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Analysis of variation between stands and intra-treeon cork quality parameters in northwestern Tunisia

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Abstract - Cork quality mainly depends on caliber and visual aspects and is manually classified into $k$grades (9 classes according to IPROCOR). The main purpose of this study was to investigate the effects of variability both between sites and intra-tree, as well as the interaction between these factors, on cork caliber, some physical properties and cork quality, characterized mainly by caliber and the presence of some visual defects. A total of 240 trees were sampled at six sites in northwestern Tunisia. From each tree, two cork planks were sampled at ~ 0 m and 1.3 m tree height. Cork caliber (median: 59 mm), as well as density (240.1 kg/m^3)did not seem to vary significantly with the site, but it did seem to vary with tree sampling height; the farther up the tree the thinner and less dense was the cork. Cork quality index (Q), at cork plank level, was treated as an ordinal rating scale k'(9 grades), based on cork commercial price, and analyzed using a rank-based nonparametric method. k' varied significantly only according to site. For convenience, cork quality grade could be reduced to five classes (Stopper quality; Thick; Thin; Poorquality; and Discarded cork). Discarded cork had the highest percentage rate (50%), followed by Stopper quality (24%) and Poorquality (21%) once. Both Thick and Thin classes had percentage rates of only 2% and 4%, respectively, and were therefore merged with Stopper and Poorquality classes, respectively. A simple cork quality classification limited to three classes (bad, medium and good quality) was then defined.As for Cork quality index, this variable was significantly dependent on site, but not on tree sampling height, and couldalso be used to study cork quality based onenvironmental factors. Permanent plots should be installed to better understand environmental factors influencing cork quality.

Keywords: *Quercus suber* L.; cork; cork caliber; cork defects; northwestern Tunisia; Generalized Linear Mixed Models.

1. Introduction

Cork oak (Quercus suber L.) is a species endemic to the forests of the western Mediterranean region and the Atlantic coast.It is spread over about 2 million hectares (Pereira 2007), and occupies an area of 60,000 ha in Tunisia (IFN 1995).Cork is the bark of the cork oak. It is periodically harvested when it reaches a sufficient caliber, usually every 12 years in Tunisia. It is a low density cellular material with large compressibility, very low permeability to liquids and gases, thermal and acoustic insulation properties, dimensional recovery, and chemical stability and durability (Pereira 2007).It hasdifferent market opportunities (insulation, decorative elements), especially for producingcork stoppers.

Cork is usually graded according to its potential to produce stoppers, by taking into account the following parameters: 1) porosity, 2) caliber, and 3) defects (Ferreira et al. 2000). It is composed of dead hexagonal prismatic cells, aligned in rows in tree radial direction, without intercellular space, but includes some macroscopic pores, which are lenticular channels crossing the plank in a radial direction (Pereira 2007). These pores vary in distribution and size, and affect both cork porosity and quality. Good quality cork has few and small lenticular channels, whereas that of poor quality has pores with large cross-sectional areas (Pereira2007). Cork with great values usually belong to 27-32 mm, and 32-40 mm caliber classes (Ferreira et al. 2000). Cork defects, such as insect galleries, marked irregularities at the inner or the outer side of the plank, stains, lignified,are manually classified by professionals(Courtois and Masson 1999), and some defects limit use for producing stoppers.The cork color is also considered a factor influencing cork quality; a pinkish color is usually preferred to dark (Prades et al. 2017). Experts from the Cork, Wood and Vegetal Coal Institute (IPROCOR, Merida-Spain), have developed a cork quality classification of nine classes (Antonioand Montero 2004).ThisIPROCORcork classification seems to be subjective (Ferreira et al. 2000), with high misclassification rate, especially for medium cork quality classes (Pereira2007). In order to improve accuracy, the nine classes have often been reduced to 3-5by those in the industry.
Cork manufacturers are seeking better control of their cork supply by identifying factors, which contribute to producing good quality cork (Courtois and Masson 1999). Cork quality is mainly influenced by: 1) tree variables: tree age, tree size (Sánchez-González et al. 2007a), tree health state (Montoya, 1988) and genetic variability (Teixeira et al 2014); 2) managementpractice related variables: cork debarking coefficient and cork debarking rotation period (Guerchi and Sghaier 2008; Pizzurro et al.2010; Paulo and Tomé 2017), pruning (Canelas and Montero 2002), understory and soil management (Caritat et al. 1990); 3) ecological site variables: geomorphological site characteristics (Corona et al. 2005), site fertility (Costa et al 2008), precipitation and temperature (Courtois and Masson 1999; Paulo et al. 2017); and 4) stand variables: tree stocking (Bossuet, 1988; Sánchez-González et al.2007a; Pizzurro et al 2010).
Most of the work carried out on cork quality has been limited to the effect of the aforementioned variables on cork caliber. Few studies, however, have examined the influence of factors on cork qualityor cork physical proprieties, and almost none have studied intra-tree variability of cork quality. In addition, despite the relatively large number of studies carried out to analyze factors influencing cork quality in different countries of the Iberian Peninsula and the Mediterranean region, very few studies have been carried out in Tunisia, despite the economic importance of cork in this country. The only study done in this country was limited to examining the effect of the debarking coefficient and stem diameter on cork caliber (Guerchi and Sghaier 2008).
The purpose of this study was toevaluate intra-tree (cork at stem base vs cork at1.30 m tree height) and between-sitevariation of cork quality grade, as well as of other cork quality parameters (caliber, density and cork expansion).The study area was located in the Kroumirie Mountains, the main cork producing areas, in northwestern Tunisia.

2. Materiels And Methods

2.1. Study area and sampling

The studied area was located in Kroumirie, a mountainous region in northwestern Tunisiawith productive cork-oak forests. Six stands (S1: Khthayria, S2: Mejen Erumi, S3: Ein El khassa, S4: Uled Hlel, S5: El Mreej and S6: Bumershen) were sampled (Figure 1). They were distributed according to a bioclimatic gradient starting from the vicinity of Tabarka, a coastal town belonging to a humid Mediterranean bioclimate with temperate winter, according to the Emberger Climate Biogeographic Classification. They had different ecological characteristics (elevation, slope gradient, slope aspect and scrubland density). Within each stand, two circular plots of radius 25.2 m were delineated and twenty trees in full production (carrying female cork) were identified and marked; the total number of sampled trees was 240.
Cork was extracted during the most active cork growth phase, during the month of July 2009 in the studied areas.From each sampled tree, two cork planks (10 cm x 10 cm) were taken at the base level (~ 0 m) and at breast height (1.3 m) from the same north-facing side of the trunk.

2.2. Cork measurements

Cork samples were boiled for 1 hour in water at 100°C, according to standard post-harvest operation for raw cork planks, and left to dry in well-ventilated conditions until equilibrium. Cork caliber (mm or line=2.25 mm) of each sample was then measured using a digital gauge.Cork caliber was then subdivided into 5 grades: (1) more than 42.75 mm (more than 19 lines); (2) between 33.75 mm and 42.75 mm (15 – 19 lines); (3) between 29.25 and 33.75 mm (13 – 15 lines); (4) between 24.75 mm and 29.25 mm (11 – 13 lines); and (5) less than 24.75 mm (less than 11 lines). Cork density (kg/m3) for each sampled plank was evaluated on an air-dried sample. Cork expansion was also measured according to three directions : radial, axial and tangential.

Finally, cork samples were classified by an expert in the cork industry from IPROCOR (Spain) Institute into nine classes, taking into account: 1) cork caliber, and 2) defects (Figure 2). A Quality Index (Q) was then calculated either at plot levelor even at individual sample plank level ($Q = \frac{5}{100}\sum_{k=1}^{n} ip_k p_k$, where ip_k: index price for the cork quality k, p_k: proportion of cork planks or weight in cork quality class k in the plot, n=9: number of cork quality classes; Q varies between 1.3 and 19.5 when all cork planks in the plot belong to cork quality class 9 or 2, respectively) (Sghaier et al, 2011; Santiago, 2015). The index priceswere based on the price (in pesetas per Kg of cork in 1993) of each cork quality class for industry (Sghaier et al., 2011) (Table 1).

2.3. Stand and tree measurements

For each stand, climatic data (temperature, precipitation), as well as geomorphological (altitude, slope angle and slope aspect) and dendrometric (number of tree per hectare, basal area over cork and quadratic mean diameter over cork) data were collected. Only trees with diameter at 1.3 m over 7.5 cm were counted and measured.For each sampled tree, various tree-growth variables were measured : total tree height, vertical debarking height and diameter at 1.3 m over bark. The debarking coefficient (DC) was calculated as the ratio between debarking height and circumference over cork at 1.3 m height.Table Table 2 summarize some of the data collected.

2.4. Statistical analysis

A linear mixed model was fit to each quantitative cork parameter (cork caliber, cork density, cork expansions in radial, axial and tangential directions)in order to test the effect of the two fixed factors Tree Sampling Height(~ 0 m vs 1.3 m tree height sampling) and Site(six sites), as well as their interaction. Plotinside site, as well as treeinside site and plotwere considered as random effects.Error normality andhomoscedasticityassumptions within each factor were tested using Shapiro-Wilk W (Shapiro and Wilk 1965) and Bartlett methods (Snedecor, and Cochran 1989), respectively. In case the residuals were normally distributed, mean comparison tests were performed using Tukey-Kramer (homogeneity of the variances) or Dunnett's T3 (heterogeneity of the variances) methods (Dunnett 1980). On the other hand, if the residuals were not normally distributed, a power transformation proposed byBox and Cox (1964) would be performed in order to normalize the variable and a linear mixed model would be fit on the transformed variable.

The GLIMMIX procedure of SAS (version 9.4; SAS Inst. Inc., Cary, NC) was used to fit Generalized Linear Mixed Model (GLMMs) to the aforementioned dependent variables.

At individual plank level, cork quality index (Q) was treatedas an ordinal rating scale (k'=1,…,9) and analyzed using rank-based nonparametric methods, and not with parametric techniquessuch as analysis of variance. This parameter was repeatedly assessed on cork planks, sampled at 0 m and 1.3 m tree height in the same experimental units (trees). The experimental design is thus a repeated measures design, with three factors: 1) Site (6 levels), 2) Plot (2 levels within Site) 2) Tree sampling Height (2 levels). Relative effects were computed from ranks for each experimental unit (subject) and for each sampling height, and then an ANOVA-type statistic (ATS) was performed by taking into account the dependencies within subject ratings. The effects of Site, Plot and Tree Sampling Height, as well as the interactions between them were tested. Estimated relative treatment effects (p̂_ij) between Tree Sampling Heightand Sites with appropriate confidence limits were computed.

Concerning Q calculated at plot level, the same non-parametric analysis was performed. Only the Site, Tree sampling Height and interaction Site x Tree sampling Height were tested.

Cork quality Index (Q) was analyzed using R Package 'nparLD' (Noguchi et al 2012)

3. Results and Discussion

Some dendrometric parameters of the sampled trees, as well as of the studied sites, were reported in Table 1.

3.1. Quantitative cork parameters

For all of the quantitative cork characteristics studied, the Site effect, as well as the interaction between Site and tree sampling heightwere not significant at the 5% level (Table 3).

3.1.1. Cork thickness

After a debarking rotation period of 12 years, cork thickness varied between 8 mm and 59 mm, with amedian, interquartile range (IQR=Q3–Q1) and variation coefficient of 29 mm, 12 mm and 29.7%, respectively.

Overall, the thinnest cork grade (<24.75 cm) had the highest frequency (30.19%), followed by intermediate grades belonging to [24.75 cm, 29.25 cm [, [29.25 cm, 33.75 cm [and [33.75 cm, 42.75 cm [, with a frequency of 20.13%, 17.61% and 25.58%, respectively. The thickest cork grade (≥42.75 cm) had the lowest frequency (6.50%) (Figure 3). The thinnest cork grade (<24.75 cm) appears to be relatively abundant in some studied sites (especially sites 1 and 2 in the Tabarka region), suggesting that the debarking rotation period should be readjusted according to stand "fertility" (the lower the site fertility, the longer the debarking rotation period is), and eventually "state of health", and not set at 12 years for all Tunisian cork oak stands, as is currently the case.

Cork thicknesssignificantly varied only according to tree sampling height. The average cork caliber was significantly thinner at 1.3 m height, in comparison with that at 0 m height. The studied sites were chosen according to an altitudinal gradient and consequently according to a temperature / precipitation gradient. The absence in this study of a significant site effect and therefore of an altitudinal gradient on cork caliber could possibly be explained by: 1) the low geographical dispersion of the data set in this study, with precipitation values ranging from 1095 to 1547 mm, 2) the low number of sampled sites, and 3) the high variation between treesin cork growth response resulting from the genetic variability of the trees (Teixeira et al. 2014), tree health (Montoya, 1988) and/or microsite conditions (e.g. tree competition, soil depth). Sánchez-González et al. (2007) did not find a significant relationship between annual precipitation and cork caliber, in the Cadiz region (Spain), characterized byhigh annual precipitation (from 1070 to 1391 mm). However, Paulo et al. (2016) did find that precipitation had a significant effect on cork growth index, defined as the radial width of the first eight complete years of cork growth after stripping, where the data set was collected along the cork oak distribution area in Portugal, and includes precipitation values ranging from 445 to 1064 mm.

3.1.2. Cork density

Cork density varied between 158 kg/m³ and 542 kg/m³ (Median=240.1 kg/m³; IQR=64.9kg/m³; VC=20.7%). It is positively skewed and a lognormal model was usedin order to get normally distributed errors. According to ANOVA results, this parameter varied significantly only according to tree sampling height. As for cork caliber, the average cork density was significantly lower at 1.3 m height, in comparison with that at 0 m height. Cork density was significantly negatively correlated with cork thickness (Kendall Tau-b Correlation Coefficient=–0.34591; Prob > |tau|<0.0001).

3.1.3. Cork expansions in radial, axial and tangential directions

Cork radial, axial and tangential expansions had median (IQR) values of 12.00% (6.72%), 5.77% (1.21%), and 7.77% (1.88%), respectively. Cork expansion in a radial direction varied between 2.70 and 23, with a highervariation coefficient of 36%. Cork expansion in a tangential direction had a lower variability, with minimum and maximum values of 4.7% and 13.8%, and a variation coefficient of 16%. Cork expansion in an axial direction had similar variability as the tangential one, with minimum and maximum values of 2.9% and 7.8%, and a variation coefficient of 18%. Only cork expansion in an axial direction varied significantly according to tree sampling height, with an average value significantly higher for planks sampled at 1.3 m tree height.

3.2. Qualitative cork parameters

La fréquence mensuelle des feux au cours des 28 années (1985-2012) évolue durant une période de 5 mois, de juin à octobre (figure 2). Ceci est dû au fait que cette période coïncide avec la saison sèche favorisant ainsi le développement des feux de forêt. C'est durant le mois le plus chaud et le plus sec de l'année (août) que l'on enregistre le plus grand nombre de foyers avec 1856 départs de feu. Même constatation concernant la superficie brûlée qui est de 35.751,61 ha, soit 57,97%.

3.2.1. Cork quality index Q

At plot level, Q values calculated from samples collected at tree base varied between 3.75 and 9.89, with an average (± SE) of 6.27 (±0.53) whereas Q calculated from samples collected at 1.3 m tree height, varied between 3.42 and 9.47 with an average of 6.96 (±0.56). Site 4 had the highest Q value at 1.3 m (8.57), followed by Site 6 (Q=8.34) and Site 5 (Q=7.35), all from the Ain Draham region; Site 1 had the lowest Q value at 1.3 m (3.9125), followed by Site 3 (Q=6.33) and Site 2 (Q=7.28), from the Tabarka region. Nevertheless, ANOVA-Type Statistics (ATS) did not reveal either a significant effect of Station (p=0.2485181), orTree sampling position (p=0.1831809), or Station x Tree sampling interaction (p=0.3141979) for this parameter.

Q calculated at plot level could not really be used to statistically compare sites; it gave an overall idea about site cork quality. In this study, itwas estimated from a sample of 20 trees per plot, with two plots per site. The number of sampled plots per site should be increased in order to take into account site variation and reduce error, and therefore detect significant differences between sites concerning Q.

On the other hand, at plank sample level, analysis of Q value is nothing less than an analysis of an ordinal rating scale (k'=1,…,9; Table 1), based on market price, using a rank-based nonparametric method. ANOVA-Type Statistc (ATS) showed a significant stand effect (p=0.009110755), whereas the effects of tree sampling position (p=0.218462256), plot (p=0.055813593) and the interactions between these factors were not significant at 0.05 level. Sites from the Ain Draham region (6, 5 and 4) had betterEstimated relative treatment effects than those from the Tabarka region, but the difference was not always significant (Figure 4).

The use of Q index at plank level, or the ordinal rating scale k', based on cork market price, and a rank-based nonparametric method was helpful in studying cork quality. This approach should be generalized in the study of cork quality according to ecological factors.

3.2.2. Cork quality grade

Cork quality was grouped into 5 categories (1: stopper quality cork; 2: thick cork; 3: thin cork; 4: poor quality cork; 5: discarded cork). Overall, sampled planks belonging to the discarded corkcategory had the highest frequency percentage (49.9%), followed by stopper quality cork (23.6%), and poor quality (20.7%) (Figure 5). The other two categories had low percentages: 1.5% for thick cork and 4.4% for poor quality cork. In order to analyze this variable using the ordinal logistic model, these two grades were merged with other categories in order to avoid zero frequency per cork quality category according to site or tree height-sampling position. The thick cork category was merged with that of stopper quality cork, and the thin cork with the poor quality.According to this new simplified classification of cork quality grade, a Chi-square test showed a significant dependence between cork quality grade and site (df=10 ; Chi-square value=24.2645 ; p=0.0069). The percentage rate of discarded cork was the highest in site 1 (62.5%), followed by sites 3 (61.25%) and 2 (48.75 %), and the lowest percentage rate was found in site 6 (36.25%) ; sites 4 and 5 had intermediate percentage rates (43.04% and 47.5%, respectively). On the other hand, there was no significant dependence between cork quality grade and tree sampling height (df=2 ; Chi-square value=1.3709 ; p=0.5039).

Cork qualitygrade, which depends not only on cork defects but also on cork thickness, did not seem to vary according to tree sampling height. Thus, it seems that debarking height did not influence cork quality grade. Similar results were reported by Courtois and Masson (1999), who did not find a significant correlation between debarking height and cork quality grade (8 categories were defined), evaluated on a random sample of cork stoppers per tree.Therefore, Montoya's (1988) observationaccording to which "a better quality of cork, less porous, would be expected when the debarking height applied is greater" was not supported in this study. As a matter of fact, cork quality improvement with tree height is often limited by the gradual decrease in cork thickness in the upper parts of the tree.According to Courtois and Masson (1999), if the debarking height is increased too much, cork quality would be degraded, and there would be more injuries caused by debarking, which would in turn reduce the productive life of the tree.

Reducing the number of cork quality grades into three ordinal categories (bad, medium and good quality cork) was helpful in screening sites according to their cork quality grade.

4. Conclusion

According to this study, it seems that cork caliber as well as cork density did not vary significantly between sites, likely because of the great variability of these two parameters inside plots within sites. Nonetheless, these two variables seemed to vary according to tree sampling height ; corks sampled at 0 m had higher average values for these variables than for those sampled at 1.3 m tree height. As for cork expansions in radial, axial and tangential directions, they did not seem to vary according to either site or tree sampling height.

Cork quality grade, ordered into 9 classes according to commercial value or limited for convenience to three classes, seemed to vary according to site, but not according to tree sampling height.

In order to better understand the effects of environmental factors on cork (grade, caliber, and even color and defects), treevariables (dimension and health state), stand variables (stand density), pedoclimatic and geomorphological site features, and management practices (debarking coefficient) should be studied in detail by increasing the number of sites.Other automated methods (electric conductivity) assessing cork quality directly on the treeshould also be used in addition to manual methods. Permanent plots spread out over the cork production area should be installed, making it possible to study cork quality and growth over successive cork debarking rotations.

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