.65	0.01^{a} ± 0.01	1.42^{a} ± 0.76	1439^{a} ± 500	125.2^{a} ± 23.0	93.1^{a} ±53.4
Medium (3-5)	1.38^{a} ± 0.63	0.11^{a} ± 0.13	0.02^{b} ± 0.01	1.24^{a} ± 0.48	1416^{a} ± 398	132.9^{a} ± 30.4	102.8^{a} ± 58.6
Old (≥6)	2.16^{b} ± 1.20	0.12^{a} ± 0.11	0.03^{b} ± 0.01	1.47^{a} ± 1.26	1372^{a} ± 455	118.3^{a} ± 28.2	95.1^{a} ± 39.8

Mean values with same superscript were not statistically different ($p<0.05$).

Significant differences in the mean concentrations of Fe, Mg, Na, and K were observed based on the grape cultivars used for wine production. However, the influence of origin (island and Denomination of Origin) was more pronounced, with notable differences observed among the mean concentrations for most of minerals except for Cu.

Tenerife exhibited the greatest overall variability in mineral content, which is understandable given that the island includes the largest number of wine samples, as well as five distinct Denominations of Origin, each with differential terroir characteristics that likely contribute to the significant differences observed across samples. This is particularly evident for elements such as Mg, Fe, and Mn, as shown in Figure 2.

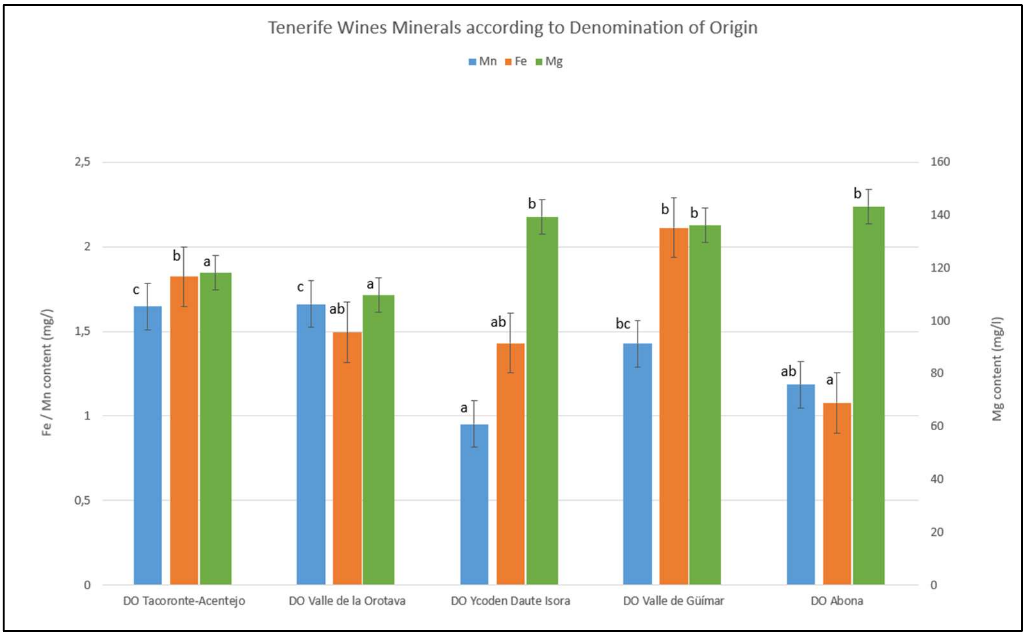

Figure 2. Mn, Fe and Mg concentrations in Tenerife Denomination of Origin Wines.

3.3. Correlations

The relationships between the concentrations of the minerals analyzed can be found in Supplementary Materials (Table 6), based on Pearson's correlation coefficient (r), which measures the strength and direction of the linear relationship between two variables. P-values below 0.05 were considered statistically significant.

All the significant intermetallic correlations were positive, suggesting that these minerals are closely linked in the vine's nutrient uptake processes or share similar pathways of absorption. For instance, the strong positive correlations observed between Na, K, and Mg indicate that these minerals are either co-dependent or influenced by similar factors in the soil, such as availability, mobility, or the vine's metabolic requirements. Figure 3 illustrates the relationship between K and Mg in the final wine for the red wines analysed. Cu did not show any correlations; in contrast, both Fe and Co were correlated with three minerals each one. Moderate correlations were found between Fe and Co, Mn, and Na; and Co with Mg and Na.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

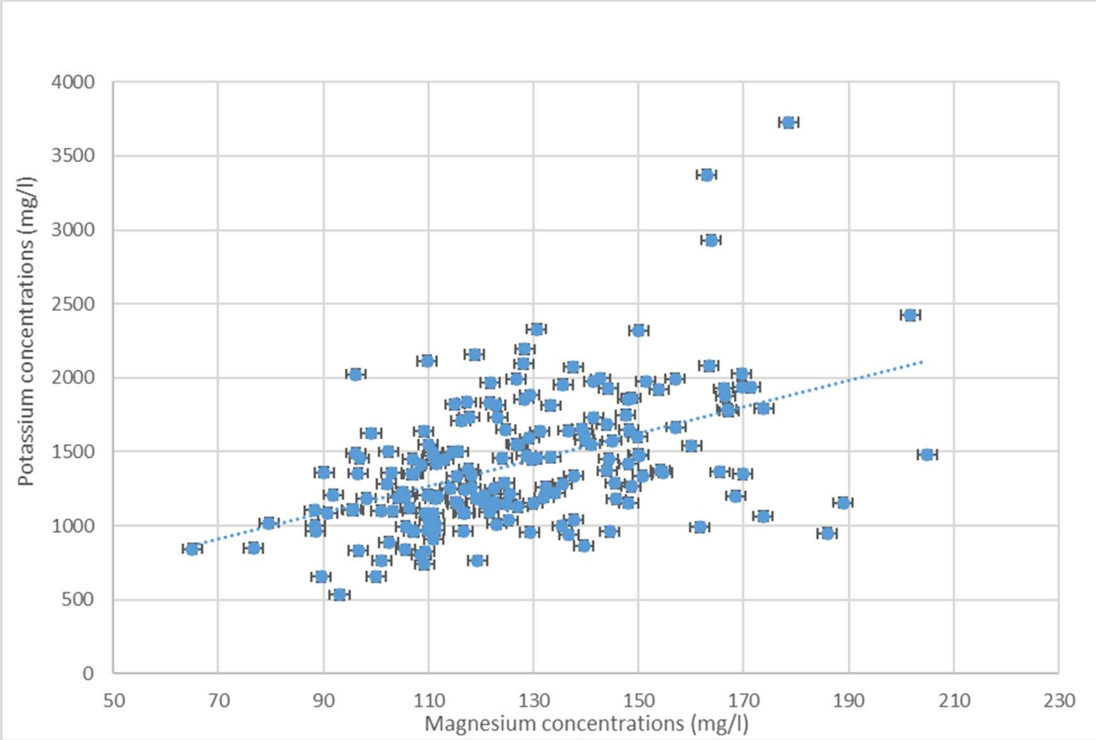

Figure 3. Relationship between magnesium and potassium concentrations in the red wines analyzed.

3.4. Discriminant Analysis

Linear Discriminant Analysis (LDA) was performed in monovarietal Canary red wines using two approaches: one including all variables and a stepwise method to select the most significant minerals. The analysis was conducted for different grouping variables: grape cultivar, island, Denomination of Origin, and wine ageing. Table 4 presents the results of both types of analysis in terms of the total percentage of correct classification, both directly and after cross-validation, for each grouping variable. Additionally, the table shows the number of functions, the main discriminant minerals, and the selected variables from the stepwise analysis, along with the most correlated minerals for each function.

Table 4. Results of Lineal Discriminant Analysis (LDA) to classify red wines.

Grouping variable and type of LDA	Correct classification (% after cross-validation)	All minerals (Functions 1 & 2, highest variables and %variance) Selected variables in stepwise LDA
1. Grape Cultivar		
All variables	68.0% (65.6%)	6 Functions (F1: Mg and K; F2: Na, 76.4%)
Stepwise LDA	55.4% (48.6%)	Mg, K
2. Island of precedence		
All variables	81.4% (79.2%)	5 Functions (F1: Mn; F2: Fe, 80.5%)
Stepwise LDA	79.8% (74.1%)	Mn, Fe, Mg, Na
3. Denomination of Origin		
All variables	66.7% (58.9%)	7 Functions (F1: Mg; F2: Mn, 73.0%)
Stepwise LDA	41.5% (40.4%)	Mg, Mn
4. Wine ageing		
All variables	80.6% (77.5%)	3 Functions (F1: Cu, Mg, Na; F2: Fe, Co, Mn, 95.0%)

 doi:10.20944/preprints202411.0270.v1

Stepwise LDA	76.3% (74.7%)	Fe, Cu, Co

When classifying red wines by grape cultivar, a relatively low classification rate of 68.0% was observed (65.6% after cross-validation). Mg, K, and Na emerged as the most significant minerals in this classification. However, stepwise LDA, which selected only Mg and K, resulted in lower classification accuracy. Conversely, classification by island demonstrated a much higher accuracy, reaching 81.4% (79.2% after cross-validation) when using all variables. Mn and Fe were identified as the most influential minerals for island classification. Even stepwise LDA performed well for island classification, achieving 79.8% (74.1% after cross-validation), with Mn, Fe, Mg, and Na as the key discriminating variables.

Using Denomination of Origin as a discriminant variable resulted in a more moderate classification accuracy of 66.7% (58.9% after cross-validation) when all variables were included. Mg and Mn were identified as the most important factors, suggesting that additional factors beyond mineral composition may influence Denomination of Origin classification. When wine aging was used as a discriminant variable, a high classification accuracy of 80.6% was achieved (77.5% after cross-validation). Three key functions dominated by Cu, Mg, Na, Fe, Co, and Mn contributed to this accuracy.

Table 5 presents the results of the LDA for classifying Canary wines according to island. The table shows the percentage of correct classification for each island, along with the misclassification rates for wines predicted to originate from other islands. The LDA aimed to assess how effectively the mineral composition of the wines could differentiate between the six islands, highlighting both successful classifications and instances of overlap or misclassification. These results provide insight into the distinctiveness of mineral profiles associated with each island's terroir, as well as the challenges in accurately classifying certain regions

Table 5. Percentage of correct classification in discriminant analysis by Island.

↓ Original	Predicted →	La Palma	Tenerife	El Hierro	Lanzarote	La Gomera	Gran Canaria
La Palma		**86.7**	6.7	0.0	0.0	0.0	6.7
Tenerife		0.8	**91.5**	0.8	0.8	1.5	4.6
El Hierro		0.0	53.3	**40.0**	6.7	0.0	0.0
Lanzarote		0.0	20.0	0.0	**80.0**	0.0	0.0
La Gomera		0.0	33.3	0.0	0.0	**66.7**	0.0
Gran Canaria		8.3	66.7	0.0	0.0	0.0	**25.0**

Table 6. Correlations among the mineral concentrations obtained in red wine.

	Fe	Cu	Co	Mn	K	Mg	Na
Fe	1	-0.106	0.307**	0.214**	0.045	0.088	0.235**
Cu		1	-0.126	-0.044	-0.105	-0.116	-0.027
Co	0.003		1	0.010	0.165	0.240*	0.266*
Mn	0.004			1	-0.0058	-0.058	-0.081
K					1	0.485**	0.184*
Mg			0.020		<0.001	1	0.457**
Na	0.001		0.010		0.013	<0.001	1

r values are exposed above the diagonal, while those below represent p-values. ** The correlation is significant at $p < 0.01$ (two-tailed); and * The correlation is significant between 0.01 and 0.05 (two-tailed).

Table 5 revealed varying levels of accuracy in classifying red wines based on their island of origin. Tenerife exhibited the highest classification success, with 91.5% of wines correctly identified. La Palma followed closely at 86.7%, and Lanzarote also performed well with 80% accuracy. However, classification accuracy was lower for El Hierro, La Gomera, and Gran Canaria. Notably, only 40% of wines from El Hierro were correctly classified, with a significant proportion (53.3%) mistakenly identified as originating from Tenerife. In fact, a majority of misclassified red wines from other islands were erroneously attributed to Tenerife.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

Figure 4 presents the results of the LDA performed to classify Canary red wines according to island. An overall correct classification rate of 81.4% was observed; and Figure 4 displays the LDA according to Denomination of Origin for the red wines samples from Tenerife. Focusing on Tenerife's distinct Denomination of Origin regions (Figure 5), the correct classification rate was slightly lower at 80%. These figures depict the separation of wines based on the first two discriminant functions, illustrating how well the wines cluster according to their origin.

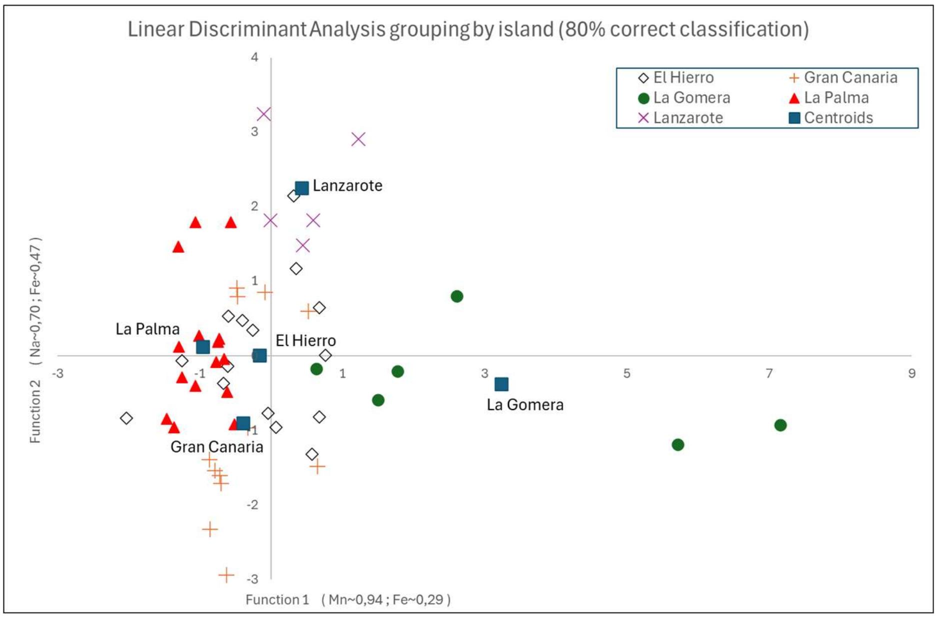

Figure 4. LDA function 1 and 2 for differentiating red wines according to precedence island (except Tenerife).

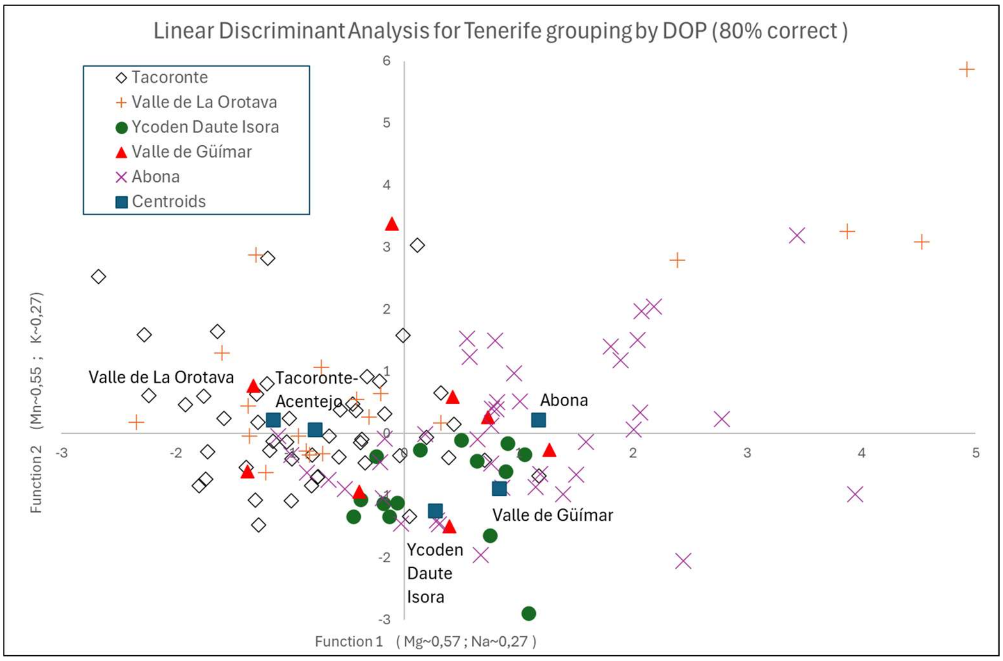

Figure 5. LDA functions 1 and 2 for differentiating Tenerife island wines according to Denomination of Origin.

Figure 4, which represents red wines from all the islands (except Tenerife): La Palma, El Hierro, Lanzarote, La Gomera, and Gran Canaria; it demonstrates the effectiveness of LDA in separating most islands. Lanzarote, La Gomera, La Palma, and El Hierro exhibit distinct clustering around their

 doi:10.20944/preprints202411.0270.v1

centroids, indicating strong separation with classification accuracies of 100%, 100%, 86.7%, and 86.7%, respectively. However, some overlap is observed in the samples from Gran Canaria (58.3%), suggesting different mineral profiles. The first discriminant function is primarily associated with Mn and Fe, while the second function is driven by Na and Fe, highlighting the importance of these elements in differentiating the wines by island.

Figure 5, which focuses on Tenerife's Denominations of Origin, demonstrates a similarly effective classification. The regions of Tacoronte-Acentejo and Valle de La Orotava are relatively well separated, while some overlap is observed between other regions like Ycoden Daute Isora and Abona. The first discriminant function is heavily influenced by Mg and Na, while the second function is driven by Mn and K.

4. Discussion

4.1. Overall Mineral Content

Compared to global averages for red wines, Canary Island wines exhibit distinctive characteristics, including generally higher concentrations and wider ranges. Notably, Canary red wines show elevated levels of K and Na, along with slightly higher average concentrations of Fe, Mn, Mg, and Co compared to most winemaking regions [26]. Previous studies have suggested that acidic soil pH may facilitate the absorption of microelements by grapevines, potentially contributing to the significant differences observed in some mineral compositions of Canary Island wines [27].

The sodium content from the wines analysed is unusually high, likely due to ocean winds affecting the coastal vineyards of the Canary Islands through marine spray, as it has been previously observed in other winemaking regions like Azores [27] or Mexico [28]. Canary Islands wines are normally described in tastings notes, but also in sensory studies, as mineral [29] and salty taste [30]. Previous researchers have related wine minerality with sodium content [31,32] or with a saline character [33]. Thus, this unusually elevated sodium content can, to some extent, be responsible for the traditional minerality perceived in many Canary Islands red wines. It would be useful to compare these values with sodium levels from vineyards in similar coastal regions to determine if this minerality is a distinctive feature of island terroirs.

The significant variability in K and Cu content may be attributed to their use as fertilizers in cultivation for some wine producers. Additionally, the use of fungicides containing Cu compounds during the growing season of vines, as well as its potential use in winemaking due to its deodorizing properties for mercaptans could also contribute to its presence in the final wine. It is notable that the coefficient of variation (CV) for Cu was abnormally high, reaching 220%, which was significantly greater than the CVs observed for the other minerals analysed (usually <50%). A relatively high Fe concentration is traditionally associated with prolonged contact between the wine and materials such as winemaking machinery, pipes, and casks used for handling and storage. However, modern wineries predominantly use stainless steel. Therefore, differences in Fe content might be related to the Canary Islands soils, as recent volcanic soils tend to contain higher levels of mineral elements such as iron, magnesium, and potassium [34].

Regarding legal limits, comparing the maximum observed values of certain minerals in Canary Island red wines to regulatory standards reveals potential compliance issues. Maximum wine limits vary significantly by country or export administration [35], often reflecting domestic production practices or trade barriers. While international standards exist, such as the OIV's maximum Cu concentration of 1 mg/l, 3.7% of our samples exceeded this limit. Additionally, 8.9% of samples had Mn levels above the Chinese normative of 2 mg/l. Cu excess may be attributed to the use of copper-based pesticides and deodorizers, while a correlation between fungicides and elevated Mn levels has been previously reported [36]. None of the samples surpassed the stringent Fe limit of 8 mg/l established by Chinese legislation. K limits vary significantly, with Mexico's import limit of 1700 mg/l exceeded by 23.7% of Canary Island red wines. Most of Canary Island red wines (58.4%) did not exceed the Chilean limit of Na (80 mg/l); however, all the Canary red wines could be commercialized in Quebec, Canada, due to its higher permitted limit of 500 mg/l.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

4.2.1. Cultivar

In general, the influence of the grape cultivar used in the elaboration of red wines was not remarkable, although there are some data that reveal interesting patterns in the mineral content across different vine cultivars. International cultivars introduced to the islands approximately 30 years ago, such as Merlot, Syrah, and Ruby Cabernet, tend to have higher sodium and magnesium concentrations than the traditional red grape cultivars. Traditional cultivars are planted ungrafted and on their own roots, having been present on the islands since the eighteenth century. This difference could be influenced by environmental factors, such as marine spray, which can increase sodium levels in vineyards located near coastal areas. Nevertheless, these international cultivars represent only a small proportion of the total wines (9%), primarily from Lanzarote Island, where, according to Table 2, marine spray has a more significant impact. This suggests that the higher sodium and magnesium levels may be a result of both the genetic predisposition of these international cultivars and their different adaptation to local environmental conditions.

Moreover, international cultivars are typically grafted onto commercial rootstocks, often hybrids or non-*Vitis vinifera* vines, while traditional Canary Island cultivars are planted on their own roots. The influence of vine rootstocks on the composition of wine is an emerging area of study [37]. Previous research has shown that rootstocks can significantly impact the Mg content in grape juice, as demonstrated in studies on Sauvignon Blanc wines [38].

Manganese levels are relatively consistent across the cultivars, with no cultivar displaying an extreme outlier in Mn concentration. In terms of Co, some international cultivars, such as Merlot and Ruby Cabernet exhibit slightly elevated levels compared to traditional cultivars. This could reflect differences in vine nutrient absorption due to their grafted rootstock, as mentioned earlier. However, the differences are not highly significant, given the generally low concentrations of this mineral in wine.

Potassium is an essential nutrient for vine growth and fruit ripening, but high concentrations of K in wine are often associated with a lower acidity, higher pH and potential wine instability [39]. Castellana cultivar samples shows a particularly high K concentration compared to the other cultivars. This grape cultivar also presents the lowest Fe content while Listán Prieto stands out with the highest concentrations of iron and Cu, both of which play key roles in the chemical stability of wines [40]. The mean Cu concentration exhibited minimal variation among the analysed monovarietal red wines, regardless of the grape cultivar used in their production, after excluding samples that exceeded established Cu maximum limits. This could be attributed to the possible use of Cu-containing fungicides or the addition of anti-mercaptan agents to the wine, as previously mentioned.

These findings suggest that varietal differences play a significant role in determining the mineral composition of wines, which in turn can influence the flavour, quality, and aging potential of the wines produced.

4.2.2. Island and Denomination of Origin

The mineral composition of red wines shows, in general, significant variability based on the island of origin, likely due to differences in the mineral content of the local soils (Table 2). Only K and Cu concentrations did not exhibit statistically significant differences among the mean values from the different islands, suggesting that these elements may be more uniformly distributed or could be influenced by other factors. It is important to note that the use of copper sulphate to combat downy mildew [41], that increase the Cu concentration in wines is a treatment less common in Lanzarote due to its special climatic conditions. Within Tenerife, the Orotava Valley stands out with significantly higher Cu concentrations, which could be due to such vineyard practices.

Wines from La Gomera exhibited significantly higher mean Mn concentrations compared to other islands, while La Palma had the lowest Mn levels, which is in agreement with findings observed in other studies [25]. The influence of marine spray on Na levels is well-documented, and the elevated Na levels observed in red wines from other islands may be linked to the proximity of vineyards to the sea. The mean Na concentration in red wines from Lanzarote was notably higher than those mean

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

concentrations found in other islands. This could potentially be due to the island's low altitude and its exposure to marine aerosols.

Additionally, the mean Fe concentrations were higher in red wines from La Gomera and Lanzarote, which are among the oldest islands geologically, potentially contributing to the elevated Fe levels.

Mg and Co concentrations were relatively consistent among the wines from different islands, showing little variation according to the geographic origin. This suggests that the factors influencing Mg and Co uptake by grapevines may be more stable across regions, unlike minerals such as Fe and Mn, which are more variable. Only Lanzarote showed a slightly elevated Co concentration compared to the rest of the islands, but these differences were not statistically significant.

Analysing the mineral content in wines from Tenerife, as shown in Figure 1, it can be observed that the Denominations of Origin of Abona and Valle de Güímar, both located in the south of the island, along with Ycoden-Daute-Isora, which has vineyards on both the north and south sides, exhibit higher Mg content and lower Mn content ($p<0.05$) compared to the northern Denominations of Origin of Tacoronte-Acentejo and Valle de La Orotava

4.2.3. Ageing

Mineral composition does not seem to be significantly influenced by the ageing process or vintage; probably it is determined more by the vine's absorption from the soil and the geographical conditions. In fact, mineral studies focusing on vintage encourage the use of isotope ratio analysis rather than elemental analysis for more accurate vintage differentiation [13].

Some minerals, such as Cu and potassium K, exhibited slightly higher concentrations in young wines compared to medium-aged and old wines. This could be linked to precipitation processes that occur during ageing, as these elements are closely associated with wine stabilization. In fact, K ions have a propensity to form insoluble precipitates which remain adhered to the barrel or settle out in the bottle.

4.3. Correlations

Iron and Mn exhibit a positive correlation, showing a significant relationship between both mineral contents in the final wine. Although Co is a relatively minor mineral, it also shows a positive correlation with Fe. This could reflect a relationship in how these trace minerals are absorbed by the vine or the influence of soil composition.

Interestingly, neither Cu nor Mn showed significant correlations with the other minerals. In the case of Cu, this lack of association may be because of Cu is often introduced into wine through external treatments, such as fungicides, and is less dependent on the natural mineral composition of the soil or vine absorption.

Potassium and Mg positive correlation (Figure 2) is an interesting finding, as both K and Mg are essential for plant growth and play key roles in maintaining the acidity and stability of the red wine. In nutrient horticulture, the antagonism between these two minerals and sodium is well-documented, as cellular binding sites cannot easily distinguish between these cations [41]. However, no significant inverse correlation was observed in our study. This positive relationship might reflect the salt adaptation mechanisms developed by Canary Island vines, enabling them to thrive in challenging environmental conditions.

Magnesium, as a component of chlorophyll, is vital for photosynthesis and grape ripening, while K is a major nutrient for plants as it directly controls the opening and closing of stomata by regulating the water pressure in guard cells [42]. K and Na also display a moderate positive correlation, which could indicate a relationship between these elements in soils affected by external factors, such as salinity and the need to maintain osmotic pressure in the vine.

Sodium shows significant correlations with several minerals analysed, including Fe, Co, K, and Mg, suggesting that sodium content in wine could influence the vine's natural uptake of these elements from the soil. This Na content is likely linked to environmental factors, such as marine

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 November 2024 doi:10.20944/preprints202411.0270.v1

aerosols or soil salinity, particularly in vineyards located near coastal areas. Specifically, magnesium can help reduce the toxicity of sodium in plants, enabling better growth in saline environments [42].

4.4. Discriminant Analysis

The discriminant analysis results provide valuable insights into how mineral composition can differentiate Canary monovarietal red wines, particularly according to island and wine ageing. The high number of red wines correctly classified into their island of precedence suggests that specific minerals such as Mn and Fe are closely linked to the distinct terroirs of the different islands. This could be due to the variations in volcanic soils and microclimates. This highlights the importance of these minerals in reflecting the differential environmental conditions of each island. Similarly, the strong performance in classifying wines according to ageing stage indicates that Cu, Fe, and Co might be significant markers of the ageing process, which could be related to their involvement in redox reactions and stabilization during maturation as wine age.

On the other hand, the application of LDA to classify wines according to cultivar and Denomination of Origin was relatively low. The moderate accuracy in the classification of grape cultivar and Denomination of Origin suggest that these categories may not be as strongly defined by mineral content alone. The limited number of significant minerals (Mg and K) selected for classification of grape cultivars may not capture the full complexity of grape variety differences. Other factors such as winemaking practices and environmental conditions could be influencing the mineral contents. Similarly, the lower classification rates for Denomination of Origin indicate that while some minerals are important, other regional factors play a larger role for defining the differences of red wines within a given Denomination of Origin. Overall, these findings highlight the complex interplay between environmental, biological, and production factors in Canary red wines and suggest that mineral composition is a strong, but not exclusive, marker for classification, particularly in the context of cultivar and Denomination of Origin differentiation.

The results of the discriminant analysis reveal clear patterns of mineral composition that help differentiate monovarietal red wines according to precedence island, but also indicate overlaps between certain regions. The high classification rates for Tenerife, La Palma, and Lanzarote suggest that the red wines from these islands have distinct mineral profiles that set them apart from those of other islands. This is likely due to the unique volcanic soils and microclimates present on these islands, which contribute to more differentiated mineral compositions in their red wines. As seen in Figure 3, the X-axis, representing Mn, allows the significant separation of La Gomera from most of the other islands, while the Y-axis, mainly influenced by Na, plays an important role in separating Lanzarote from the rest of the Canary Islands.

However, the high misclassification rates for wines from El Hierro and Gran Canaria highlight challenges in distinguishing wines from these islands. Both islands' low correct classification rates, with most wines being misclassified as Tenerife wines, suggest that their wines may lack sufficiently distinct mineral markers to be easily differentiated from those of Tenerife.

The results shown on the X-axis in Figure 4 illustrate how Mg and Na concentrations may allow the differentiation between red wines from the southern side of Tenerife (Denomination of Origin Abona and Valle de Güímar) and those from the northern side of the island (Denomination of Origin Tacoronte-Acentejo and Valle de La Orotava). Denomination of Origin Ycoden-Daute-Isora is positioned closer to the axis, likely because its vineyards span both sides of the island. The Mn and K concentrations on the Y-axis further help classify the wines, as those from Valle de Güímar and Ycoden-Daute-Isora exhibit lower concentrations of these minerals.

Overall, LDA demonstrates a strong ability to classify red wines analysed according to their geographical origin, particularly for islands like Tenerife, La Palma, and Lanzarote. Our findings highlight the complexity of Canary Island terroirs and their influence on wine composition. While mineral content serves as a powerful differentiator, the interaction of various environmental and production factors likely plays an equally important role in defining the differential characteristics of wines from this volcanic region.

 doi:10.20944/preprints202411.0270.v1

5. Conclusions

This study demonstrates significant differentiation in the mineral composition of Canary Island red wines by island and Denomination of Origin. Notably, Tenerife wines exhibited substantial variability in mineral content, attributed to its five distinct Denominations of Origin with varying terroir characteristics. Lanzarote wines were distinguished by higher sodium content, likely due to coastal exposure to marine aerosols, which supports the differentiation of these wines from other islands. Meanwhile, La Gomera wines presented significantly elevated manganese levels compared to other islands, and El Hierro wines showed higher average concentrations of magnesium. Such regional distinctions underscore the influence of volcanic soils and microclimatic factors across the islands, reinforcing the potential of mineral profiling for site differentiation among Canary wines.

In this study, we aimed to shed light on the mineral composition of Canary red wines and its potential as an authenticity marker. However, several limitations warrant consideration. The influence of factors such as the acidic pH of volcanic soils, the presence of ocean currents, and the possible accumulation of copper due to pesticide use were posited as influencing elements on mineral content but were not empirically tested. Furthermore, the effects of specific cultivars on mineral uptake remain speculative and require targeted analysis. Future research could systematically investigate these factors through controlled experiments to verify their impact on mineral composition in the context of volcanic terroirs. Expanding the study to include comparisons with other island and coastal terroirs could also offer a deeper understanding of environmental influences. Lastly, additional studies on white and rosé wines may provide a broader foundation for using mineral profiling as a tool for wine authentication across diverse wine types

This study highlights the significant role that mineral composition plays for distinguishing monovarietal red wines according to their geographical origin, Denomination of Origin, cultivar, and wine ageing. Mn, Mg, Na, and Fe, were found to be critical markers of island volcanic terroirs. The clear differentiation observed between islands, especially Tenerife, La Palma, and Lanzarote, underscores the differential impact of volcanic soils and microclimates on mineral composition. In spite of some overlap, particularly in islands like El Hierro and Gran Canaria, the discriminant analysis demonstrated the potential for using mineral content as a reliable tool for classification according to Denomination of Origin. Furthermore, wine ageing was associated with Cu and Fe concentrations, while the analysis of red wines according to grape cultivars revealed that international grape cultivars displayed slightly different mineral profiles compared to traditional ungrafted cultivars. These findings contribute to a deeper understanding of how environmental and viticultural factors interact to shape the differential characteristics of wines from volcanic regions as the Canary Islands. This research supports the ongoing use of mineral profiling as an effective, low cost-efficient method for ensuring the authenticity and traceability of wines in the global marketplace.

Author Contributions: Conceptualization, J.Darias-Martin and C.Díaz-Romero.; methodology and formal analysis, J.Heras-Roger; data curation C.Díaz-Romero, J.Darias-Rosales and J.Heras Roger; writing—original draft preparation, J.Heras-Roger.; writing—review and editing, C.Díaz-Romero..; supervision, J.Darias-Martín. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Data Availability Statement: Data is unavailable due to the winemakers and cellar privacy.

Acknowledgments: We acknowledge Canary Island wineries for their support with the samples

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Waterhouse, A.L.; Sacks, G.L.; Jeffery, D.W. *Understanding wine chemistry*, John Wiley & Sons: 2024;.
2. Shimizu, H.; Akamatsu, F.; Kamada, A.; Koyama, K.; Iwashita, K.; Goto-Yamamoto, N. Variation in the mineral composition of wine produced using different winemaking techniques. *Journal of bioscience and bioengineering* **2020**, *130*, 166–172.
3. Suhaj, M.; Korenovska, M. Application of elemental analysis for identification of wine origin: a review. *Acta Aliment* **2005**, *34*, 393–401.

 doi:10.20944/preprints202411.0270.v1

4. Su, Y.; Zhao, Y.; Cui, K.; Wang, F.; Zhang, J.; Zhang, A. Wine characterisation according to geographical origin using analysis of mineral elements and rainfall correlation of oxygen isotope values. *Int J Food Sci Tech* **2022**, *57*, 552–565.
5. Giaccio, M.; Vicentini, A. Determination of the geographical origin of wines by means of the mineral content and the stable isotope ratios: A review. *J.Commod.Sci.Technol.Qual* **2008**, *47*, 267–284.
6. Arvanitoyannis, I.S. Wine authenticity and traceability. In *Managing Wine Quality*Elsevier: 2022; pp. 279–338.
7. Master, O.; Patronage, O. Compendium of International Methods of Wine and Must Analysis. *International Organisation of Vine and Wine* **2024**.
8. Del Signore, A. Environmental discrimination of wines using the content of lithium, potassium and rubidium. *Journal of Trace Elements in Medicine and Biology* **2003**, *17*, 57.
9. Geana, I.; Iordache, A.; Ionete, R.; Marinescu, A.; Ranca, A.; Culea, M. Geographical origin identification of Romanian wines by ICP-MS elemental analysis. *Food Chem* **2013**, *138*, 1125–1134.
10. Đurđić, S.; Pantelić, M.; Trifković, J.; Vukojević, V.; Natić, M.; Tešić, Ž; Mutić, J. Elemental composition as a tool for the assessment of type, seasonal variability, and geographical origin of wine and its contribution to daily elemental intake. *RSC advances* **2017**, *7*, 2151–2162.
11. Rodrigues, N.P.; Rodrigues, E.; Celso, P.G.; Kahmann, A.; Yamashita, G.H.; Anzanello, M.J.; Manfroi, V.; Hertz, P.F. Discrimination of sparkling wines samples according to the country of origin by ICP-OES coupled with multivariate analysis. *LWT* **2020**, *131*, 109760.
12. Martin, A.E.; Watling, R.J.; Lee, G.S. The multi-element determination and regional discrimination of Australian wines. *Food Chem* **2012**, *133*, 1081–1089.
13. Popîrdă, A.; Luchian, C.E.; Cotea, V.V.; Colibaba, L.C.; Scutarașu, E.C.; Toader, A.M. A review of representative methods used in wine authentication. *Agriculture* **2021**, *11*, 225.
14. González, G.; Peña-Méndez, E.M. Multivariate data analysis in classification of must and wine from chemical measurements. *European Food Research and Technology* **2000**, *212*, 100–107.
15. Frías, S.; Conde, J.E.; Rodríguez, M.A.; Dohnal, V.; Pérez-Trujillo, J.P. Metallic content of wines from the Canary Islands (Spain). Application of artificial neural networks to the data analysis. *Food/Nahrung* **2002**, *46*, 370–375.
16. Frías, S.; Conde, J.E.; Rodríguez-Bencomo, J.J.; García-Montelongo, F.; Pérez-Trujillo, J.P. Classification of commercial wines from the Canary Islands (Spain) by chemometric techniques using metallic contents. *Talanta* **2003**, *59*, 335–344.
17. Díaz, C.; Conde, J.E.; Estévez, D.; Pérez Olivero, S.J.; Pérez Trujillo, J.P. Application of multivariate analysis and artificial neural networks for the differentiation of red wines from the Canary Islands according to the island of origin. *J Agric Food Chem* **2003**, *51*, 4303–4307.
18. Conde, J.E.; Estevez, D.; Rodriguez-Bencomo, J.J.; García Montelongo, F.J.; Perez-Trujillo, J.P. Characterization of bottled wines from the Tenerife Island (Spain) by their metal ion concentration. *Ital J Food Sci* **2002**, *14*, 375–387.
19. Perez Trujillo, J.P.; Pérez Pont, M.L.; Conde González, J.E. Content of mineral ions in wines from Canary Islands (Spain) Contenido de iones minerales en vinos de las islas canarias (España). *CyTA-Journal of Food* **2011**, *9*, 135–140.
20. Frias, S.; Pérez Trujillo, J.; Peña, E.; Conde, J.E. Classification and differentiation of bottled sweet wines of Canary Islands (Spain) by their metallic content. *European Food Research and Technology* **2001**, *213*, 145–149.
21. Pérez-Trujillo, J.; Barbaste, M.; Medina, B. Chemometric study of bottled wines with denomination of origin from the Canary Islands (Spain) based on ultra-trace elemental content determined by ICP-MS. *Anal Lett* **2003**, *36*, 679–697.
22. Barbaste, M.; Medina, B.; Sarabia, L.; Ortiz, M.C.; Pérez-Trujillo, J.P. Analysis and comparison of SIMCA models for denominations of origin of wines from de Canary Islands (Spain) builds by means of their trace and ultratrace metals content. *Anal Chim Acta* **2002**, *472*, 161–174.
23. Perez-Trujillo, J.; Barbaste, M.; Medina, B. Contents of trace and ultratrace elements in wines from the Canary Islands (Spain) as determined by ICP-MS. *Journal of Wine Research* **2002**, *13*, 243–256.
24. Moreno, I.M.; González-Weller, D.; Gutierrez, V.; Marino, M.; Cameán, A.M.; González, A.G.; Hardisson, A. Differentiation of two Canary DO red wines according to their metal content from inductively coupled plasma optical emission spectrometry and graphite furnace atomic absorption spectrometry by using Probabilistic Neural Networks. *Talanta* **2007**, *72*, 263–268.
25. Alonso Gonzalez, P.; Parga-Dans, E.; Arribas Blázquez, P.; Pérez Luzardo, O.; Zumbado Peña, M.L.; Hernández González, M.M.; Rodríguez-Hernández, Á; Andújar, C. Elemental composition, rare earths and minority elements in organic and conventional wines from volcanic areas: The Canary Islands (Spain). *PLoS One* **2021**, *16*, e0258739.
26. Pohl, P. What do metals tell us about wine? *TrAC Trends in Analytical Chemistry* **2007**, *26*, 941–949.

 doi:10.20944/preprints202411.0270.v1

27. de Lima, M.T.R.; Cabanis, M.; Cassanas, G.; Matos, L.; Pinheiro, J.; Cabanis, J.; Blaise, A. Volcanic soils composition impact on the major mineral elements content of grapes and wines. *OENO One* **2003**, *37*, 171–179.
28. Cruz, T.L.E.; Esperanza, M.G.; Wrobel, K.; Barrientos, E.Y.; Aguilar, F.J.A.; Wrobel, K. Determination of major and minor elements in Mexican red wines by microwave-induced plasma optical emission spectrometry, evaluating different calibration methods and exploring potential of the obtained data in the assessment of wine provenance. *Spectrochimica Acta Part B: Atomic Spectroscopy* **2020**, *164*, 105754.
29. Alonso González, P.; Parga Dans, E.; Hernández González, M.M.; Arribas Blázquez, P.; Acosta Dacal, A.C.; Pérez Luzardo, O. Unveiling terroir: evaluating the magnitude of the heterogeneity and its main drivers in the Canary Islands wines. *Cogent Food & Agriculture* **2024**, *10*, 2334997.
30. Afonso, V.L.G.; Darias, J.; Armas, R.; Medina, M.R.; Diaz, M.E. Descriptive analysis of three white wine varieties cultivated in the Canary Islands. *Am J Enol Vitic* **1998**, *49*, 440–444.
31. Parr, W.V.; Maltman, A.J.; Easton, S.; Ballester, J. Minerality in wine: Towards the reality behind the myths. *Beverages* **2018**, *4*, 77.
32. Parr, W.V.; Valentin, D.; Breitmeyer, J.; Peyron, D.; Darriet, P.; Sherlock, R.; Robinson, B.; Grose, C.; Ballester, J. Perceived minerality in sauvignon blanc wine: Chemical reality or cultural construct? *Food Res Int* **2016**, *87*, 168–179.
33. Zaldívar Santamaría, E.; Molina Dagá, D.; Palacios García, A.T. The Influence of the bottle's price and label reported information on the perception of the minerality attribute in white wines. *Beverages* **2022**, *8*, 42.
34. Dahlgren, R.A.; Saigusa, M.; Ugolini, F.C. The nature, properties and management of volcanic soils. *Adv Agron* **2004**, *82*, 113–182.
35. Stockley, C.S. Analytical specifications for the export of Australian wine: a list of analysis requirements and specifications for Australian wine export destinations, Australian Wine Research Institute: 2001;.
36. La Pera, L.; Dugo, G.; Rando, R.; Di Bella, G.; Maisano, R.; Salvo, F. Statistical study of the influence of fungicide treatments (mancozeb, zoxamide and copper oxychloride) on heavy metal concentrations in Sicilian red wine. *Food Addit Contam* **2008**, *25*, 302–313.
37. Chen, Y.; Liang, Z.; Krstic, M.; Clingeleffer, P.; Howell, K.; Chen, D.; Zhang, P. The Influences of Rootstock on the Performance of Pinot Noir (Vitis vinifera L.): Berry and Wine Composition. *Australian Journal of Grape and Wine Research* **2024**, *2024*, 7586202.
38. Pulko, B.; Vršič, S.; Valdhuber, J. Influence of Various Rootstocks on the Yield and Grape Composition of Sauvignon Blanc. *Czech Journal of Food Sciences* **2012**, *30*.
39. Dabare, P.R.; Reilly, T.; Mierczynski, P.; Bindon, K.; Vasilev, K.; Mierczynska-Vasilev, A. A novel solution to tartrate instability in white wines. *Food Chem* **2023**, *422*, 136159.
40. Cacho, J.; Castells, J.E.; Esteban, A.; Laguna, B.; Sagristá, N. Iron, copper, and manganese influence on wine oxidation. *Am J Enol Vitic* **1995**, *46*, 380–384.
41. Weitbrecht, K.; Schwab, S.; Rupp, C.; Bieler, E.; Dürrenberger, M.; Bleyer, G.; Schumacher, S.; Kassemeyer, H.; Fuchs, R.; Schlücker, E. Microencapsulation–An innovative technique to improve the fungicide efficacy of copper against grapevine downy mildew. *Crop Protection* **2021**, *139*, 105382.
42. Parida, A.K.; Das, A.B. Salt tolerance and salinity effects on plants: a review. *Ecotoxicol Environ Saf* **2005**, *60*, 324–349.