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Chapter 12

Characterization of Red Wines from Macaronesia

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Additional information is available at the end of the chapter

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Abstract

Wines from the Atlantic Islands of Macaronesia come from unusual *terroirs* due to their volcanic soils and the tropical and subtropical climatic conditions from this region. Some of these Islands produce highly appreciated fortified wines traded around the world since the sixteenth century, such as Madeira or Canary. Nowadays their distinct winemaking techniques and sweet wine traditions combine with the production of table wines. Previous studies described peculiar properties in wines from these regions, mostly related with their phenolic content and color, which are particularly important in the less produced red wines. The main purpose of this chapter is to characterize red wines produced in the Atlantic Islands of Macaronesia in terms of oenological and physicochemical properties. Wines from these islands are extremely atypical, as their climates conditions are exceptional and red grape cultivars are exclusive. Furthermore, specific viticulture techniques are applied in these latitudes to proportionate the unique characteristics outlined in this work. Original experimental data from 300 red wines produced in 8 Atlantic islands from Canary and Cape Verde archipelago and an important reviewing study for Azores and Madeira red wines are considered herein. Results are presented according to archipelago.

Keywords: Macaronesia, red wine, characterization, grape varieties, Canary Islands, Cape Verde Islands

1. Introduction

Macaronesia is a collection of four archipelagos located in the North Atlantic Ocean, in front of the coast of Europe and Africa (see **Figure 1**). The Macaronesian archipelagos from North to South are Azores and Madeira (Portugal), Canary Islands (Spain) and Cape Verde. All the Islands of Macaronesia are volcanic and none of them were part of a continent, so their native plants reached the islands via geographical dispersal but many are endemic [1].

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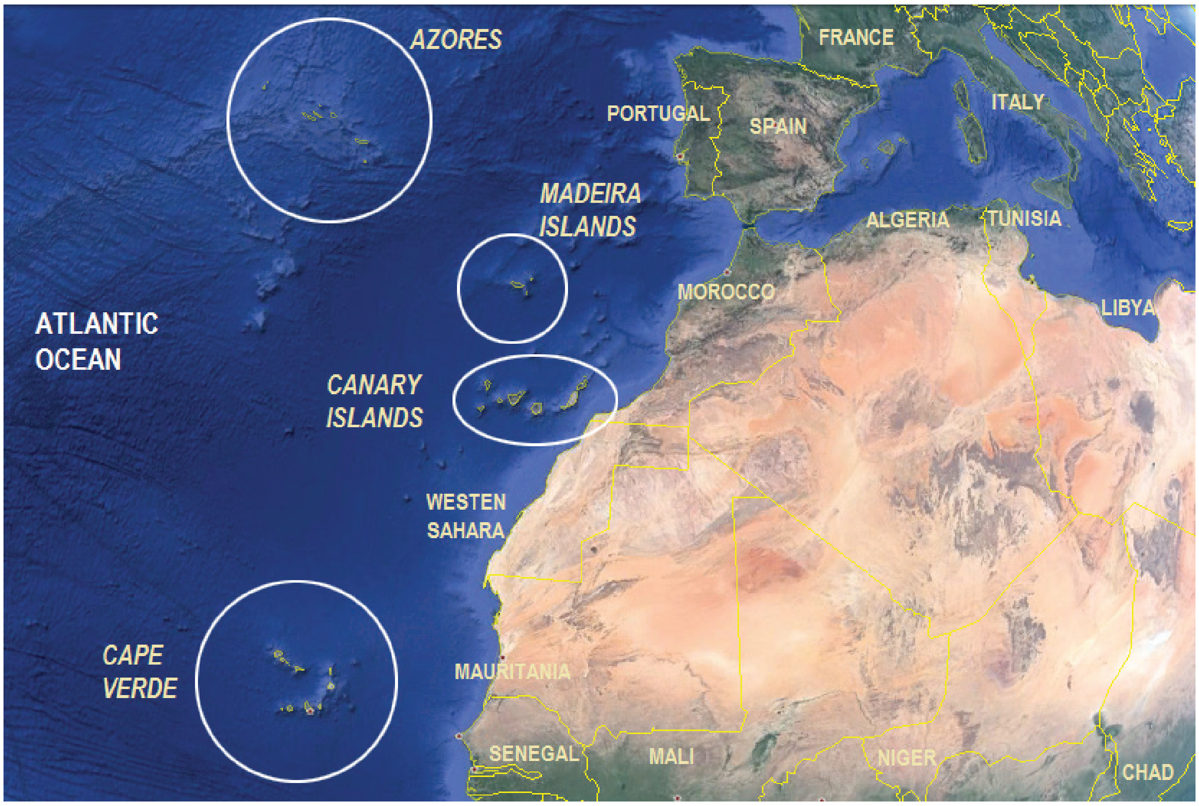

Figure 1. Geographical situation of Macaronesian archipelagos.

Volcanic soils are usually related with highly appreciated wines, as many traditional winemaking regions highlight their volcanic origins like Tokaj in Hungary, Struma valley in Bulgaria, Santorini in Greece or Sicilia in Italy. Nevertheless peculiarities from Macaronesia wines come not exclusively from their volcanic origin, but mostly from their specific *terroirs*. These islands present unusual geographical conditions in terms of soil and location but also atypical traditions and extremely particular microclimates. The climate from these archipelagos ranges from Mediterranean in the Azores and Madeira to arid in some islands of the Canaries (Lanzarote and Fuerteventura) and Cape Verde (Sal and Maio), subtropical in some Canary Islands (Tenerife, La Palma and El Hierro) or even tropical in the case of Fogo in Cape Verde. In general, Portuguese archipelagos enjoy a cooler climate and higher rainfall than Canary Islands and Cape Verde with warmer winters and irregular rainfalls.

Winemaking grapes were introduced in the Macaronesian archipelagos hundreds of years ago by the first Portuguese and Spanish inhabitants. Their volcanic soils are mineral rich and relatively fertile, so it is possible to naturally obtain wines with high acidity. This peculiarity makes most of these islands well suited to elaborate fortified and white wines. Moreover wines from these areas benefit from an acid/sugar balance not easily achieved in other regions. Traditional grape cultivars used in Macaronesia are characterized by a high potential alcoholic content and a valuable acidity ideal to produce fortified wines [2].

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Macaronesia archipelagos are similar because of their volcanic origin and oceanic influences but very different between themselves. There is also high contrast inside the archipelagos. Azores, Madeira Island or west Canary Islands (La Palma and El Hierro) are extremely mountainous, with deep valleys and steep slopes where the vines grow on little terraces rich in organic matter. Nevertheless there are also plain arid islands like Porto Santo in Madeira or the east Canary Islands (Fuerteventura and Lanzarote) where grape cultivation is highly adapted. An exceptional climatic contrast is present in Tenerife (Canary Islands), Pico (Azores) and Fogo (Cape Verde), which are the most important wine producers in their, respectively, archipelagos and also islands characterized by steep volcanoes. The fertile terraces from each of these islands volcanoes permit to cultivate quality winemaking grapes from near to the see, as in Pico or Fuerteventura, to very high altitudes with an important day/night temperature contrast as in Tenerife or Fogo.

Macaronesia climatic conditions combined with rugged terrain, the potential for volcanic activity, extreme winds, difficulties for mechanical harvesting and inconveniences derived from fungal attacks do not exactly add up to the most ideal winemaking environment. Moreover vines need warm and dry condition combined with regular winters to grow well, but in these areas humidity from the ocean is constant and winters are extremely mild, therefore grape cultivars have adapted and only pursued the less sensible to fungal diseases.

Red wine is produced nowadays in all Macaronesian archipelagos with several varieties. Most of the production is quality wine bottled by firms with certified origin protection figures, as *DOP* or *Vinho Regional*. Nevertheless, there are also artisanal productions for self-consumption through all the productive islands. The peculiarities from these regions in terms of volcanic soil, hours of sun, humidity and climatic conditions proportionate specific attributes to the red wines produced. This research is particularly original as the vast majority of quality winemaking regions lay between 30 and 50° latitude and there are only a few subtropical and tropical winemaking regions producing red wines. Macaronesian wines have been previously researched, but results are rarely compared.

2. Red wine production in Macaronesia

Macaronesian archipelagos have a long winemaking tradition associated with fortified and white wines, thus these wines are the most studied [3–10]. Furthermore the production of red wine in Macaronesia is uneven. While some islands have a long winemaking history related to fortified wines and started red winemaking just some years ago, other islands produce red wines protected by European quality figures such as DOP for decades now. Moreover some regions export red wine to international markets whereas in other areas it is only produced artisanally for self-consumption. This section briefly presents the most important conditions associated with wine production and the current red winemaking state-of-the-art in each one of the Macaronesian archipelagos from North to South. In general, these regions present relatively mild winters with irregular rainfalls, therefore viticulture has been adapted to adequately handle the sprout of the vine.

2.1. Azores

The archipelago of Azores is an autonomous region of Portugal located on a line between Lisbon and New Jersey, about 1400 km west of Portugal and about 1925 km southeast of Canada. All islands have high mountains, being mount Pico, on the island of Pico, the highest point in Portugal at 2351 m. All populated islands show conditions to elaborate quality wines, but most of the production is found in the islands of Pico, Graciosa and Terceira in the center group and São Miguel in the east group.

The climate of the Azores is mild and moist all year, as it is influenced by the distance to continents and the passing Gulf Stream. Due to the marine influence, temperatures remain mild year-round being climate generally wet and cloudy. The archipelago's mid-Atlantic location means that the greatest threats to the grapes are wind and sea water, not harsh temperatures. Wind effects have been traditionally solved by building peculiar stonewalls of volcanic rocks around the vines; these walls give protection from ocean winds and radiate heat at night. Humidity and cloudy consequences are controlled continuously evaluating the risk of fungal attack [11].

Azores winemaking history starts soon after the settlement of Portuguese conquerors in the mid-fifteenth century. Winemaking traditions from this area are related to fortified wine styles, as it might be expected from a region with its oceanic mild climate. Azores fortified wine resembles Porto and Madeira wines, but its production is characterized by the vines present in the island and the distance from the continent. Azores was affected by the *phylloxera* [12].

There are no *DOP* regions in this archipelago but there are three *IPR* regions: Pico, Biscoitos and Graciosa. Pico and Biscoitos traditionally produced fortified wines but today the three regions are mostly focused on unfortified white wines. Red wine has no tradition, as the cool oceanic climate lend to produce white wines with an adequate natural acidity. Nevertheless red wines are produced as table wines classified as *Açores Vinho Regional* using European well-known cultivars as Syrah, Merlot and Cabernet Sauvignon but also Touriga Nacional, Castelão and Complexa.

2.2. Madeira

The archipelago of Madeira is an autonomous region of Portugal located about 1000 km southwest of Portugal, and about 400 km north of the Canary Islands. In Madeira and Porto Santo Islands, grapes are cultivated to elaborate quality wines. The terrain of the mountainous volcanic island of Madeira is difficult to cultivate and vineyards are planted on terraces of basaltic bedrock. Their climate is oceanic with tropical influences, such as high rainfall. The archipelago enjoys mild temperatures strongly influenced by the ocean throughout the year.

The islands of Madeira have a long winemaking history. Madeira is internationally famous for the eponymous fortified wine produced there and extensively researched [6, 13]. As in most European countries, the *phylloxera* reached the island by the nineteenth century and Madeira vines were hardly affected. Their climatic conditions also mean constant viticulture hazards related to fungal grape diseases.

Not fortified wines production in Madeira have been relatively rare, but in the last decades these volcanic and fertile lands produced red wines that break the traditional fortified wine image of the industry from this region. These wines are labeled as *Terras Madeirenses*, a Portuguese wine region for both islands classified as *Vinho Regional* or table wines for non-fortified wines. The most used red cultivar is Tinta Negra Mole (also known as Negramoll or Mulata), but Bastardo (also known as Trousseau or Maturana Tinta), Complexa and Touriga Nacional are also present in red wine blendings. Some winemakers introduce international varieties such as Cabernet Sauvignon or Merlot.

2.3. Canary Islands

The archipelago of Canary Islands is an autonomous community of Spain located about 100 km west of Africa. Red wine is produced in all the islands with European figures of protection, as the archipelago counts with 10 *DOP*. The largest of the archipelago's islands, Tenerife, is the only island with more than one *DOP* and also home to the majority of the region's production, particularly for export, but most Canary table wines are present in their local markets. These islands are the largest and most populated archipelago of Macaronesia.

These islands have a subtropical climate with long hot summers and moderately warm winters. The absence of low temperatures during winter involves problems for the sprout of the vine, as cold hours are usually not enough to obtain a regular vine cycle. Therefore grape ripening can be extremely irregular even for the same vine plant depending on the microclimate. Moreover precipitation levels and maritime influences are highly dependent on location and elevation. Thus completely fertile green areas with high humidity as well as deserts can be found on the same archipelago and sometimes even in the same island.

Wine-growing in this fertile islands dates back to the Spanish conquest in the fifteenth century. Tenerife was the most important centre of "*Malmsey*" (*Malvasia*) production in the past with a strong reputation for fortified white wines as well as other Macaronesian regions. White sweet wines from these islands were greatly appreciated in England and the States during the sixteenth century, being known as "*Canary*". Rivalry between kingdoms restrained their commerce in the eighteenth century and red winemaking grapes were then introduced to elaborate similar products to Madeira fortified wines, being this fact the first step toward the red winemaking tradition from Tenerife [14].

Canary Islands grape producers' adapted viticulture to their own specific conditions. For instance, in the arid and windy Lanzarote *DOP*, they found an indigenous way of cultivating vines on the arid ground known as *"gerias"*. This grape production system consists on funnel-shaped hollows dug into thick layers of coarse volcanic ashes with only one vine per hollow. Hollows are filled with soil and poured thick layers of volcanic ashes over it, as the porous volcanic granules known as *"picón"* retain the night humidity to feed the plants during the day and concentrates heat at night. Furthermore producers built low semicircular walls around vines to protect them from the constant winds. Another example can be found in *"La Orotava" DOP* with a unique system of vine training called *"cordón trenzado"*, literally meaning braided or plaited cord. This method of vine training evolved as a result of constraints on the areas used for cultivation as the island present limited space. Traditionally, this vine training method allowed the braids to be easily moved and thus allow the soil below them to be used for growing additional crops.

In general vines from Canary Islands are old when compared to other winemaking regions as the *phylloxera* never reached the archipelago. Most vines are not planted on rootstocks but directly on the ground and draw water solely from the terrain as usually they are not irrigated. Mechanical harvesting is impossible given the specific methods of vine training and the small pieces of land. Vineyards are fragmented and can be found near the coast or at elevated altitudes. Most vineyards are planted on the gentle lower slopes of the mountains present where humid mists created by the winds moderate the hot maritime climate.

Red winemaking is important in the Canary Islands but some islands traditionally produce more than others. Most of these red wines are fresh and young because of the natural acidity balance of their soils but some regions are also specialized in oak-aged red wines. These red wines are usually elaborated with indigenous grapes present for centuries in the islands, but international grape varieties (Syrah, Merlot and Cabernet) can also be used. The most widespread red grape cultivar is Listán Negro (also known as Almuñeco), a variety well suited to Beaujolais-like wine style made using carbonic maceration. The workhorse grape of Madeira Tinta Negra is also present in Canary Islands known as Negramoll. The varietal richness of these islands is amazingly high, as many other red grapes can be found exclusively vinified by some winemakers, such as Tintilla, Bastardo (also known as Trousseau), Baboso (also known as Alfrocheiro or Tinta Preta in Cape Verde), Listán Prieto (also known as Mission Grape in the United States of America), Vijariego Negro or Castellana among others. Not just the grapes from ungrafted and often extremely senior vines make Canary red wines atypical. The combination of little-known grapes, high-elevation vineyards and volcanic soils made these red wines distinctive.

Red wine is produced in the 10 *DOP*. Tenerife houses half of the region's *DOP* with Abona, Tacoronte-Acentejo, Valle de Guimar, Valle de la Orotava and Ycoden-Daute-Isora. The remaining designations cover other islands in their entirety such as El Hierro, Gran Canaria, La Gomera, La Palma and Lanzarote *DOP*s. There is also a general *DOP* including all islands (also Fuerteventura). Each area has a unique microclimate and different soil composition, lending to distinctive wines with mineral notes. Some areas even present clear subzones inside the same *DOP*. For instance, only in the North area of La Palma Island a peculiar red wine called *"Vino de Tea"* is produced. These wines are sold straight from atypical barrels not made from oak but from *pinus canariensis.* These traditional red wines share organoleptical characters with Greek retsina wines, as their introduce pine in their winemaking techniques giving them a peculiar resin aroma.

2.4. Cape Verde

The archipelago of Cape Verde is a sovereign nation located about 650 km west of the coast of Africa and about 1300 km south of Canary Islands. Fogo is the only island producing grapes in sufficient quantity to elaborate quality wines because it registers the greatest precipitations. Fogo is characterized by its particular steep volcano covered with ash where vegetation and cultivation of the vine is extremely complicated.

As in the rest of Macaronesia, the culture of vines was started by the first settlers during the sixteenth century. Fogo wine was even exported to Guinea and Brazil during the eighteenth century. Wines from this area are mostly white as grapes cultivated there produce refreshing wines with pleasant mineral notes. There is also a strong tradition of fortified sweet wines locally known as *"Pasito"*, as the homonym wine from Italy. Red wines are not the most produced in the island but they can be easily found in restaurants and local markets even though they have no origin protection figure. In fact wine tourism is taking an important role in this island [15, 16].

The importance of latitude and altitude is one of the most relevant aspects when it comes to understanding the *terroir* from this region. Fogo is located much closer to the equator than most of the world's key wine-growing regions and its vineyards are generally more than 1500 m above sea level. These conditions temper the high temperatures and the heat associated with its latitude. Cooler nights delay grape ripening and sunlight absorbed by black soils during the day keeps the vines isolated at night. In this sense, climate cannot be strictly described as tropical. Due to its altitude and high irregular rainfall, it is possible to obtain quality wines, even with the possibility of a second harvest in the month of January given the natural vine cycle in this environment.

In Fogo, vine cultivation is not exclusive and is normally associated with other products such as corn or sweet potatoes. At the foot of the volcano is the wine-growing community of Chã das Caldeiras where most of the samples from this study come from. Chã is located at 1700 m altitude and characterized by small vineyards around the active volcano erupted several times recently (1995, 2000 and 2014). This area enjoys a microclimate with thermal amplitude, good rainfall and rich volcanic soils, being all these factors important for quality winemaking production using adequate viticulture practices [17]. Oidium is the only fungal disease detected and the *phyloxera* never reached Cape Verde.

A range of European grape varieties are cultivated in the Island. The most used red cultivar is Tinta Preta (also known as Baboso Negro, Bruñal or Alfrocheiro Preto), but also other red cultivars are present such as Castelão (also known as Periquita), Bastardo (also known as Trousseau or Maturana Tinta) and Moscatel Negro (also known as Black Hamburg).

Most of the samples from this study are red wines from the vineyards located around the caldera and produced by Chã das Caldeiras wine cooperative. These wines are mainly elaborated Tinta Preta and destined to early consumption without periods of guard. In addition to the bottled quality wines from Chã our study also consider sweet red wines produced artisanally from other vineyards situated on the volcanic soils inside the caldera. These wines are less representative, produced in small volumes and mostly destined for self-consumption soon after the fermentation. These traditional homemade wines are known as *"manecom"*. *"Manecoms"* can be both white or red but sweet red wines are the most popular and the only ones considered in our study. Although homemade, some of these wines are intended for both personal consumption and to be marketed in bulk.

In addition to Chã Caldeiras winery whose vineyards are in the caldera, there are other wineries in the island like Monte Barro or Achada Grand producing bottled red wines. Most probably these wines differ in the physico-chemical characteristics due to the differences in the vine cultivation area, related to both altitude (1700 m vs. 700 m) and rainfall.

3. Macaronesian red wine characterization

3.1. Material and methods

Experimental results from 300 red wines produced in Canary Islands and Fogo (Cape Verde) are described herein together with scientific literature from red wines produced in Azores and Madeira. The 250 samples from Canary Islands and 40 red wines from Fogo were bottled as quality wine destined to the regional market. The remaining 10 samples of red wine from Fogo were *"manecom"*; this means red wine elaborated for self-consumption.

Samples come from different harvest (2003–2014). Most analysis was performed using International Organisation of Vine and Wine (OIV) reference methods [18]. A phenolic and metallic profile was also obtained. Color characteristics using CIELab and magnitude of co-pigmentation are important in red wines and thus were analytically quantified. **Table 1** presents the methods applied with the uncertainty associated to each parameter. All data have been grouped and compared according to the archipelago of origin introducing similar data from published scientific works when available. Significant differences between islands from the same archipelago or even between regions from the same island have been previously detailed in the literature due to particular microclimates influences. Nevertheless differences inside archipelagos are not considered in the present chapter as they are not part of the aim of this study.

3.2. Oenological parameters

Results for the most important oenological parameters in red wines are summarized in **Table 1**. Canary wines are characterized by a great variability and heterogeneity, as these wines come from different harvest and are elaborated with different varietals in various

Wine characteristics	Canary (bottled with DOP)		Cape Verde/Fogo	
	(n = 250)	(n = 60) [19, 20]	Chã Caldeiras bottled (n = 40)	"Manecom" (n = 10)
Alcoholic content (%v/v)	13.72 ± 1.20 (11.00–19.54)	12.28 ± 0.60	15.58 ± 0.61 (14.70–17.66)	16.67 ± 0.87 (16.06–17.29)
Density (g/cm^3)	0.9941 ± 0.006 (0.9893–1.0513)	0.9922 ± 0.001	0.9896 ± 0.0116 (0.9370–0.9944)	1.0130 ± 0.0096 (1.0062–1.0198)
pH	3.74 ± 0.18 (3.23–4.54)	3.55 ± 0.17	3.99 ± 0.18 (3.46–4.23)	3.94 ± 0.02 (3.93–3.95)
Titrable acidity (g. tart./l)	5.16 ± 0.72 (3.93–7.59)	5.10 ± 0.54	4.95 ± 0.71 (4.15–6.62)	7.89 ± 1.61 (6.75–9.03)
Ethanal (mg/l)	16 ± 39 (n.d.–246)	30 ± 24	30 ± 45 (n.d.–150)	50 ± 65 (15–310)
Glucose + fructose (g/l)	1.90 ± 6.90 (n.d.–59.00)	1.95 ± 0.95	1.70 ± 2.21 (n.d.–5.9)	43.05 ± 31.75 (20.60–65.5)
Free SO_2 (mg/l)	16.0 ± 8.0 (5.0–48.0)	16.0 ± 9.0	24.4 ± 13.8 (7.0–47.0)	1.5 ± 0.71 (1.0–2.0)
Total SO_2 (mg/l)	78.0 ± 34.0 (11.0–184.0)	57.0 ± 32.0	83.4 ± 27.6 (26.0–129.0)	12.5 ± 3.5 (10.0–15.0)
Nitrogen ammonia (g/l)	38.0 ± 29.0 (n.d.–207.0)	–	27.6 ± 19.1 (10.3–59.8)	53.3 ± 20.4 (20.1–60.8)
Glycerol (g/l)	11.0 ± 2.9 (0.4–20.2)	–	7.6±0.3 (7.4–7.8)	8.0 ± 0.1 (7.8–8.2)
IPT DO 280 nm (UA)	52.7 ± 12.9 (14.6–103.1)	35.0 ± 5.6	68.3 ± 8.7 (56.7–89.3)	70.6 ± 16.2 (59.1–82.0)
Folin–Ciocalteu Index	50 ± 11 (27–83)	–	62 ± 15 (32–93)	32 ± 25 (15–76)
Total tannins (g/l)	2.00 ± 0.80 (0.20–4.40)	1.30 ± 0.40	4.78 ± 0.61 (3.97–6.25)	4.94 ± 1.13 (4.14–5.74)
Total anthocyanins (mg/l)	296.1 ± 178.8 (29.2–798.4)	108.2 ± 55.2	350 ± 202 (33.7–815.3)	123.1 ± 198.9 (12.2–489.5)

Results expressed as X ± σ (Min.–Max. value if available). n.d. = not detected.

Table 1. Conventional red wine parameters from Canary and Cape Verde islands.

islands. Most red wines considered were produced to be consumed in the short term, so they have typical young wines values in terms of phenolics. Nevertheless some samples present high potential for aging, as they are distinguished by high total phenol index (IPT).

All samples conformed to the established legal wine standards as far as analytical parameters are concerned. Canary Islands results are within the usual ranges and comparable to those published for the same geographic origin [19, 20], although pH is slightly higher than usual [21]. This can be due to their characteristic soils and warm climate conditions, as it have been previously demonstrated that wines produced in warm areas trend to present higher pHs than those produced in colder regions [22]. Moreover the tannin content is also higher than the values described for French vines [21], although this can be due to an over-quantification, since the method counts with limited specificity.

Most wines from Cape Verde present high ethanol content, probably due to the natural conditions affecting this archipelago and to late grape picking. The lowest ethanol content in Fogo attained 14.7%vol, higher than the average in Canary. *"Manecoms"* show an alcoholic graduation even higher than bottled wines, probably because Fogo inhabitants are used to wines with high alcoholic content.

Fogo wines also present unusual high pHs. These values lead to color losses in red wines due to anthocyanins chemical form and their greater oxidation [23]. High pH also reduces the protective action from SO_2. pH depends on various factors from soil, climate or grape ripening to winemaking techniques and the values observed might be due to regional characteristics, such as soil potassium content, climate and skins macerations. In this sense Fogo winemakers could diminish wine pH by reducing maceration periods, with earlier harvest or introducing specific rootstocks. The relationship between high pH in these wines and potassium content are further discussed in the metallic profile section.

The residual nitrogen ammonia for most *"manecoms"* samples is high in relation with conventional levels [21]. This nitrogen bioavailability leads to a greater ease of wine diseases increased by their high pH and low SO_2 protection. Nevertheless Fogo wines avoid many microbiological problems due to their high alcoholic content. In general, these wines contain low levels of ethanol, as most samples are not subjected to micro oxygenation. Their high pHs discourage winemakers to elaborate oak-aged wines, as color stability would be hardly affected by time [24]. Red wines from both archipelagos were also characterized by high glycerol values in agreement with their high alcohol content.

3.3. Acid profile

Wine acids are classified in two groups. The first one includes those whose concentrations evolve during grape ripening, such as tartaric, malic and citric acid. In the second group are those derived from fermentations such as lactic, acetic and succinic acid. Gluconic acid is out of this classification because of its fungal origin. These acids content is detailed on **Table 2**.

None bottled wine exceeds the legislated 1.2 g/l value for volatile acidity. Those presenting greater values correspond to sweet wines with greater limits. "*Manecoms*" show extremely high values due to their artisan winemaking. The initial malic acid content in wine depends on grape ripening, but its concentration drastically reduces after malolactic fermentation. This fermentation was completed in most red wines, even though some samples present high values above 4 g/l. These wines acid content is within the values considered normal [21], although some Canary wines present lactic acid contents above the average.

The very low gluconic acid in Fogo wines reveals none important fungal incidences, probably due to the extremely dry climatic conditions derived from latitude and altitude. Nevertheless

	Canary (bottled with DOP)		Cape Verde/Fogo		Madeira
	(n = 250)	(n = 60) [19]	Chã Bottled (n = 40)	*"Manecom"* (n = 10)	(n = 12) [25]
Tartaric acid (g/l)	2.50 ± 1.00 (1.10–4.90)	2.08 ± 0.42	1.60 ± 0.61 (1.20–2.30)	1.95 ± 0.92 (1.30–2.60)	1.97 ± 0.33 (1.50–2.73)
Lactic acid (g/l)	1.78 ± 1.00 (0.07–5.53)	–	2.40 ± 0.26 (2.20–2.70)	1.35 ± 1.39 (0.10–2.70)	–
Acetic acid (g/l)	0.60 ± 0.24 (0.15–1.53)	0.50 ± 0.14	0.81 ± 0.14 (0.53–1.19)	2.09 ± 1.56 (0.99–3.20)	–
L-malic acid (g/l)	0.38 ± 0.71 (n.d.–4.21)	0.24 ± 0.34	0.56 ± 1.11 (0.10–3.72)	0.27 ± 0.31 (0.05–0.50)	–
Gluconic acid (g/l)	0.36 ± 0.42 (n.d.–2.29)	–	0.05 ± 0.05 (n.d.–0.1)	0.02 ± 0.04 (n.d.–0.10)	–
Citric acid (mg/l)	140 ± 102 (n.d.–620)	–	70 ± 42 (n.d.–150)	30 ± 12 (n.d.–50)	445 ± 220 (141–707)

Results expressed as X ± σ (Min. – Max. value if available). n.d. = not detected.

Table 2. Red wine acid profile from canary, Cape Verde and Madeira islands.

grapes fungal attacks are common in Canary Islands according to our results. Madeira's citric acid content is unusually high and extremely low in Fogo. In Canary Islands, the citric acid content highly varies probably due to the different elaborations considered.

3.4. Metallic content

Some scientist previously addressed wine metallic differentiation depending on the Canary Island of origin [26–28] and studied the content from Azores and Madeira wines [29]. Differences between *DOP* and islands are in some cases highly significant. The cited references are useful to study these specific profiles but this is not our aim, as it introduces other considerations. **Table 3** resumes experimental data and average results from literature.

The metallic content conforms to commercial standards though potassium concentration is slightly higher than values previously reported [30]. Its source in wine is diverse; on one hand the addition of potassium during winemaking can increase it, but soil content due to other crops enrichment or fertilizers is also relevant. However, soil characteristics considered alone cannot explain its high content. It can be also increased by winemaking techniques, such as excessive macerations with grape skins for instance. Most probably its concentration is related to the grapevine needs, as in warm, dry and windy climates vine plants need more water as it is constantly evaporating from their leaves. Therefore grapevines breathe intensively in order to absorb soil water in a greater extent than those plants located in cold or humid climates. Greater water absorption contributes to a greater mineral absorption. Thus in warm climates plants absorb more water and by addition more potassium, concentrating

	Canary (bottled with DOP)		Fogo Chã (n = 40)	Madeira (n = 36) [29]	Azores (n = 28) [29]
	(n = 250)	**(n = 249) [30]**			
K	1428 ± 459 (531–3727)	835 ± 333	1270 ± 247 (988–1849)	936 ± 215	923 ± 217
Na	98 ± 57 (19.0–351.2)	92.0 ± 38.2	23.6 ± 3.6 (17.1–29.0)	51.0 ± 30.1	57.7 ± 30.5
Ca	69.3 ± 22.1 (24.1–83.2)	68.7 ± 15.0	50.5 ± 35.4 (30.5–90.3)	73.1 ± 23.8	80.5 ± 15.7
Mg	129.0 ± 27.0 (65.0–263.1)	84.1 ± 15.4	115.0 ± 40.0 (75.0–125.6)	101.2 ± 13.9	112.5 ± 41.8
Fe	1.7 ± 1.0 (0.3–7.4)	2.6 ± 1.1	2.6 ± 1.9 (0.9–7.3)	2.3 ± 1.4	1.5 ± 1.0
Cu	0.20 ± 0.70 (n.d.–6.70)	0.17 ± 0.20	0.02 ± 0.01 (n.d.–0.1)	0.63 ± 0.66	0.22 ± 0.41
Zn	0.26 ± 0.15 (n.d.–0.53)	0.56 ± 0.31	0.18 ± 0.10 (0.10–0.20)	1.02 ± 0.60	0.63 ± 0.55
Mn	1.3 ± 0.7 (n.d.–5.1)	1.0 ± 0.4	0.4 ± 0.1 (0.3–0.5)	1.9 ± 0.8	0.7 ± 0.2

Results expressed as X ± σ (Min. – Max. value if available). n.d. = not detected.

Table 3. Metallic content (mg/l) from canary, Cape Verde, Madeira and Azores islands.

this metal in grapes and latter in wine. The greater or lesser concentration might depend on the climatic conditions of each harvest, on the grapevine situation as greater winds or dryness enhances it, and even on the vine itself, as roots absorb potassium differently depending on the cultivar. This climate influence might explain the potassium increase in Canary Islands wine, as the literature cited is almost 15 years old and today vines are exposed to warmer conditions due to the temperature increase from the last decade.

Potassium concentrations correlate with high wine pHs, a peculiar characteristic already observed in the previous section for Fogo wines. Since high pHs lead to a greater wine sensitivity to microbiological diseases, it is advisable to control potassium content. Obviously potassium is not the only factor conditioning the final wine pH, although it is one of the most important according to our experimental results.

The sodium content for all Macaronesian regions except Fogo is higher than those from other origins [31], probably due to oceanic winds and the marine aerosol. Fogo samples contain significantly less than most Canary, Azorean and Madeiran red wines because of the high altitude of Chã vineyards. In fact Fogo sodium content is similar to continental wines, where the marine aerosol is non-existent and its origin is essentially due to soil and agronomic practices. Some Canary red wines also presented low sodium content when compared with most samples from the same region, coming these wines from Tenerife vineyards located at high altitudes, which are presumably less influenced by oceanic winds.

The content of iron is noteworthy in all the archipelagos probably because of their volcanic soils, as it is difficult to suggest any other cause affecting all islands. Copper concentration is unusually variable between regions, relatively high in Madeira but extremely low in Fogo. Similarly, zinc and manganese content are low in Fogo wines when compared to other Macaronesia regions. Calcium and magnesium content are similar between archipelagos. The different concentration of all these minerals might be an interesting source for wine characterization according to geographical area using them as potential origin markers.

3.5. Volatile compounds

Wines from Madeira are mostly characterized by 2-ethylhexan-1-ol, 3,5,5-trimethylhexan-1-ol, ethyl 2-methylbutanoate, ethyl DL-2-hydroxycaproate, decanoic acid and 2-ethoxythiazole, whereas wines from Azores and Canary Islands are mainly characterized by 3-ethoxypropan-1-ol, 1-octen-3-ol, (Z)-3-hexenyl butanoate, 2,3-dihydrobenzofuran and 4-(methylthio)-1-butanol [32]. This latter compound is particularly important in Fogo, where red wines present an unusual high concentration of heavy sulfur volatiles in its aroma [33]. These concentrations might be due to the active volcano where grapevines are located. Fogo wines also present the highest concentration in the minor volatiles fatty acids. Results for the most common volatile compounds in red wines are summarized in **Table 4**.

Higher alcohols followed by ethyl esters and fatty acids are the most predominant chemical groups among the volatiles from red wines elaborated in Macaronesia. In fact hexanol-derived compounds with decaonic acids and whiskey lactones discriminate Madeira red wines from the rest of Macaronesian archipelagos [32] and a characteristic profile for alcohols, ethyl esters and fatty acids has been obtained for these wines [13]. Similarly, the concentration of esters in Azores wines revealed to be significantly lower than in red wines from the other Macaronesian archipelagos. The unique exception is the ethyl hexanoate compound, which seems to be present in a greater extent than in other islands [33–36].

Canary wines studies conclude that 3-metyl-1-butanol, 2,2-butanodiona and ethyl butirate were the main odorants [37, 38]. Moreover specific studies have been conducted to analyze the volatiles from red wines aged in pine casks from La Palma Island [39].

3.6. Phenolic content

Phenolic compounds are responsible for the most important sensory attributes of red wines. Phenolic content depends on the winemaking, which are influenced by factors such as variety, ripening, cultivation techniques and climatic conditions among other considerations [40]. Thus the phenolic composition of Macaronesian red wines is potentially different from other regions because of their specific *"terroir"*. Gallic and caftaric acids are the most concentrated hydroxybenzoic and hydroxycinnamic acid respectively in Canary wines [41] but there is high heterogeneity. Previous studies for the same region confirmed that these wines polyphenolic composition is highly heterogenic and depends on various factors such as local climate

Compound group	Volatile compound	Canary (n = 6) [34]}	Fogo (n = 4) [33]	Madeira (n = 48) [35]}	Azores (n = 3) [36]
Alcohols (µg/l) (50–60%)	Hexanol	–	0.214 ± 0.011 (0.167–0.256)	8.359 ± 0.469 (7.604–8.779)	0.076 ± 0.03 (0.042–0.1)
	Benzyl alcohol	–	0.131 ± 0.01 (0.032–0.184)	0.137 ± 0.007 (0.106–0.224)	0.113 ± 0.129 (0.022–0.204)
	Phenylethanol	1.086 ± 0.122 (0.961–1.313)	7.320 ± 0.739 (6.250–8.300)	12.348 ± 1.011 (9.706–18.005)	0.745 ± 0.181 (0.574–0.935)
	2-(Methylthio) ethanol	0.139 ± 0.012 (0.091–0.175)	54.333 ± 10.204 (25.500–74.500)	0.002 ± 0.001 (0.001–0.005)	–
	Linalool	2.522 ± 0.678 (0.151–5.021)	3.664 ± 0.461 (0.475–6.301)	–	0.147 ± 0.031 (0.120–0.180)
Esters (mg/l) (30–40%)	Ethyl lactate	–	4.138 ± 0.710 (2.250–6.370)	5.300 ± 0.175 (3.088–7.206)	0.004 ± 0.001 (0.003–0.005)
	Ethyl hexanoate	3.348 ± 0.288 (2.751–4.560)	2.383 ± 0.155 (2.050–2.760)	1.788 ± 0.404 (1.544–2.271)	4.402 ± 1.615 (2.55–5.516)
	Diethyl succinate	–	1.479 ± 0.088 (0.957–2.180)	0.566 ± 0.041 (0.184–1.049)	0.005 ± 0.002 (0.003–0.007)
	Ethyl octanoate	1.223 ± 1.014 (0.848–2.351)	2.530 ± 0.133 (2.150–2.930)	34.506 ± 6.598 (20.069–54.823)	0.186 ± 0.119 (0.066–0.304)
	Phenylethyl acetate	0.945 ± 0.451 (0.316–1.641)	1.565 ± 0.104 (1.160–1.770)	3.584 ± 0.113 (2.993–5.090)	–
	Ethyl decanoate	1.184 ± 0.751 (0.561–1.905)	3.985 ± 0.152 (3.300–4.730)	0.248 ± 0.014 (0.181–0.380)	0.197 ± 0.025 (0.176–0.224)
	Isoamyl acetate	–	2.048 ± 0.091 (1.350–2.660)	0.542 ± 0.343 (0.491–0.654)	0.038 ± 0.019 (0.022–0.059)
Fatty acids (µg/l) (5%)	Butanoic acid	0.065 ± 0.154 (0.026–0.073)	–	0.026 ± 0.004 (0.019–0.040)	0.100 ± 0.127 (0.010–0.190)
	Decanoic acid	0.194 ± 0.088 (0.098–0.286)	2.750 ± 0.781 (2.500 – 3.000)	0.694 ± 0.080 (0.098–1.607)	–
	Hexanoic acid	9.674 ± 0.546 (8.486–11.056)	n.d.	1.537 ± 0.208 (1.486–1.625)	0.123 ± 0.145 (0.030–0.290)

Results expressed as X ± σ (Min. – Max. value if available). n.d. = not detected.

Table 4. Volatiles compounds from Canary, Cape Verde, Madeira and Azores islands.

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	Canary wines		Fogo (n = 4) [33]	Madeira		Azores (n = 3) [36]
	(n = 250) [41]	(n = 55) [43]		(n = 12) [25]	(n = 5) [44]	
Gallic acid	41.8 ± 24.0 (3.6–125.8)	21.1 ± 11.5 (5.6–44.7)	–	–	398.1 ± 34.5 (341.2–429.0)	–
Syringic acid	7.9 ± 2.8 (2.1–20.4)	2.0 ± 0.8 (0.9–4.0)	10.8 ± 3.4 (6–13.7)	–	18.6 ± 8.8 (4.8–28.6)	–
Coumaric acid	9.7 ± 9.8 (<0.9–67.8)	2.1 ± 2.3 (0.1–6.8)	10.9 ± 5.5 (7.4–19.1)	–	8.1 ± 5.4 (4.5–16.1)	–
Catechin	85.9 ± 29.9 (6.6–199.7)	20.2 ± 8.5 (9.4–38.4)	6.9 ± 2.5 (3.8–10.0)	0.7 ± 0.1 (0.5–0.9)	–	–
Resveratrol	5.1 ± 3.0 (<0.7–13.3)	3.3 ± 1.1 (0.2–5.7)	–	0.3 ± 0.1 (0.2–0.5)	24.5 ± 25.4 (4.5–57.7)	4.2 ± 2.1 (2.8–5.7)
Quercetin	2.8 ± 2.5 (n.d.–13.7)	17.5 ± 11.48 (1.9–49.8)	4.1 ± 0.5 (3.4–4.5)	–	55.7 ± 18.0 (35.9–79.1)	5.6 ± 4.1 (3.0–12.0)
Malv.3gluc.	92.7 ± 79.4 (1.5–371.2)	–	68.5 ± 39.6 (19.6–116.0)	–	–	–

Results expressed as X ± σ (Min. – Max. value if available). n.d. = not detected.

Table 5. Phenolic compounds (mg/l) from Canary, Fogo, Madeira and Azores islands.

and vinification conditions [42]. Results for the most common phenolic compounds in red wines are summarized in **Table 5** for all Macaronesian archipelagos.

Quercetin is the most concentrated flavonol and the content of this compound group, that is flavonols, in Azores [36], Madeira [44], Fogo [33] and Canary [41] is unusually higher than in other winemaking areas [45, 46]. Stilbenes content in Macaronesia red wines has been also described as higher than in continental wines [25, 36, 43] but similar to those from Greek red wines [47]. These differences may be due to the sunny climate of Macaronesia. Flavonol and stilbene content depends on sun exposure because these phenolics protect against solar radiation, thus Macaronesian vines might increase their synthesis to combat UV radiation [48]. Anthocyanins content is also in the upper quartile when compared with other winemaking regions probably because of these solar radiation influences, which are more important in the most southern islands. In fact it has been considered that the content of catechins and proanthocyanidins in Canary wines is higher than in Madeira red wines [44].

3.7. Color

Phenolic reactions are responsible for the colorimetric changes observed while wine aging [24]. **Table 6** summarizes the main colorimetric indexes for Canary and Fogo red wines. Wines from both archipelagos present high chromacity, as the average color intensity for Canary is 9 Units of Absorbance (U.A.) and *"manecom"* even achieves 17.7 U.A. Hue color values lead to low perceptions of oxidation.

	Canary (n = 250)	**Fogo Chã (n = 40)**	***Manecom* (n = 10)**
Color intensity $A_{420} + A_{520} + A_{620}$ (U.A.)	9.00 ± 3.60 (1.41–24.15)	10.73 ± 4.00 (2.10–18.00)	17.67 ± 0.80 (17.10–18.23)
Hue color (A_{420}/A_{520})	0.75 ± 0.16 (0.51–1.28)	0.69 ± 0.15 (0.41–0.99)	0.73 ± 0.11 (0.48–0.105)
Lightness, L* (C.U.)	19.90 ± 10.12 (1.42–68.02	6.87 ± 2.58 (3.87–10.14)	1.07 ± 1.10 (0.29–1.85)
Chroma, C* (C.U.)	53.71 ± 11.12 (9.91–70.60)	36.15 ± 6.68 (27.14–43.39)	7.41 ± 7.69 (1.98–12.85)
Hue angle, h* (C.U.)	28.91 ± 6.51 (13.72–44.03)	18.56 ± 3.95 (14.24– 23.62)	14.45 ± 0.15 (14.35–14.56)
Redness-greenness axis a* (C.U.)	41.61 ± 12.83 (5.40–60.43)	34.09 ± 5.58 (26.31–39.75)	7.18 ± 7.45 (1.92–12.45)
yellowness-blueness axis b* (C.U.)	29.81 ± 11.83 (2.52–56.01)	11.82 ± 4.42 (6.68–17.39)	1.84 ± 1.90 (0.50–3.18)
Saturation, S (C.U.)	3.52 ± 1.22 (0.61–7.33)	5.61 ± 1.16 (4.28–7.01)	6.91 ± 0.07 (6.86–6.96)
Co-pigmentation (parts per unit)	0.18 ± 0.11 (0.05–0.41)	0.11±0.09 (0.02–0.35)	0.09 ± 0.08 (0.02–0.25)
Polymeric pigments (parts per unit)	0.41 ± 0.15 (0.06–0.80).	0.40 ± 0.14 (0.10–0.60)	0.49 ± 0.12 (0.19–0.72)

Results expressed as X ± σ (Min.–Max. value if available).

Table 6. Colorimetric red wines parameters from canary and Cape Verde islands.

The minimum values for coordinates a* and b* in CIELab Units (C.U.) are lower than those obtained in wines from the mainland of Spain [49]. Chroma (C*) and saturation (S*) reveal great heterogeneity. Fogo red wine lightness (L*) is significantly lower than Canary red wines giving a darker color, probably due to a higher anthocyanin extraction derived from the wine-making techniques applied to maximize color and alcoholic content.

One of the most important pigment interactions is co-pigmentation, which occurs when anthocyanic pigments associates with itself or with another substance known as co-pigment, these compounds can be very variable, from other colorless anthocyanin to phenolic acids or flavonols depending on the red wine considered [40]. The percentage of co-pigmentation in parts per unit provides an estimation of co-pigments and their influence in color. The average co-pigmentation in Canary wines is 18 ± 11% of color, ranging from 0.5 to 40%. Co-pigmentation in Fogo wines is lower in disagreement with studies where warm regions produced wines with significantly higher co-pigmentation than cold areas [50]. This low co-pigmenation is related with the high amount of polymeric pigment present in Fogo red wines.

The percentage of polymeric pigments in the young Fogo wines is similar to the percentage quantified for Canary wines where also oak-aged red wines are considered. Short-aged red wines do not normally present so many polymeric pigments. Its content in Fogo wines might be related to late harvest, excessive grape ripening and peculiar winemaking techniques which maximize oxidation and thus increase phenolic polymerizations during winemaking and storage.

4. Conclusion

Macaronesian red wines present peculiar characteristics and wide diversity. Their detailed study is still a current research issue with a promising future as these winemaking regions are mostly known because of fortified and white wines. Their atypical *terroir* combined with traditions and exclusive grape cultivars makes them a prospective red winemaking region. Red wines from Macaronesia can be grouped according to archipelago of origin but are also highly heterogeneous due to microclimates. Significant differences have been obtained in terms of oenological properties, acids, minerals, volatiles, phenolics and color influencing their organoleptic peculiarities. These wines are highly affected by the unusual circumstances of their regions making them unique. For instance, their volcanic soil might increase the iron concentration, whereas oceanic winds modify their sodium content. Moreover the warm and dry climates from these islands determine higher water needs from grapevines, which carry out a greater potassium absorption and thus a greater wine content increasing pH. Furthermore solar radiation involves a higher flavonols and stilbenes biosynthesis in grapes. In summary, Macaronesian red wines need further research but most probably their valorization as atypical food products from an exclusive environment would be enhanced during the coming years.

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