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PLANT SCIENCES | RESEARCH ARTICLE

Comparing cork quality from Hafir-Zarieffet mountain forest (Tlemcen, Algeria) vs. Tagus basin *Montado* (Benavente, Portugal)

Amina Ghalem[1], Inês Barbosa[2], Rachid Tarik Bouhraoua[1] and Augusta Costa[2,3]*

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*Corresponding author: Augusta Costa, Center for Environmental and Sustainability Research (CENSE), Nova University of Lisbon, Campus de Caparica, 2829-516 Caparica, Portugal; Instituto Nacional de Investigação Agrária e Veterinária, I.P., Quinta do Marquês, Av. da República, 2780-159, Oeiras, Portugal
E-mails: augusta.costa@iniav.pt, augusta.costa.sousa@gmail.com

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Raffaele Dello Ioio, Universita degli Studi di Roma La Sapienza, Italy

Additional information is available at the end of the article

Abstract: In the southwestern Mediterranean Basin, cork oaks (*Quercus suber* L.) are periodically harvested for their cork. This natural product is valued by its homogeneity which heightens the importance of characterizing cork tissue discontinuities, or cork pores. Cork porosity profile in natural cork planks has been reported to be affected by forest management practices but, so far, has been scarcely addressed. We characterize the cork porosity profile in two contrasting cork oak woodland; at a mountain forest, in Western Algeria (absence of forest management) and at a peneplain "montado," in southern Portugal (intensively managed toward the optimization of cork production). Image analysis techniques were applied on transverse sections of more than 40 cork samples from both woodland, and a stepwise discriminant analysis was used to discriminate between the cork pore features datasets. Cork porosity profiles were similar between regions but; in the cork samples from Algeria, cork pores were having higher values for linear dimensions of pores (length and perimeter) and contrasting shape values (roundness) which depreciate cork quality, when compared to the cork samples from Portugal. However, improved woodland management strategies at Algeria should ensure adequate cork homogeneity and suitability for more valuable cork products.

ABOUT THE AUTHORS

The authors were motivated by the spatial variability of cork oak woodland across Mediterranean environments, the implications in the cork yield, and cork quality and, consequently, in the economic and ecological sustainability of these sensitive forest ecosystems. Authors used image analysis techniques to study cork porosity in cork planks, in a similar way that cork industry detects cork porosity in cork products such as natural cork stoppers and disks, the most valuable cork product in the cork industrial processing.

This study will be one first original report from a young research group, integrating young MSc and PhD students from the Center for Environmental and Sustainability Research (NOVA University of Lisbon, Portugal) and Tlemcen University (Algeria) (http://www.augustacosta.net/people.html) addressing a comprehensive understanding on cork planks quality and cork oak woodland management, working at INIAV, I.P.

PUBLIC INTEREST STATEMENT

Cork is the outer bark of cork oak trees; one natural product generating US $2 billion annually, and, currently, the sixth most valuable global non-timber forest product. Cork oaks are strictly distributed in the western Mediterranean Basin, between the southwestern Europe and northern Africa. An increasingly important challenge for the later region is to apply adequate forest management practices toward the optimization of high-quality cork production. In their research, authors assessed cork quality of two contrasting cork-producing regions: Portugal, the world leader in cork production; and Algeria, one potential cork-producing region. Results showed strong similarities between cork quality profiles, but higher cork quality heterogeneity at Algeria. Clearly, at this region, adequate forest management practices such as thinning (for selecting the best cork-producing trees) or pruning (for optimizing trees' cork-harvesting surface), and appropriate cork-harvesting cycles should improve the cork yield and quality, at medium term.

Subjects: Environment & Economics; Forestry; Resource Management–Environmental Studies

Keywords: *Quercus suber* L.; cork oak; Mediterranean Basin; cork porosity; image analysis; lenticular channels; stepwise discriminant analysis

1. Introduction

Cork oak (*Quercus suber* L.) is a strictly Mediterranean species distributed in the western Mediterranean Basin, between the southwestern Europe and northern Africa, a climatic, ecological, and socioeconomical sensitive region (Bugalho, Caldeira, Pereira, Aronson, & Pausas, 2011; Costa, Madeira, Santos, & Plieninger, 2014; Giorgi, 2006). Cork oak woodland are considered keystone ecosystems (Vicente & Alés, 2006), while enhance other important provisioning/regulating ecosystem services (Plieninger, van der Horst, Schleyer, & Bieling, 2014). Moreover, cork oak woodland are important biodiversity hotspots where cork oak is harvested throughout their lifetime for their bark (Oliveira & Costa, 2012; Ticktin, 2004), the cork, one valuable global non-timber forest product (FAO, 2013).

In Portugal and Algeria, the cork oak woodland ecosystems are under high human pressure; in Portugal, these woodland are iconic examples of domesticated nature featuring savannah-like ecosystems carefully managed for a sustainable cork yield (Costa & Oliveira, 2015; Costa et al., 2014). In Algeria, cork oak woodland are disturbed forest ecosystems with strong, political, economical, and technological underlying factors, leading to the depreciation of cork value in relation to other tree's products such as acorn or (fire)wood (Messaoudène & Merouan, 2009). Despite the differences found between cork oak woodland conditions and management in Portugal and Algeria, a common increasingly important challenge for both regions is maintaining the trees producing high-quality cork. Cork quality depends on the homogeneity of the cork tissue, and on the presence of cork tissue discontinuities, pores or lenticular channels crossing radially the transverse sections of cork planks (Costa & Pereira, 2010).

Given the importance of the quality grading of cork planks in the industrial processing, namely for the production of natural disks and stoppers (Costa & Pereira, 2006; Pereira, 2007), the cork quality has long being determined in raw cork material by visual inspection (Costa & Pereira, 2010). In the surface of the transverse sections of cork planks, the high porosity variability in-between the transverse section of the cork samples have been reported in technical studies in industries, and a strong radial variability from the inner part (with lower porosity) to the outer part (with higher porosity) has been generally accepted. However, it is urgently needed a more comprehensive understanding on the extent of lenticular channels, i.e. on the cork porosity variability profile in the cork plank transverse sections, so far, scarcely addressed.

In this study, the goal is to reinforce the existent knowledge on the cork quality profile of cork planks by a large-scale assessment of cork yield in the Mediterranean area, including those of areas of northern Africa. In fact, given the ever-increasing demand for cork raw material, and with the Portuguese cork industry leading the world market with about a 65% share (APCOR, 2015), all the cork oak woodland areas should constitute potential cork-producing areas, contributing to the high cork-value chain.

We propose to use image vision inspection systems currently used in the industry for stoppers and disks quality classification, to identify and quantify the lenticular channels, in transverse sections of cork planks. The goal is to fill the existent knowledge gaps on the porosity profile of cork by generating comparable data on cork porosity in the cork plank's transverse sections of the two Mediterranean Basin cork-producing regions, Portugal and Algeria. Similar porosity (i.e. cork tissue discontinuities attributed to lenticular channels) features will be addressed and we hypothesized that in both regions the cork porosity variability profile will be similar, with larger and more porosity in outer part of the transverse section of cork planks. Moreover, it is hypothesized that appropriate forest management practices should improve cork quality, given the presence of porosity features, at each study area.

2. Material and methods

2.1. Study areas

Cork sampling was made during the cork-harvesting season, in the summer of 2010, at two study areas in the western Mediterranena Basin: at the cork oak woodland of Hafir-Zarieffet (ZA) (34°50′ N, 1°23′ W), at Tlemcen Mountain, in northwestern Algeria, close to the Mediterranean Sea and; at the cork oak woodland of Benavente (CL) (38°04′ N, 8°40′ W), in the Tagus Basin peneplain, in southwestern Portugal, close to the Atlantic Ocean (Supplementary material, Figure S1).

The climate in both study areas is of Mediterranean type, smoothed by the influence of the Mediterranean Sea (at ZA) and the Atlantic Ocean (at CL). Mean annual temperature and annual rainfall are 13.5°C and 654 mm, and 15.3°C and 577 mm at ZA and CL, respectively (Figure 1). The mean temperature of the coldest month (January) is 3.5 and 5.0°C and for the hottest month (July) is 30.7 and 28.7°C, for ZA and CL, respectively. The highest temperatures are in summer, when precipitation is the lowest, and a dry period ($p < 2T$) generally occurs extending from May to September (Figure 1).

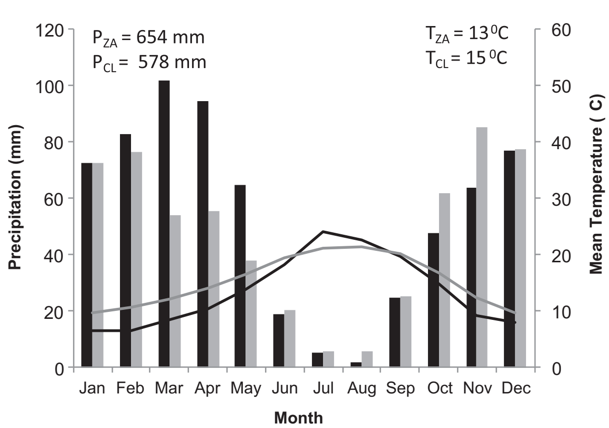
The study areas are within the potential vegetation area for cork oak, corresponding to the meso-Mediterranean (ZA) and thermo-Mediterranean (CL) thermotypes and to the sub-humid ombrotype (Capelo et al., 2007; Dehane, 2012).

At ZA, the elevation ranges from 1,000 to 1,220 m a.s.l. and the landscape is steeply undulated (with slopes ranging between 3 and 12%). The dominant Jurassic formations are related to the predominant shallow (less than 30 cm depth) carbonated soils, from sandy loam to sandy clay. At CL, Pliocene formations are dominant, occupying the flat or gently undulating (with slopes lower than 5%) areas adjacent to the Tagus river alluvial area. Mostly related to the nature of these geological formations, the predominant soils are deep sandy soils. In both study areas, ZA and CL, the soils are poor in nutrient and organic matter, and with low water storage capacity (Costa, Madeira, & Oliveira, 2008; Dehane, 2012).

At ZA, the cork oak woodland are mainly open woodland and scattered-tree woodland, with the occurrence of thorny trees due to fire recurrence (Letreuch-Belarouci, Letreuch-Belarouci, Benabdeli, & Medjahdi, 2009) and overgrazing. Exploited tree's density is under 50 trees ha^{-1}, and trees are old and poorly managed, within heterogeneous cork-production cycles, extending largely from typical Iberia's 9 to 12-years. Cork oak management oriented to the cork production management is lacking.

Figure 1. Climatic diagrams for the study areas, Hafir-Zarieffet (in black) and Benavente (in gray).

Notes: Data from the meteorological stations of Mefrouche (Hafir-Zarieffet, ZA) 34°51′ N, 1°16′ W (1961–1990 for the precipitation and 1975–1990 for temperature) and Salvaterra de Magos (Benavente, CL) 39°02′ N, 8°44′ W (1961–1990). Precipitation (in bars) and mean temperature (in lines).



At CL, the cork oak forest management practices, from planting or seeding to pruning, thinning, and cork harvesting, all are oriented toward optimizing cork productivity (Costa, Oliveira, Vidas, & Borges, 2010; Costa et al., 2008). The cork oak woodland are uneven-aged and resulted of assist natural regeneration complemented with local artificial seeding and plantation. Trees are pruned in juvenile ages for maximize harvesting surface, before the beginning of the 9-year cork production cycles, at the 20–25 years of age. Thinning occurs regularly, only to eliminate dead trees. The mean tree density was 86 trees ha^{-1} (with 62 trees ha^{-1} under exploitation) and an average annual cork production of 110 kg ha^{-1} $year^{-1}$ was to be expected (Costa et al., 2010). The cork productivity at CL, Portugal, 110 kg ha^{-1} $year^{-1}$, is higher than at ZA, Algeria with 33 kg ha^{-1} $year^{-1}$ but mean annual cork growth is similar 2.9 and 3.1 mm $year^{-1}$, respectively.

2.2. Image acquisition and cork quality assessment

A total of 41 cork samples were randomly selected in the two study areas. The cork samples, with dimensions of 10 × 10 cm^2, were prepared for image acquisition. The preparation included boiling in water at 100°C for 1 h, and dried in open air until equilibrium (minimum one week), and an optical quality surface finishing: the cutting and the sanding of a plan surfaces in the transversal section in order that cork pores and cork annual rings were clearly visible (Costa, Nunes, Graça, & Spiecker, 2015). The image acquisition of the transversal sections was made through snapshot images scanned at a resolution of 300 dpi and stored in TIF graphic format (Supplementary material, Figure S2). Images were then analyzed using ImageProPlus® image-processing software.

Cork quality assessment was made at the transversal section within a defined rectangular area of interest (AOI). A set of 13 pore variables at cork sample level was selected for cork quality assessment (Table 1). Pore data were filtered out by pore area, only pores with an area equal or superior to 0.5 mm^2 were kept for analysis as small porosity is functionally and esthetically irrelevant and only brings higher variance and variability to the cork sample (Costa & Pereira, 2007).

The exploratory analysis of cork porosity was made in the transverse section of the cork sample at an AOI-level; firstly, considering the AOI and as a whole and then considering the inner part of the AOI (one third of the AOI transect length, from cork belly to cork back); the middle AOI (second third); the external AOI (one third of the AOI length). At these subsections (inner, middle, and external AOI) of the cork sample transverse section, the found cork porosity will be therefore comparable and independent on the cork age, cork thickness, and cork production cycles.

2.3. Statistical analysis

Stepwise discriminant analysis (SDA) was used to investigate differences between the cork-producing regions, ZA and CL, the categorical dependent variable, and the cork porosity features, the independent pore-level metrics variables (Costa & Pereira, 2006; Gonzalez-Adrados, Lopes, & Pereira, 2000). The stepwise discriminant functions were evaluated using the Wilk's λ value: the smaller the Wilk's λ value, the more important is the independent variable or feature to the canonical discriminant function. The purpose of using SDA was to find the pore features that contribute the most to distinguish these regions (SPSS vs. 21.0). This statistical analysis creates a new (reduced) set of variables, called canonical discriminant functions, each one a linear function of the original independent (predictor) variables, in this case the cork porosity at pore level. These discriminant functions would account for most of the variance and would define the maximum possible difference between both regions. The relative importance of the predictor variables is evaluated through their correlation (Pearson coefficients) with each discriminant function.

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Table 1. Pore variables measured in the transverse section of the cork samples at both regions

Pore variables	Acronym	Description	Range	P_o[1]	C_o[2]
Dimension					
Area	a	Area of pore (mm²)	≥ 0	x	–
Perimeter	pe	Perimeter of pore (mm)	≥ 0	x	–
Diameter	di	Diameter of pore (mm)	≥ 0	x	–
Length	le	Length of pore (mm)	≥ 0	x	–
Width	wi	Width of pore (mm)	≥ 0	x	–
Mean area	Mpa	Average pore area (mm²)	≥ 0	–	x
Maximum area	Maxpa	Maximum pore area (mm²)	≥ 0	–	x
Mean perimeter	Mpe	Average pore perimeter (mm)	≥ 0	–	x
Mean diameter	Mdi	Average pore diameter (mm)	≥ 0	–	x
Mean length	Mle	Average pore length (mm)	≥ 0	–	x
Mean width	Mwi	Average pore width (mm)	≥ 0	–	x
Shape					
Shape factor	sh	Perimeter-area ratio by adjusting for a circle standard	≥ 1	x	–
Aspect ratio	as	Ratio between width and length of a bouding pore rectangle	≥ 2	x	–
Fractal dimension	fr	Pore perimeter increase per unit increase in pore area	0–2	x	–
Roundness	ro	Ratio between the largest and smallest equivalent pore ellipse	≥ 1	x	–
Mean shape factor	Msp	Mean pore shape index	≥ 1	–	x
Mean aspect ratio	Mas	Mean pore aspect ratio	≥ 2	–	x
Mean fractal dimension	Mfr	Mean pore fractal dimension	0–2	–	x
Mean roundness	Mro	Mean pore roundness	≥ 1	–	x
Concentration					
Number	np	Total number of pores per 100 mm² (#)	≥ 1	–	x
Mean nearest neighbor distance	Menn	Average distance to the nearest neighboring	> 0	–	x
Area fraction	af	Area-edge-to-edge squared distance ratio	≥ 0	–	x

[1]P_o—pore-level variable.

[2]C_o—cork plank-level variable.

3. Results

3.1. Cork porosity

The porosity profile of the transversal sections of the cork planks from Hafir-Zarieffet (ZA) and from Benavente (CL) showed similarities in the range of the values variation for all the selected features (Table 2). Regarding the dimension features, the mean pore area (Mpa) ranged between 4.5 mm² (at ZA) and 5.3 mm² (at CL). The mean values for maximum pore area (Maxpa) ranged between 29.2 mm² (at ZA) and 47.6 mm² (at CL). At the later region, the Maxpa was almost the double, confirming the relatively higher Mpa found in CL.

Lenticular channels are the dominant cork tissue discontinuities, mostly linear shape objects crossing radially the transverse section of the cork planks. Shape features such as aspect ratio, fractal dimension, or roundness showed compatible values in both regions, CL and ZA (Table 2). The mean fractal dimension was 1.1 in average in both regions and the roundness and aspect ratio mean values at ZA, respectively, 8.9 and 6.2, were superior to those found at CL, respectively, 4.6 and

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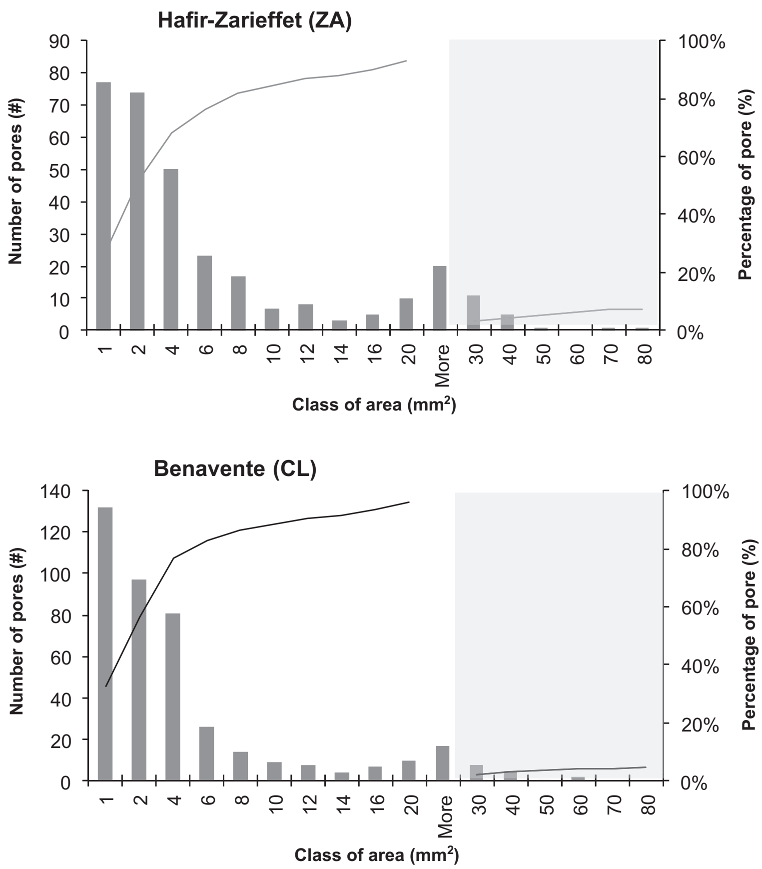
Table 2. Cork porosity of the transverse section of cork samples

Variables	Hafir-Zarieffet (ZA)					Benavente (CL)				
	AOI	Outer cork	Middle cork	Inner cork	Yearly	AOI	Outer cork	Middle cork	Inner cork	Yearly
Dimension										
Mpa	4.5 ± 4.02	3.2 ± 2.55	5.9 ± 7.30	5.6 ± 5.62	3.5 ± 5.17	5.3 ± 3.17	3.7 ± 2.67	17.7 ± 26.12	4.0 ± 1.64	3.1 ± 3.17
Maxpa	29.2 ± 37.70	9.6 ± 10.24	19.9 ± 30.39	20.4 ± 34.16	8.8 ± 16.08	47.6 ± 45.52	16.8 ± 12.57	39.7 ± 48.57	17.2 ± 9.40	11.4 ± 15.94
Mpe	14.6 ± 6.01	10.7 ± 3.39	19.0 ± 14.91	16.7 ± 8.35	11.1 ± 6.46	14.2 ± 4.42	11.1 ± 4.35	32.8 ± 35.47	12.6 ± 3.37	9.2 ± 4.62
Mdi	2.2 ± 0.74	1.8 ± 0.54	2.5 ± 1.43	2.3 ± 1.08	1.9 ± 0.90	2.1 ± 0.36	2.0 ± 0.57	3.3 ± 1.69	2.0 ± 0.46	1.7 ± 0.53
Mle	6.2 ± 2.65	4.5 ± 1.44	8.5 ± 6.75	7.3 ± 3.56	4.4 ± 2.04	4.9 ± 1.01	4.1 ± 1.41	9.9 ± 7.90	4.4 ± 1.45	3.1 ± 1.64
Mwi	1.1 ± 0.47	1.1 ± 0.44	1.0 ± 0.58	0.9 ± 0.56	1.0 ± 0.80	1.5 ± 0.38	1.4 ± 0.47	2.4 ± 1.75	1.5 ± 0.40	1.2 ± 0.21
Shape										
Msp	37.5 ± 29.05	22.0 ± 14.30	33.4 ± 26.08	34.0 ± 25.89	22.9 ± 20.02	21.5 ± 7.76	18.9 ± 13.68	40.9 ± 35.54	16.8 ± 6.49	15.3 ± 12.75
Mas	6.2 ± 2.24	4.7 ± 1.27	7.8 ± 3.37	6.9 ± 4.11	5.8 ± 2.68	4.7 ± 1.15	4.2 ± 1.71	7.4 ± 4.09	4.5 ± 1.22	3.4 ± 1.25
Mfr	1.1 ± 0.02	1.1 ± 0.02	1.1 ± 0.03	1.0 ± 0.36	1.1 ± 0.02	1.1 ± 0.02	1.1 ± 0.02	1.1 ± 0.04	1.1 ± 0.03	1.1 ± 0.02
Mro	8.9 ± 3.60	6.6 ± 2.25	12.5 ± 6.53	9.9 ± 5.62	7.8 ± 4.92	4.6 ± 1.63	4.6 ± 2.27	6.3 ± 2.74	4.1 ± 1.74	3.0 ± 1.27
Concentration										
np	280 ± 116	468 ± 299	165 ± 87	188 ± 135	334 ± 188	250 ± 79	330 ± 149	140 ± 61	230 ± 100	420 ± 143
Menn	3.2 ± 0.78	2.6 ± 0.66	4.3 ± 1.12	3.5 ± 1.69	3.1 ± 0.97	3.3 ± 0.47	2.9 ± 0.58	4.6 ± 1.21	3.7 ± 1.17	2.5 ± 0.42
af	9.2 ± 4.48	11.4 ± 5.84	7.7 ± 8.96	9.2 ± 7.26	7.6 ± 7.45	13.2 ± 8.23	13.9 ± 14.04	16.6 ± 19.69	9.3 ± 5.23	12.7 ± 11.65

Notes: Mean values (mean ± standard deviation) for the study areas, Hafir-Zarieffet (ZA) and Benavente (CL). Range of mean values for all the AOI and along a virtual radial transect across the transverse section, from the outer (older) to the inner (younger) layers of the cork plank.

Figure 2. Histogram for the pore area feature in all cork samples from Hafir-Zarieffet (ZA) and Benavente (CL).

Note: In bars is the frequency distribution of the number of pores and in lines is the curve for the cumulative percentage of pores.



4.7. These differences are confirmed by the fact that at ZA, the lenticular channels are longer (6.2 mm mean length) and relatively thinner (1.1 mm mean width) than at CL (4.9 and 1.5 mm, respectively for length and width) (Table 2).

In relation to the concentration features, ZA presents a porosity coefficient of 9.2% against 13.2% at CL. In average, the cork samples from CL showed higher porosity, at CL, the larger Mpa and higher Maxpa directly influences the porosity coefficient as CL presents smaller number of pores, 250 pores per 100 cm^2 against 280 pores per 100 cm^2 at ZA.

The distribution of cork porosity per classes of pore area showed similarities between the two regions of ZA and CL. However, at CL, a larger number of pores with area smaller than 2 mm^2 (# 229 pores) is noticeable when compared to ZA (# 151) (Figure 2) and the correspondent pore area (of pores with area <2 mm^2) was higher (288 mm^2) at CL when compared to the correspondent area of 186 mm^2, at ZA. This difference could significantly increase the porosity coefficient (area fraction) of the cork samples at CL (see Table 2). In addition, at CL, pores of extremely large dimension (>30 mm^2) were noticed in the cork samples, increasing the range of pore area variation (Figure 2).

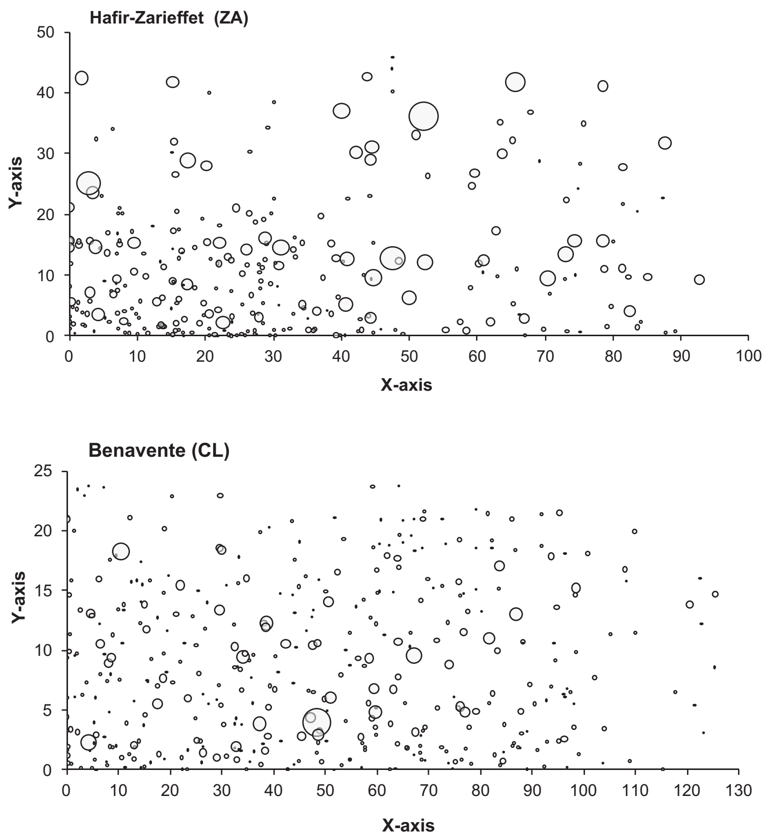
3.2. Cork quality profile

The porosity from the cork samples of ZA and CL was represented in a pore centroid scatterplot (Figure 3), showing the location of the total number of pores, 205 at ZA and 494 at CL, from cork back (minimum *y*-value) to cork belly (maximum *y*-value) and the correspondent area, represented by a proportional circle.

The spatial distribution of pores in the transverse section of cork samples showed that the porosity at ZA ranged between *y*-values of 0 and 50 mm, while at CL ranged between *y*-values of 0 and 25 mm

Figure 3. Representation of pore centroids in a *XY*-scatter plot for all cork samplers at Hafir-Zarieffet (ZA) and Benavente (CL).

Note: Circle diameter is proportional to pore area located from cork back (minimum *Y*-value) to cork belly (maximum *Y*-value).



(Figure 3), i.e. cork samples thickness at ZA are almost the double than the ones at CL. At CL, the pore area decreases from the cork back (outer cork) to cork belly (inner cork) (Table 2), while this trend is not as consistent at ZA as there are relatively larger cork pores in the inner cork layers (Figure 3).

The pore centroids of the larger pores at ZA and CL are located in the middle cork layers in result of the linear projection of the lenticular channels in a transverse section, but it is in the yearly cork layers (more than at the inner cork layers) that are located the smallest porosity in both regions (Table 2). Pore area (pa), length (le) and fractal dimension (fr) of the lenticular channels at CL showed a effectively a consistent decreasing trend of from cork back (outer-cork layers) to cork belly (inner-or yearly cork layers). However, at ZA, none of these pore variables allowed such as consistent trend and it is noticeable in the spatial representation of the porosity (Figure 3).

3.3. Cork quality regions

The SDA functions allowed distinguishing the porosity of the two regions (Wilks' Lambda significant at $p < 0.001$). Two SDA functions ($F1$ and $F2$) explained about 98% of the variation in porosity of the transverse section of the cork planks: 77.5% variation was explained by $F1$ and 20.7% was explained by $F2$.

The strongest correlations between the first SDA function, $F1$, and the independent variables were found for pore length (equal to 0.698) and pore roundness (equal to 0.694). Between the second SDA function, $F2$, which explained less variability, and the independent variables the higher correlation was found with pore perimeter (equal to 0.727) (Table 3).

The results (Table 3) showed that, at the AOI-level, and considering the cork layers, the selected independent pore-level variables, with the highest correlation with the SDA functions were those quantifying pore linear dimension, as pore perimeter and pore length, and related to pore shape, as roundness.

Table 3. Eigenvalues, canonical correlation coefficients, and variance explained by the first two discriminant functions (*F*1 and *F*2)

Variables	*F1*	*F2*
Lenght	0.698	0.497
Perimeter	0.444	0.727
Roundness	0.694	0.677
Eigenvalue	0.212	0.057
Variance (%)	77.5	20.7
Cannonical correlation	0.618	0.331

Notes: Significant variables at pore level for the cork planks porosity by SDA, for the study areas, Hafir-Zarieffet (ZA) and Benavente (CL): pore length, pore perimeter and pore roundness.

The cork layer that was decisive to discriminate between the study regions, ZA and CL was the middle-cork layer. The lenticular channel-driven porosity be the most prominent feature of the transverse section of the cork planks. At ZA, the cork thickness is rather larger when compared to CL, and there are also some cork tissue discontinuities, such as cracks or heavy porosity, that were present in the transverse section, and this abnormal porosity lead to an increasing variability on porosity features, between cork layers when compared to the cork samples at CL (see Figure 3).

4. Discussion

This study show the possibility of using image analysis techniques for quality evaluation of the cork planks, currently made based only on visual appreciation by an experienced operator. Despite the fact that the quality of the cork planks directly conditioned the quality yield profile of the cork products, such as cork stoppers or disks (Costa & Pereira, 2010), the image analysis in the raw material is not done only because as a natural raw material, cork is more heterogeneous and the image analysis is done in the end product.

The porosity values found in the transverse section of the cork samples were in agreement with the values found in cork planks by previous reports for both regions (Dehane, Bouhraoua, González-Adrados, & Belhoucine, 2011; Gonzalez-Adrados et al., 2000; Pereira, Lopes, & Graça, 1996), and porosity was in general mostly related to the radial development of the lenticular channels in the bark of the living tree (Graça & Pereira, 2004).

The intrinsic variability of porosity is higher in the ZA cork samples than in CL cork samples (Table 2) and this could be in result of the difference in the area observed by image analysis, which is higher for the larger cork samples of ZA (Figure 3). The importance of dimension of the observed area for porosity determinations by image analysis was previously addressed for cork planks (Pereira et al., 1996).

According to the results obtained, the high area fraction found at CL, when compared to ZA, was driven by small porosity (mostly inferior to 2 mm^2). This *so called* small porosity should not be as detrimental for the cork planks quality as larger cork porosity. However, at CL there are also larger pores as in ZA and this is highly detrimental for cork quality. As previously reported (Costa & Pereira, 2010), small porosity could represent 75% of the total number of the pores and less than 20% of the total pore area.

At ZA, the longer and thinner lenticular channels are mainly related to the larger cork production cycles, larger cork thickness of the cork planks. These longer cork production cycles should be reconsidered in the cork oak woodland management as could also be detrimental to cork quality yield in the sense that the cork quality profile could not be as consistent as in CL. In Algeria regions, where the annual cork growth is relatively high, similar to the one found in the study area where cork samples were collected (annual cork growth rate between 3.1 and 3.6 mm $year^{-1}$), forest management should include the shortening of the typical cork production cycles (to minimum of 9-year cork production cycle as in Benavente (Portugal). This way, the cork oak woodland would provide a more sustainable productive land use, maintaining their ecological resilience to cork harvest and a fine adaptation to the Mediterranean environments.

The porosity profile found in the transverse section of the cork samples is, however, consistent and emphasis the typical techniques when punching the natural cork stoppers, near the cork belly, in relation to the cork back, as in this region the lenticular channels, and porosity, are a more conspicuous feature. Thus, from the inner (recent) cork layers to the outer (older) cork layers, the porosity increases.

The results on the decision-making of the cork planks porosity discriminated by regions highlighted the importance of dimensional variables at pore level, length, and perimeter, in agreement with previous studies (Pereira et al., 1996). However, in contrast to these previous reports, the importance of the area of the pore was not decisive. This apparent discrepancy could be related to the fact that in this study the cork samples were more heterogeneous and large lenticular channels were found in the cork samples, which could be classified as cracks or heavy porosity, with a relatively poor match for a SDA analysis. Further studies should be made with more cork samples, in order to have a clear understanding on the cork quality profile for both regions, and mainly for Algeria, showing higher heterogeneity in the cork porosity features.

5. Conclusion

The porosity profile of cork samples of the two study areas, Benavente (CL) and Hafir-Zarieffet (ZA), were compared and results showed strong similarities related to lenticular channels presence and their correspondent cork tissue discontinuities. At both regions, CL and ZA, in the transverse section of the cork samples, larger and conspicuous porosity was found in outer part of the transverse section of cork planks, when compared to the one found in the inner part. However, when comparing cork quality of both regions, CL and ZA, clearly ZA had more heterogeneous cork quality, discriminated by porosity linear features, such as length and perimeter. Clearly, at Algeria (ZA), adequate thinning and pruning of cork oak woodland and appropriate cork production cycles should be applied toward the improvement of the cork quality production.

Supplementary material
Supplemental material for this article can be accessed here http://dx.doi.org/10.1080/23312025.2016.1236431

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Competing Interests
The authors declare no competing interest.

Author details
Amina Ghalem[1]
E-mail: aminaghalem@ymail.com
Inês Barbosa[2]
E-mail: inesalexandrabarbosa@gmail.com
ORCID ID: http://orcid.org/0000-0003-1827-8660
Rachid Tarik Bouhraoua[1]
E-mail: rtbouhraoua@yahoo.fr
Augusta Costa[2,3]
E-mails: augusta.costa@iniav.pt, augusta.costa.sousa@gmail.com
ORCID ID: http://orcid.org/0000-0002-0400-8523
[1] Faculty of Science, Laboratory n 31, Department of Agro-Forestry, Management Conservatory Water, Soil and Forests, University of Tlemcen, P.O. Box 119, Tlemcen, Algeria.
[2] Center for Environmental and Sustainability Research (CENSE), Nova University of Lisbon, Campus de Caparica, 2829-516, Caparica, Portugal.
[3] Instituto Nacional de Investigação Agrária e Veterinária, I.P., Quinta do Marquês, Av. da República, 2780-159 Oeiras, Portugal.

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