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Short communication. Effect of the health status on the cork production characteristics of Western Algeria cork oak stands

B. Dahane[1], R. T. Bouhraoua[1], J. L. Garcia de Ceca[2]* and J. R. Gonzalez-Adrados[2]

[1] *Départament de Foresterie. Faculté des Sciences. BP 119. Université de Tlemcen. Argelia*
[2] *INIA. Centro e Investigación Forestal. Departamento de Productos Forestales. Ctra. A Coruña, km 7,5. 28040 Madrid, Spain*

Abstract

Aim of study: To analyze the effect of health status on cork production, analyzing if this influence is uniform or is affected by site conditions.

Area of study: Two Western Algerian cork tree forests have been studied: M'Sila located in the coastal plains under semiarid climate, and Zarieffet, located in the mountainous interior under sub-humid climate.

Material and methods: 40 trees were selected in each forest and classified according to their health status as healthy, weakened, or decaying. A sample of cork from each tree has been obtained to measure the key variables related to cork production. A two-way ANOVA was performed considering two factors: site and health status.

Main results: *Quercus suber* L. productivity is affected by the vitality of trees in the same way in both sources, showing values between 5.96 ± 7.1 kg · m^{-2} (coast, weakened trees) and 8.13 ± 0.45 kg · m^{-2} (mountain, healthy trees). The health status also affects the number and area of pores, especially in the cork oak groves of the coast, where the coefficient of porosity ranges from 3.79 ± 0.84% (healthy trees) to 8.11 ± 1.91% (decaying trees). The variables where the site has presented a stronger effect are those related to the amount of cork produced by the phellogen (density —kg · l^{-1}, $p < 0.000$— and productivity —kg · m^{-2}, $p = 0.001$—), and pore density (1 · cm^{-2}, $p = 0.001$). Scrap thickness (mm) and porosity (%) show a smaller effect although still representative ($p = 0.041$ and 0.038 respectively). Porosity and pore density show interaction site*health status. They all have higher values in the mountain (Zarieffet) than in the coast (M'Sila). The effect of tree vitality on the formation of pores in the cork oak phellogen is lower in the mountain than in the coast. No significant effects were found for any of the two factors neither on the annual growth rate nor on the thickness of the cork.

Research highlights: Results lead to the conclusion that the effect of health status on traumatic phellogen formation and activity is clear but not uniform. Further studies are necessary for a deeper understanding of the effect of stress situations on pore formation and characteristics.

Key words: decay; density; mean annual growth; porosity; productivity.

Introduction

Cork world production drop from 380,000 t in 1999 to 299,300 t in 2008 (Aronson *et al*., 2009). Though bearing a traditional management of the cork oaks stands, the part of Algeria in the cork market (414,000 ha and 15,000 t) currently shows a rate of 5%, which implies a low production (*e.g.*, Italy with 92,000 ha, produced 17,000 t) (Pereira *et al*., 2008). Meanwhile, due to its nature and the heterogeneity of the factors affecting its production, cork is a product with a high variability, and so the concept of quality is difficult to define (Carrasquinho, 1987).

Through its formation process, changes occur in the cork due to environmental perturbations that affect its growth, color, texture, density and frequency of its porosity (Molinas and Oliva, 1990). Among these alterations is necessary to quote the decay. This is a clear, persistent and progressive decline of the trees extended beyond a region or forest. This phenomenon is characterized by the appearance of abnormal leaves (yellowish, premature fall, necrosis, small size, clustered), the death of the trunk from the branch tips toward the stem, and the death of rootlets and reduction in radial growth (Auclair, 1993). The decay is related to several factors including periods of exceptional drought, adverse soil conditions, absent or unsuitable silvicultural practices, fires and plagues of insects or other parasites (Bakry and Abourouh, 1996).

* Corresponding author: ceca@inia.es
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The problems of health degradation of forests (deciduous and conifers) are very old, dating from the late nineteenth and early twentieth century in many countries, especially in Europe, but also in North America. But the emergence of the most dramatic decline has been in the early years of the eighties (Delatour, 1983; Bonneau and Landmann, 1988). In Algeria, the health problems of cork oak forests date back to early last century, especially in the middle and even towards the West of the country, appearing the decay in young trees (under 15 years of age) as in mature trees. At mid-twentieth century, many populations already presented severe symptoms of weakness (Boudy, 1952).

This work has two main objectives:

1. To study how the cork production variables (growth rate, density, productivity, porosity, pore density, size and thickness of the scrap) are influenced by the sanitary state of the trees (healthy, weak, decadent).
2. To study whether the geographic origin can affect the behavior of these variables.

To do this there have been selected two representative forest of western Algerian cork area: in the littoral zone, M'Sila forest in Boutlelis municipality; in the mountain area, Zarieffet forest in Tlemcen municipality (Fig. 1, Table 1). In M'Sila, the phenomenon of decay of the trees is first mentioned in 1891 (Bouhraoua, 2003). Other waves of decay were recorded then between 1913 and 1926. From 1975 (date of first use of the cork after the Independence of Algeria), the decay of the forests called attention to the local administration, but the real work to diagnose and identify possible causes of the problem did not begin until the late 80. New field studies were organized between 1983 and 1995 (Lanier *et al*., 1986; Aici *et al*., 1994). During this period there was a net increase of decay, evenly distributed throughout the forest in the form of spots. The deteriorating health of Zarieffet forests began in the early twentieth century and persists to date (AEFCO, 1969), having observed a significant tree mortality in the late 80's. Data are available from the monitoring network for these forests, collected annually between 1999 and 2008. Inventories conducted for the two forests show significant increases in the percentage of trees with leaf deficit greater than 25% between 2000 and 2006, reaching values above 60% in M'Sila and 45% in Zarieffet.

The health index *Is* (Bouhraoua, 2003), was used to represent the health status of the forests. This index allows expressing directly the general state of the population from a set of trees taken individually.

It is calculated as follows:

$$Is = \frac{\sum_{i=1}^{5} n_i P_i}{N}$$

where:

n_i = number of trees of defoliation type i.

P_i = weight of type i (1 if $i = 1$; 2 if $= 2$, etc.).

N = observed total number of observed trees.

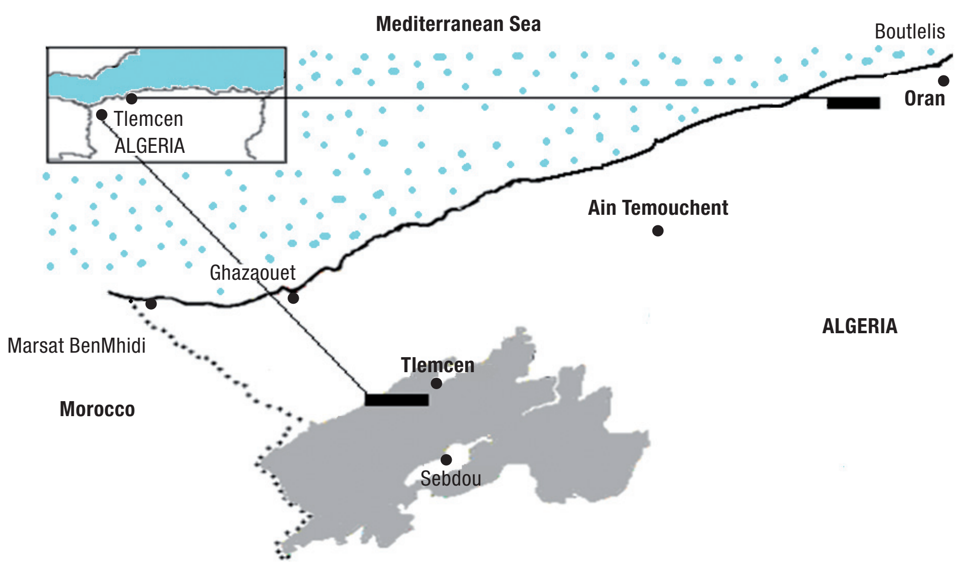

Figure 1. Geographical sample points: Boutlelis (M'Sila) and Tlemcen (Zarieffet).

Table 1. Characteristics of sampling points

Characteristics	M'Sila	Zarieffet
Mean altitude (m)	380	1,100
Topography	Plateau	Upper basin
Slope (%)	3	30
Origin of populations	Natural	Natural
Structure of populations	Irregular	Irregular
Treatment	High Forest System	High Forest System
Nature of the population	Mixed	Pure
Mean density ($tree \cdot ha^{-1}$)	160	90
Forest fires (last occurrence)	—	1994-2007
Average height of trees (m)	8.35 ± 0.39	8.40 ± 1.07
Average circumference of trees (cm)	99.09 ± 6.6	128.11 ± 35.08
Average height debarking (m)	2.44 ± 0.35	2 .26 ± 0.35
Mean coefficient of debarking	2.47 ± 0.18	1.76 ± 0.33
Health status (Is)	2.30	1.49

The criterion used is based on the defoliation resulting in the eventual loss of leaves in the functional part of the crown. It is an indicator widely used in Europe to assess the health status of forest trees (DSF, 1991). It was taken in summer by visual examination of the ramifications of the tree, assigning to each tree one of the following classes that correspond to a health category (Bouhraoua and Villemant, 2002) (Fig. 2):

— 1 (<25%, healthy trees).
— 2 (25-60%, weak trees).
— 3 (>60%, decadent trees).

The health assessment was based on annual monitoring from 1999 to 2008. The average of all visual observations gives the value of the final health status of each tree (Bouhraoua, 2003; Dahane, 2006).

Calculated for each forest (Table 1), on the coast *Is* reveals a more serious situation which can be described as «self-evident weakening» in the groves of M'Sila ($2.1 < Is < 2.5$). On the contrary, the situation on the mountain is more satisfying; being the cork oak grove of Zarieffet on the edge of the qualification of «healthy» ($Is < 1.5$).

The progressive deterioration of the two populations, both showing a similar trend of degradation and impoverishment, implies the destruction of cork working capital. Moreover, the cork annual growth is directly influenced by the decay (Cambini, 1971). This implies a reduction in both cork thickness and productivity of around 42% and 50% respectively. No studies were found concerning the influence of decay on other cork properties (porosity, density...) that were directly related to industrial quality and economic value of the product.

Figure 2. Defoliation type 1, 2, and 3 (healthy, weak, and decaying trees).

Material and methods

There was obtained a cork sample from two forests in Northwest Algeria (Table 1). In the littoral zone, the M'Sila forest (1,087 ha) was selected, with a semiarid climate characterized by mild winters and hot, humid summers. In the mountainous area, the Zarieffet forest (960 ha) was selected, with an inferior subhumid climate characterized by cold and rainy winters and hot dry summers. Both formations are integrated into the monitoring network health status of cork oak forests in Western Algeria, established since 1999.

Table 2 (*Average monthly temperatures and annual T (°C) in both forests*) shows that average annual temperatures in the littoral are of the order de 18.1°C against 15.9°C Zarieffet. January is usually the coldest month for both forests (12°C and 7°C M'Sila to Zarieffet). The warmest month is denoted by cons in August with 24.8 °C for the first zone and 25.6°C for the second.

Table 3 (*Mean monthly precipitation (mm) during the two reference periods*) shows that the mean monthly rainfall varies from one period to another. In the forest of M'Sila, the rainfall is more intense during the months of November and December (> 60 mm). Other months show less pronounced rainfall ranges mostly between May and September, indicating a significant water deficit.

In the forest of Zarieffet, the rainy season starts in part from September and reached its peak during the months from December to March (>60 mm). The months from June to August are still dry.

According to Gourinard (1958), the M'Sila forest covers an old Callabrian surface, still covered locally with marine deposits or correspondent dune. The cork oak is based on a very deep soil (> 2 m). They are covered with sand formations, coarse-textured grain size, fairly uniform from one station to another and from one horizon to another. The upper horizons, dry and mostly siliceous, contain a very small fraction of clay (< 3%) which significantly increases to over 60 cm depth (Bouhraoua, 2003).

Zarieffet forest at Tlemcen is based on geological strata that were formed mainly on an Upper Jurassic massif from a tertiary fold (Benest, 1985). The bedrock is composed mainly of Sequanian limestone, Kimmeridgian and Portlandian dolomites, and scattered outcrops. The soils are generally crossed by rock surfaces and rocky outcrops, being essentially superficial, at least 30 cm deep. These soils have a very heterogeneous texture from one station to another, ranging from sandy loam to sandy clay. Clay formations do not appear in this forest but in some places in the upper horizons of sandy clay soils. Nevertheless, they are often present beyond 80 cm depth (Kaïd Slimane, 2000).

Four circular plots of 20 m radius were marked in each forest, ranging the number of trees per plot between 25 and 30. Ten trees were sampled at random for each plot, extracting from each tree at 1.30 m high and facing the center of the plot a rectangular sample of cork with dimensions of 15 × 15cm (225 cm^2). The rotation age to obtain the sample was of 9 years. In total, 40 samples were obtained from each forest.

All plots belonged to a surveillance network dedicated to control the health status of the trees. In each tree, the health status was assessed in the summer by visual examination of the crown. Each tree was assigned to one of the following health categories (DSF, 1991; Bouhraoua and Villemant, 2002) (Fig. 2):

Table 2. Monthly average precipitation (mm) for two periods of time

Site	Period	J	F	M	A	M	J	Jl	A	S	O	N	D	Total
M'Sila	1913-34	71.3	59.4	48.6	40.0	31.3	10.8	1.08	3.2	20.5	44.3	82.1	86.4	501
	1971-01	61.5	50.0	49.2	31.9	25.7	5.2	0.2	1.5	11.5	38.0	63.1	61.9	400
Zarieffet	1913-38	83.2	101	93.2	72.3	65.5	27.7	2.2	5.6	26.6	57.7	92.2	81.0	710.5
	1961-04	76.0	75.3	103	82.9	62.2	16.7	4.00	3.3	23.2	45.5	63.9	71.3	625.5

Table 3. Average monthly and yearly temperatures (°C) for both forests

Site	Period	J	F	M	A	M	J	Jl	A	S	O	N	D	Mean
M'Sila	1913-34	11.1	11.6	12.8	14.6	17.0	19.9	22.7	23.5	21.6	18.1	14.6	12.0	16.6
	1971-01	10.5	11.4	12.5	13.8	16.5	19.5	22.8	23.7	20.7	17.5	14.2	11.4	16.2
Zarieffet	1914-38	5.9	7.1	8.8	11.2	15.2	19.6	25.4	25.8	21.1	16	10.1	6.8	14.5
	1975-04	6.7	8.5	10.6	10.9	14.3	20.2	22.5	22.9	20.4	18.9	11.7	8.9	14.7

— Class 1 (defoliation < 25%, healthy trees).
— Class 2 (defoliation 25-60%, weak trees).
— Class 3 (defoliation > 60%, decadent trees).

This classification is shorter than the commonly used in similar works (SPCAN-DGB, 2007), but is best suited for our goals.

Being nine years the rotation time, the health assessment of each tree of the sample was made from the surveillance network data files from 1999 to 2008 (year of sample collection). The average of all visual observations (1, 2, or 3) qualify a tree as healthy (mean ≤ 1.40), weak (1.40 < mean ≤ 2.40) or declining (mean > 2.40). The variables to consider are: Growth ($mm \cdot year^{-1}$), thickness (mm), scrap thickness (mm), density ($kg \cdot l^{-1}$), productivity ($kg \cdot m^{-2}$), porosity (%), and pore density ($1 \cdot cm^{-2}$).

Cork samples were put in boiling water for 1 hour according to the practice of industrial preparation of cork. Then, they were stabilized at room temperature (20°C) till constant weight to remove the water netted during the boiling.

Total thickness was determined for each sample from belly to back according ISO 1216:1998 standard. The age of the cork was estimated by counting the number of full growths (*f.g.)* plus the addition of two incomplete growths (*i.g.)* (*e.g.*, 9 years = 1/2 *i.g.* + 8 *f.g.* + 1/2 *i.g.*). The average annual growth was determined disregarding the two incomplete growths. The scrape thickness was calculated as the average of determinations made in 3 equidistant sites. These measurements were taken with the aid of a binocular microscope fitted with a graduated scale (micrometer) with 1/100 mm precision.

To determine the volumetric density ($kg \cdot l^{-1}$) and productivity ($kg \cdot m^{-2}$) of each sample their length and width were measured using a flexible rule of 1 mm accuracy. To calculate the density, the mass was determined with a precision balance of 0.001 g. Thickness value includes the thickness of the scrape.

The calculation of volumetric density responds to the following empirical formula:

$$\text{Density } (kg \cdot l^{-1}) = M/V$$

where V (l) = Volume = length * width * thickness

M (kg) = Mass of the sample

Productivity is given by the formula:

$$\text{Productivity } (kg \cdot m^{-2}) = M/S$$

where S (m^2) = length * width

M (kg) = Mass of the simple

The acquisition of the image of the tangential section of the 80 samples was performed with scanner. The samples were prepared for their study by image analysis. The belly of each sample was sanded on the entire section and then cleaned with compressed air. The porosity of the tangential section was studied by image analysis (González Adrados *et al*., 2005), using the Olympus software *cell^D*. As the limit of the images' resolution, the pores with a surface less than 0.07 mm^2 were not computed.

The following parameters were determined for each sample:

1. Coefficient of porosity (%) of the pores total surface in the cork total area.
2. Pore density (number of pores $\cdot cm^{-2}$).

After checking the ANOVA conditions, a two-way ANOVA model was applied to test the effect of health status and origin on the parameters. Two-way ANOVA is a special case of the linear model, being its form:

$$y_{ijk} = \mu + \alpha_{.j} + \beta_{i.} + \gamma_{ij} + \varepsilon_{ijk}$$

where:

y_{ijk} = is a matrix of studied variable observations (with row index *i*, column index *j*, and repetition index *k*).
μ = is a constant matrix of the overall mean
$\alpha_{\cdot j}$ = is a matrix whose columns are the deviations of each health status
$\beta_{i\cdot}$ = is a matrix whose rows are the deviations of each origin
γ_{ij} = is a matrix of interactions
ε_{ijk} = is a matrix of random disturbances

When interaction was detected, one-way ANOVA was run separately for each origin.

Results

Results from the image analysis were found anomalous in four cases, causing non-normality concerns for porosity and pore density. After analyzed, the four cases were considered as outliers, and image analysis data were eliminated from the data set. Thus, normality and homogeneity of variance conditions were considered sound enough to avoid variables transformation. The results for studied variables are shown in Table 4.

To date, there has not been found any work published about the topic for cork characterization in Algeria. On the whole, data shown in Table 4 are comparable with those published for, Portuguese (Pereira, 2007) and Spanish (González-Adrados *et al*., 1993)

Table 4. Description of the variables studied. N is the number of total samples. N2 same as N but excluding the outliers

Origin	Health status	N	Annual growth (mm · año^{-1})	Thickness (mm)	Scrap thickness (mm)	Density (kg · l^{-1})	Productivity (kg · l^{-1})	N2	Porosity (%)	Pore (1 · cm^{-2})
M'Sila	1	21	2.39 ± 0.23	21.68 ± 1.96	4.29 ± 0.72	0.29 ± 0.02	6.34 ± 0.60	21	3.79 ± 0.84	5.70 ± 1.28
	2	10	2.26 ± 0.40	20.44 ± 3.56	4.24 ± 1.20	0.29 ± 0.02	5.96 ± 1.07	10	4.34 ± 1.14	7.37 ± 1.83
	3	9	2.28 ± 0.35	20.55 ± 3.22	4.24 ± 1.10	0.30 ± 0.02	6.03 ± 0.87	8	7.35 ± 1,39	10.03 ± 1,6
	Total	40	2.34 ± 0.17	21.11 ± 1.51	4.27 ± 0.52	0.29 ± 0.02	6.17 ± 0.04	39	4.66 ± 0,74	7.01 ± 0.01
Zarieffet	1	21	2.27 ± 0.16	20.97 ± 1.48	5.62 ± 0.94	0.39 ± 0.02	8.13 ± 0.45	21	3.96 ± 0.76	6.12 ± 0.94
	2	10	2.16 ± 0.17	19.57 ± 1.64	4.76 ± 1.01	0.31 ± 0.02	7.04 ± 0.58	9	4.55 ± 1,61	4.77 ± 1.04
	3	9	2.04 ± 0.41	18.67 ± 3.72	4.91 ± 1.47	0.37 ± 0.05	6.57 ± 0.72	7	3.79 ± 1,60	5.44 ± 4,03
	Total	40	2.19 ± 0.13	20.10 ± 1.21	5.25 ± 0.65	0.38 ± 0.02	7.50 ± 0.39	37	4,07 ± 0,65	5.66 ± 0,64
Total	1	42	2.33 ± 0.12	21.32 ± 1.22	4.96 ± 0.62	0.34 ± 0.02	7.23 ± 0.47	42	3.87 ± 0.56	5.91 ± 0.78
	2	20	2.21 ± 0.22	20.00 ± 1.92	4.51 ± 0.70	0.32 ± 0.02	6.50 ± 0.64	19	4.40 ± 0,94	6.13 ± 1.21
	3	18	2.16 ± 0.27	19.61 ± 2.43	4.58 ± 0.88	0.34 ± 0.04	6.30 ± 0.56	15	5.69 ± 1,37	7.89 ± 1.55
	Total	80	2.27 ± 0.11	20.61 ± 0.97	4.76 ± 0.42	0.34 ± 0.02	6.84 ± 0.32	76	4.37 ± 0.49	6.36 ± 0.62

cork regions. It has to be highlighted the fact that, according to Pereira (2007) almost all of the samples belongs to the thin commercial class (thickness less than 27 mm).

The analysis of variance can better explain the effect of origin and health status on the variables taken into account. As an example, Table 5 shows the results for the coefficient of porosity. Table 6 summarizes the results of the other variables. Fig. 3 illustrates the distribution of the data grouped by origin and health status.

The effect of health status is shown in variables related to the presence of pores (porosity, pore density), which are also affected by the origin. Both variables present a significant interaction Origin * Health Status ($p < 0.01$). Fig. 3 and one-way ANOVA help to clarify the meaning of this interaction: for both variables the effect of health status is very clear in M'Sila ($p < 0.001$ for porosity and $p < 0.05$ for pore density in one-way ANOVA) and does not appear in Zarieffet, where the porosity has very few variations. In M'Sila, however, shifting into a worse state of health always imply an increase in the average values of porosity, both in terms of percentage and density (Fig. 3, Table 6). Pooling the data from both areas (Table 6) confirms the effect of health status ($p < 0.05$) being the coefficient of porosity of healthy trees (3.87 ± 0.56%) lower than the decadent (5.69 ± 1,37%). Similar trend occurs with pore density values (5.91 ± 0.74 *vs.* 7.89 ± 1.55 pore · cm^{-2}), though one-way ANOVA results are not significant.

Focusing on the remaining variables studied, density and thickness of the scrape are clearly affected by the geographical origin of the samples, but not by the health status. The values in Table 4 show how the density of the cork produced in the mountain area (0.38 ± 0.02 kg · l^{-1}) is significantly higher than in the littoral

Table 5. ANOVA results for Coefficient of Porosity

Inter-subjects effects test					
Source	**Type III sum of squares**	**df**	**Mean square**	**F**	**Sig.**
Corrected model	84.652[a]	5	16.930	4.274	0.002
Intercept	1,346.137	1	1,346.137	339.857	0.000
Origin	17.626	1	17.626	4.450	0.038
Health status	32.161	2	16.081	4.060	0.021
Origin * health status	42.035	2	21.017	5.306	0.007
Error	277.262	70	3.961		
Total	1,817.727	76			
Corrected total	361.915	75			

Dependent variable: tg CP (%). [a] R Squared = 0.234 (Adjusted R Squared = 0.179).

Table 6. Results summary of test between subjects effects of the variables studied (ANOVA)

Variable		Origin	Health status	Origin * health status
Growth	F	1.592	0.866	0.134
	p	0.211	0.425	0.875
Thickness	F	1.159	1.174	0.111
	p	0.285	0.315	0.895
Scrap thickness	F	4.333	0.804	0.030
	p	0.041	0.451	0.970
Density	F	25.015	0.585	0.638
	p	0.000	0.560	0.531
Productivity	F	13.166	4.072	1.555
	p	0.001	0.021	0.218
Porosity	F	4.450	4.060	5.306
	p	0.038	0.021	0.007
Pore density	F	13.014	3.131	6.471
	p	0.001	0.050	0.003

■ $p < 0.001\%$; ■ $p < 0.01\%$; ■ $p < 0.05\%$.

zone (0.29 ± 0.02 kg · l^{-1}). This increase can be attributed, at least partially, to the increased thickness of the scrape (5.25 ± 0.65 mm in Zarieffet compared to 4.27 ± 0.52 mm in M'Sila), a woody tissue with bigger density than cork itself. Though the differences are not significant, it has to be said in this regard, that the lowest annual growth rate of cork appears in the mountain areas of Zarieffet, 2.19 ± 0.13 mm · year^{-1} (2.34 ± 0.17 mm · year^{-1} in M'Sila).

Finally, productivity is affected by the origin as well as the sanitary status, although with less intensity for the latest. The effect of this last factor is the same in both areas (no interaction), being more obvious the differences (Table 4) between healthy and decadent trees in Zarieffet (8.13 ± 0.45 *vs.* 6.57 ± 0.72 kg · m^{-2}) than in M'Sila (6.34 ± 0.60 *vs.* 5.96 ± 1.07 kg · m^{-2}). Considering all samples from both forests, the results correspond directly with those obtained for the density and thickness of the scrape: productivity is significantly higher in Zarieffet (7.50 ± 0.39 kg · m^{-2}) than in M'Sila (6.17 ± 0.04 kg · m^{-2}) ($p < 0.001$). Neither growth nor the caliber achieves significant results, so it can be said that there are not differences for these variables between the groups considered.

Discussion

Results reflect the differences between cork production of forests located on the coast and in mountainous areas of Eastern Algeria. The health status varies from one area to another, so that each forest must be analyzed separately.

On the coast (M'Sila), porosity is more pronounced in the cork of trees with the worst health condition. This is probably due to the fact that these trees suffer considerable pressure from bush competition for water and mineral reserves (Bouhraoua, 2003). It is also a forest with a health deficit and high tree density, located in a semiarid climate. In this situation, the decline is affecting the proper functioning of the phellogen, causing an increase in porosity, but not in the already low growth rate (Courtois and Masson, 1999).

In the mountains (Zarieffet), the decay negatively affects productivity. These trees, located in subhumid climate with significant slopes, have an overall better health status than those from the coast. In them, mean age is greater (≥ 120 years) and tree density is lower compared to those of the coast. Thus, cork shows a late growth of predominantly small cells of the summer-autumn. Under these conditions, both the lower environmental drying as well as the cork oak lower physiological activity makes the new phellogen appearing, after the debarking, at a shallower depth in the liber. This causes thinning of the scrap and reduces the annual increases of cork, which altogether triggers a decrease in productivity.

Conclusions

In the studied area, the effect of health status on the cork production variables varies depending on ecolo-

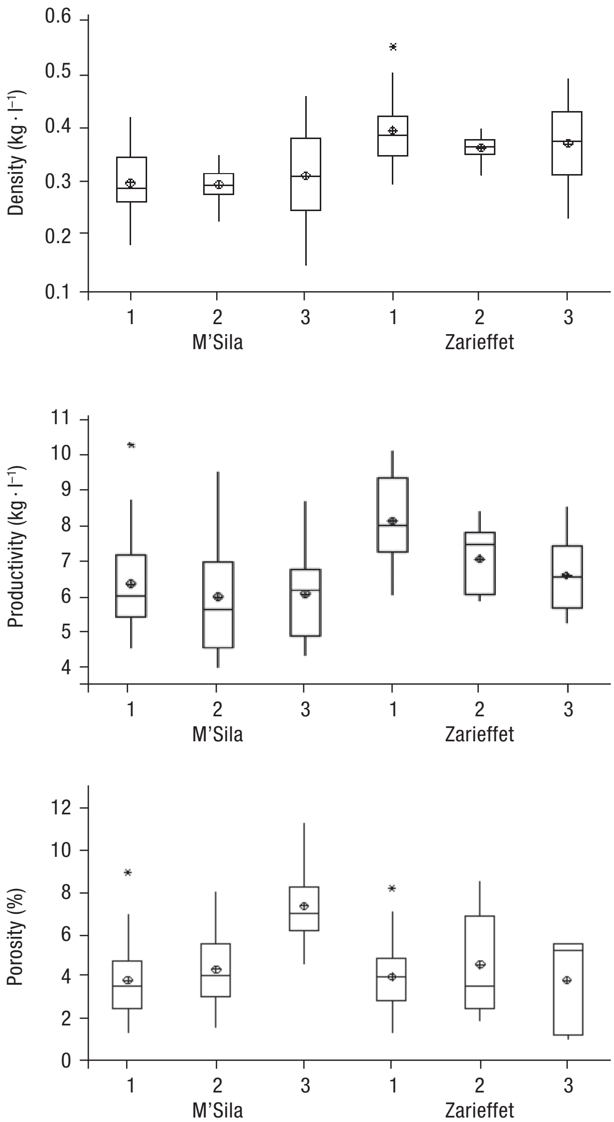

Figure 3. Results obtained in three of the variables studied.

gical and silvicultural conditions of the stands. The inland mountainous area, of subhumid climate and considerable slope, has higher productivity than the coast area in terms of surface density (cork kg produced by m^2 of debarked tree). Also, this variable is significantly affected by the loss of vigor with no appreciable effect on the porosity.

By contrast, in coastal areas of semi-arid climate and little or no slope, decay does not seem to affect the amount of cork produced by the tree, but the qualitative aspects of the material. Specifically, porosity is affected both in terms of number of pores (that differ in the phellogen) as in their extension (coefficient of porosity).

The geographical origin significantly affects the density and productivity, taking higher values in Zarieffet. The health status adversely affects productivity in mountain forests (Zarieffet) and porosity in coastal areas (M'Sila).

These results suggest the need for a deeper understanding of the factors that influence the formation and characteristics of the pores after debarking in the traumatic phellogen.

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