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Study of the variability of cork growth in northern Algeria

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ABSTRACT

The study of the growth of Algerian cork according to the concept of origin was carried out on 100 samples of 20x20cm representing ten production regions (El Tarf, Jijel, Skikda, Mila, Guelma, Bejaia, TiziOuzou, M'Sila, Hafir, Zarieffet). The caliber varies significantly from one to another (Origin 1). On average, it was about 29.75 mm with a still regressive aspect in the Western Region (Origin 2) and the Mountain Zone (Origin 3). The mean annual increments for an 8 year production cycle follow the same path, very significantly different between the samples of the Eastern Region (3,14mm $year^{-1}$: El Tarf, Jijel, Skikda Guelma and Mila), the Central Region (3.19 mm $year^{-1}$: Tizi Ouzou and Bejaia) and Western Region (2.64 mm $year^{-1}$: M'Sila, Zarieffet and Hafir), a reduction of 12% in the Mountain Area. Growth indices were very stable for samples of origin1, shades and growth irregularities appear by applying the concept of origins 2 and 3. Regardless of the origin used, the indices of growth rate are type fast in Central and Eastern Region and middle type in the Western Region. This fact also applies to the Coastal Zone more than the Mountain Area.

RESUME

Étude de la variabilité de croissance du liège dans le nord de l'Algérie. L'étude de la croissance du liège algérien selon le concept d'origine a été réalisée sur 100 échantillons de 20x20cm représentant dix régions de production (El Tarf, Jijel, Skikda, Mila, Guelma, Bejaia, Tizi Ouzou, M'Sila, Hafir, Zarieffet). Le calibre varie considérablement d'une provenance à l'autre (Origine 1). En moyenne, il était de l'ordre de 29,75 mm avec une forme régressive dans la région de l'Ouest (origine 2) et la zone de montagne (origine 3). Les accroissements annuelles moyennes pour un cycle de production de 8 ans suivent la même tendance, très significativement différents entre les échantillons de la Région de l'Est (3,14mm an^{-1}: El Tarf, Jijel, Skikda Guelma et Mila), la Région du Centre (3, 19mm an^{-1}: Tizi Ouzou et Bejaia) et Région de l'Ouest (2,64 mm an^{-1}: M'Sila, Zarieffet et Hafir), soit une réduction de 12% dans la région de Montagne. Les indices de croissance étaient très stables pour les échantillons d'origine1, les nuances et les irrégularités de croissance apparaissaient en appliquant le concept d'origines 2 et 3. Indépendamment de la provenance utilisée, les indices de rythme de croissance sont de type rapide en Région Centrale et Orientale et de type moyen dans l'Ouest. Ce fait s'applique également à la zone côtière plus que la zone de montagne.
Mots-clés : Origine, calibre, accroissements, Indice de croissance, Rythme de croissance.

1. Introduction

Mediterranean forests cover about 81 million hectares (9.4% of the world's forested area) and consist of a mosaic of forest species, mostly hardwoods (about 60%) (Mugnossa et al., 2000). The share of oak cork forest does not exceed 9%, ie a very small area of 2.7 million hectares distributed in 7 countries: 33% in Portugal, 23% in Spain, 1% in France, 10% in Italy, 15% in Morocco, 21% in Algeria and 3% in Tunisia (Aronson et al., 2009). From an ecological point of view, these stands are among the huge carbon sinks. Only Portugal's cork oak forests hold 4.8 million tonnes of CO_2/year, or 5% of the country's emissions (Forgues, 2007). These forests produce a large amount of cork with very high industrial and social values (about 300 million kg / year) of which 87% comes from Europe (55% from Portugal, 28% from Spain, 1% from France and 3% Of Italy) and the rest of North Africa (4% of Morocco, 3% of Tunisia) (Lopes, 1996, Santos Pereira, 2008).

Many authors have mentioned the process of formation of annual cork increments and have proposed a commercial classification for each cork thickness, similar to each geographical and production area (Lamey, 1893; Saccardy, 1937; Boudy, 1950 and Natividade, 1956; Pereira, 2007). The cork produced annually by the tree of *Quercus suber* is propelled to the exterior of the liber by the action of the cell division of the secondary meristems which are the cambium and the phellogen. This meristematic activity is initiated from March and ends in November with the first cold. It is imperative that two-thirds of the annual growth is carried out from March to June (Natividade, 1956). This complex nature of growth, coupled with the heterogeneity of factors affecting tree growth, has a high variability; hence the concept of sugary activity is difficult to define.

Few studies have studied the study of the variation of the growth of the Algerian cork in its geographical component of the West passing from the Center and the East of Algeria then spreading from the Littoral to the

Mountain. The species is a zonal species, it is found from the edge of the waters to the rocks of high altitudes. This zonality is synonymous with adaptation to the various abiotic factors, resulting in a radial and sub-tropical growth varying from coast to mountain and a quality of cork contradictory (Varela, 2000). Since it is a monoecious species whose allogamy is further aggravated by the frequent occurrence of interspecific hybridization phenomena, the concept of provenances is required for Algerian cork in spite of geomorphological variations and Climatic conditions that characterize the Algerian Tell.

According to Illy (1966), the provenance indicates the place where a population of trees (endemic or not), or that from which forest seeds originate, grow. Teissier-Ducros (1979), defines the concept of provenance as a reproductive material harvested from a certain number of individuals in a stand, it must be representative of the stand. In our work, the concept of provenance encompasses geographical origin according to three attributes:

- The place where the trees grow and where the samples are collected (Provenance 1).
- The geographical location of the cork oak in Algeria (Region West, Region Center and Region East). To this explanation is added the administrative belonging (conservation and others) (Provenance 2).
- The cork oak (Mountain Zone and Coastal Zone), which encompasses the maritime environment of the Mediterranean and the continentality due to the thermal amplitude (Provenance 3).

The main aim of our work is to elucidate part of this variability of growth based on samples from different sources in the West, East and Central Algerian North.

2-Materials and methods

2.1. Study area

The studied samples came from 10 cork-oak stands located along a coastal strip of 1200 km and of an incursion into the plains on 100 km to 1500 m of altitude. In the northeast, *Quercus suber* prospers on siliceous soils forming part of the east coast in sub-humid and humid climate. It forms an only one block of 250 000 ha to the Tunisian borders. Another less compact growth on sandy grounds (44 000 ha) with sub-humid climate in the center and finally some small zones isolated in the western littoral and the mountain in sub-humid and semi-arid climate (18 000ha) (Tab.1).

Table1-Climatic, topographic and forestry parameters of the ten sampling points

Provenance/code	Annual precipitation (mm)	Altitude (m)	Slope (%)	Soil parent material	Tree density (ha^{-1})	Cork thickness (mm)	Average height debarking (m)
Zarieffet (ZA)	650	1000	17	Sequanian Sandstone	60	21.82±2.99	1.8±0.13
M'Sila (MS)	350	400	4	Sand	100	29.15±5.70	2.4±0.14
Hafir (HA)	700	1100	20	Sequanian Sandstone	115	21.93±2.90	2.5±0.15
Tizi Ouzou(TZ)	1100	800	25	Screes	170	34.37±6.06	1.7±0.13
Bejaia (BJ)	800	600	12	Sandstones	150	31.25±4.15	2.5±0.16
Jijel (JJ)	1 200	410	13	Shale	160	30.20±2.31	3.5±0.32
Skikda (SK)	1100	400	-	Numidian Sandstones	180	37.05±9.01	2.8±0.15
Guelma (GL)	600	290	-	Numidian Sandstones	120	31.86±3.37	2.65±0.14
Mila (ML)	700	460	-	Numidian Sandstones	110	29.72±4.89	2.47±0.16
El Taref (ET)	1200	400	-	Numidian Sandstones	160	35.28±4.45	2.6±0.50

2.2-Samples and data collection

Rectangular samples of cork with dimensions of 12× 12cm ($144cm^2$) were taken at breast height during the cork extraction. To observe the growth rings, the samples were boiled in water for about 1 hour and dried in open air until equilibrium. To prepare them for measurements, the planks were cut into thin sections. Total thickness was determined for each sample from belly to back in a middle point of the transverse cork section. The age of the cork was estimated by counting the number of full growths (Fig.1) 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. These measurements were taken with the aid of a binocular microscope fitted with a graduated scale (micrometer) with 1/100 mm precision.

The calculation of the index of increments is calculated according to the least squares method of Waren (1980):

$Yt = at^{b}e^{-ct}E_t$
$Y_t = \ddot{y}_t E_t$,

Yt is the current measure of cork growth
$\ddot{y}_t$ is the estimated value
E_t residual value
a,b and c = constant; t= time or number of the increment
So Iac=$\ddot{y}_t / E_t$

Every time the index of increase approaches 1, annual growth is stable

The annual growth rate is calculated through the Growth Rate Index (GRI). During the production cycle, this rhythm varies from one tree to another and from one provenance to another depending on the ecological conditions of the environment. The formula proposed by IPROCOR (2013) makes it possible to define the speed or the slowness of the suberous activity according to the type of increase produced annually by the tree.

$$GRI = \frac{\sum_{i=1}^{nt} ni\ Ai}{N}$$

ni: Number of samples of class i of annual growth type
Ai: Weight of class i (1 if i = 1; 2 if i = 2 etc.)
N: Total number of samples

1-Low increase: Ac <1.5 $mm.an^{-1}$
2-Mean increase: 1.5 <Ac <2$mm.an^{-1}$
3-Rapid growth: 2 <Ac <3$mm.an^{-1}$
4-Very fast growth: Ac> 3$mm.an^{-1}$

3. Results

The measurements of the calibers and the complete annual increments of the 100 samples according to the provenance concept are given in Table 2.

Table 2- Mean values of annual caliber and increments (standard deviation)

Origin 1	**Annual growth (mm)**	**Caliber (mm)**
ML	2.93 (0.49)	27.56 (4.63)
GL	3.02 (0.37)	31.86(3.37)
ET	3.43 (0.58)	35.26 (5.45)
SK	3.27 (0.59)	30.03(2.31)
JJ	3.07 (0.25)	34.05(9.01)
BJ	3.08 (0.48)	31.33(4.97)
TZ	3.31 (0.41)	34.37(6.06)
MS	2.96 (0.23)	29.15(5.80)
HA	2.17 (0.13)	21.94(2.99)
ZA	1.82 (0.12)	21.84(2.30)
Origin 2		
Eastern region ML,GL,ET,SK,JJ	3.14(0.48)	32,21(5,52)
Central region BJ,TZ	3.19(0.44)	32.85(5.62)
West region MS,H,ZA	2.31(0.51)	24.21(5.20)
Origin 3		
Coastal zone ET, SK,JJ,BJ,MS	3.15(0.46)	31.96(6.13)
Mountain zone ML,GL,TZ,HA,ZA	2.64(0.65)	27.97(6.41)

3.1. Caliber of cork

The results in Table 2 clearly confirm that the Zarieffet and Hafir samples differ from the other provenances 1 by their reduced average sizes (21.84 and 21.84 mm). The best thicknesses relate particularly to the El Taref (35.28mm), Jijel (34.05mm), Guelma (31.86mm), Skikda (30.02mm) and Tizi-Ouzou (34.37mm) samples (Fig.1). In other words, this subdivision also seems to be related by referring to the concept of origin 2.

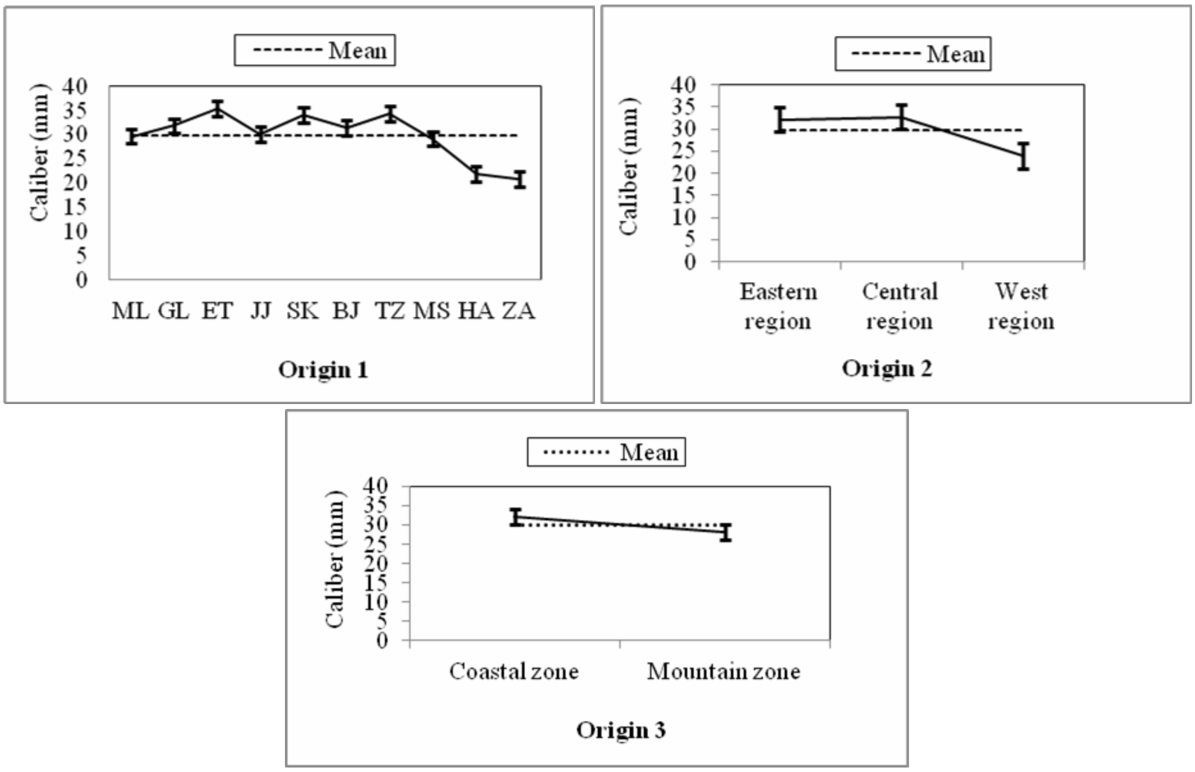

Figure 1- Range of average caliber for the studied cork samples

The results of Kruskall-Wallis test indicate a highly significant difference among the ten origins (Tab.3).

Table 3- Result of Kruskal-Wallis test

K (observed value)	47.,98
K (critical value)	16.91
df	9
p-value	< 0.0001
Alpha	0.05

3.2. Annual cork growth

Along the 8 years of the production cycle, the samples of the East and the Center generate a average annual growth (3.14mm yr^{-1} and 3.19 mm yr^{-1})higher than those of the West (2.31mm yr^{-1})(Tab. 4) .

The results of the Kruskal-Wallis test indicate the presence of two significantly different groups. The first concerns the provenances of Mila, Guelma, El Taref, Skikda, Jijel, Bejaia, Tizi-Ouzou and M'Sila. The second contains the provenances of Hafir and Zarieffet (Tab. 5).

Table 4- Annual average increases in a 9-year production cycle (8 years of full growth). Average for each provenance ± the confidence interval (n = 100).

	1st ring	2nd ring	3rd ring	4st ring	5st ring	6st ring	7st ring	8st ring	Mean±IC
ML	2.62±061	3.44±0.76	3.64±0.73	3.39±0.57	2.79±0.42	2.69±0.45	2.54±0.34	2.33±0.32	2.92±0.53
GL	2.85±0.42	3.42±0.53	3.50±0.38	2.99±0.35	3.27±0.44	2.925±0.37	2.75±0.43	2.40±0.28	3.01±1.01
ET	3.12±0.99	3.45±0.98	4.07±1.08	4.47±1.16	3.38±0.89	3.23±0.90	2.73±0.84	2.97±1.07	3.43±0.99
JJ	2.80±0.36	4.03±0.43	3.23±0.46	3.93±0.35	3.68±0.40	3.35±0.22	2.68±0.37	2.45±0.40	3.27±0.37
SK	2.82±0.32	3.05±0.43	3.27±0.55	3.22±0.57	3.27±0.63	3.22±0.56	2.57±0.46	3.07±0.94	3.06±0.56
BJ	3.55±0.43	3.70±0.45	3.50±0.60	3.17±0.56	2.72±0.46	2.90±0.32	2.72±0.52	2.35±0.48	3.07±0.24
TZ	4.00±0.66	3.75±0.74	3.37±0.51	3.31±0.58	3.22±0.35	3.17±0.39	2.97±0.38	2.70±0.40	3.31±0.50
MS	2.85±0.61	2.97±0.64	3.12±0.74	3.27±0.44	3.20±0.29	2.90±0.26	2.75±0.33	2.60±0.45	2.96±0.46
HA	2.18±0.33	2.28±0.59	2.23±0.50	2.08±0.34	2.09±0.52	2.21±0.54	2.32±0.59	1.93±0.36	2.16±0.47
ZA	1.75±0.25	1.99±0.26	1.96±0.21	1.79±0.19	1.91±0.20	1.75±0.23	1.78±0.20	1.62±0.23	1.82±0.22

Table 5 - p-values between samples from Origin 1 and 2

	ML	GL	TR	SK	JJ	BJ	TZ	MS	HA	ZA
ML	1									
GL	1.000	1								
TR	0.860	0.962	1							
SK	0.979	0.999	1.000	1						
JJ	1.000	1.000	0.937	0.998	1					
BJ	0.995	1.000	0.989	1.000	1.000	1				
TZ	0.938	0.979	1.000	1.000	0.979	0.998	1			
MS	1.000	1.000	0.674	0.989	0.989	1.000	0.638	1		
HA	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	1	
ZA	0.027	0.027	0.027	0.027	0.026	0.027	0.027	0.027	0.052	1

Level of significance: p <0.05

3.3. Growth index (GI)

Variations in the growth indexes of the ten provenances are shown in the figure 2, according to origin1, 2and 3.

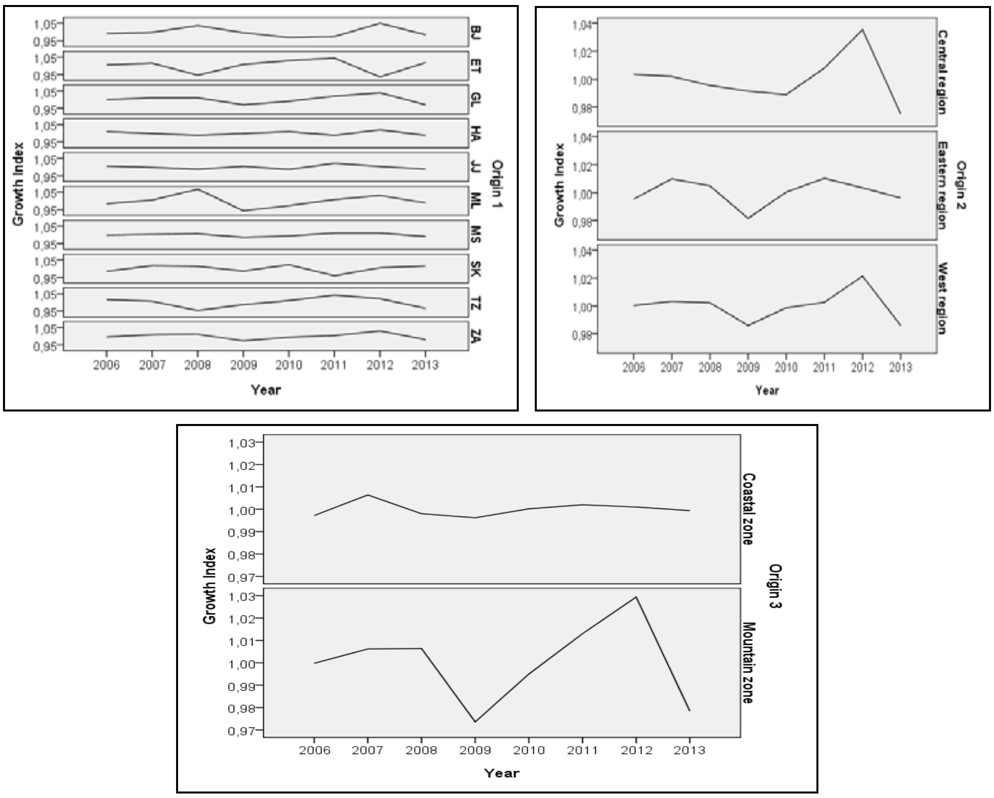

Figure 2- Indices of growth (GI) of cork under the concept of Origin 1, 2 and 3

3.4. Growth Rate Index (GRI)

The suberous activity is not similar for all provenances. The growth rate indices (GRI) calculated for all samples (Provenance1) reveal a first IRC (average type) with an average value of 2.31 (Zarieffet and Hafir) and a second (fast type) of 3.56 (Mila, Guelma, El Taref, Skikda, Jijel, Bejaia, Tizi Ouzou and M'Sila). For Progeny 2 samples, the growth rate indices adopt a different pattern with stable mean values of 3.58 and 3.62, encompassing the eastern and central regions simultaneously (fast GRI). The western region seems to stand out with an average type GRI of the order of 2.66 (Fig.3).

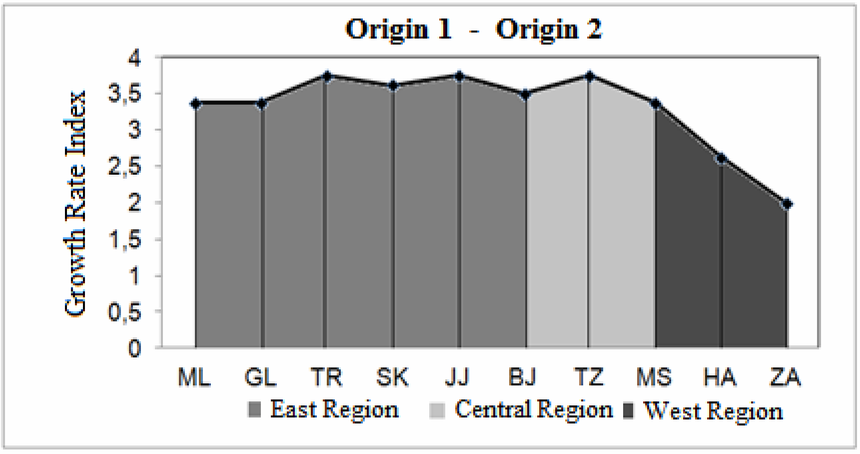

Figure 3- Growth Rate Index (GRI) under the concept of Origin 1 and 2

As for provenance 3, samples from the Coastal zone (El Tarf, Skikda, Jijel, Béjaïa and M'Sila) recorded an average of 3.52 (fast GRI). In this division, it also appears that the decline in the growth rate is still on the western side (M'Sila). In the Mountain Zone (Mila, Guelma, Tizi Ouzou, Hafir and Zarieffet), the growth rate is average (GRI = 2.94). In this division, stability of growth is visible on samples from East and Central (Mila, Guelma, Tizi Ouzou) and attenuated from the west (Hafir and Zarieftt) (Fig. 4).

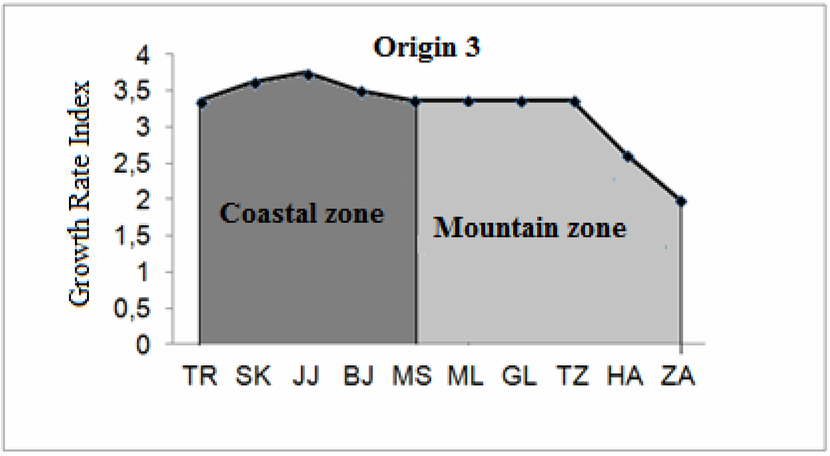

Figure 4- Index growth rate (IRC) under the concept of Origin 3

4. Discussion

The average caliber (29.96mm) obtained for all the origins seems lower than those quoted in the bibliography: Portugal (33.8mm), Spain (31,7mm) and Morocco (31.5mm) (Ferreira et al., 2000; Gonzalez et al ., 2000; Famiri, 2006). At the national level, the western cork is clearly lower than that of the center and from the east of the Algeria. We register respectively 24.30mm (Hafir, Zarieffet and M'Sila), 32.81 mm (Bejaia and Tizi-Ouzou) and 32.22 mm (Mila, Guelma, El-Taref, Skikda, Jijel). The best calibers concerning the samples of Guelma (31.86mm), El-Taref (35.28mm), Skikda (30.02mm), Tizi-Ouzou (34.37mm) and Jijel (34.05mm).The calibres of the Western Region are lower than those of the Central Region and the East Region, Order of 24.30mm

(Hafir, Zarieffet and M'Sila); 32.85 mm (Bejaia and Tizi-Ouzou) and 32.21 mm (Mila, Guelma, El-Taref, Skikda and Jijel) . Moreover, by adopting the concept of provenance 3, it is clear that the Littoral zone contains average sizes exceeding those of the Mountain zone, an average of 31.96mm against 27.97mm.

Overall, the mean value of the annual full increments measured on the cork of the 10 forests (2.90 mm) is similar to those cited in the European Research Project (Corkassess, 2001):

- In the case of the cork of Andalusia and Catalonia (Spain), falling within the limits of 2.0– 4.8 mm and in the case of cork of Sardinia, between the limits of 2.3-2.8 mm.
- In the case of cork from Corsica (France), storing between 2.8mm and 4.4mm.
- Our average is away from the Portuguese cork whose limits vary from 3.8 mm to 4.3mm.

Referring to the figure 2, we find that the growth index (GI) curves for all samples from Origin 1 are characterized by stability during the production cycle, which is in our case from 2006 to 2013. The nuances and disparities between the indices appear clearly, taking into account the concept of Origin 2 and 3 where the influence of climate, littorality and continentality is very marked when moving from eastern Algeria to its west.

5. Conclusion

In Algeria, the spatial and geographical distribution of the cork oak has been based on the geomorphological characteristics and climatic specificities of the Northern Algerian. These two parameters have generated two different types of stands in the field: a continuous block that begins at the Tell Central and extends to the east of the country until the Kroumirie in Tunisia. The other less important, scattered in the North-West Algerian in the form of insignificant spots is very often very relics individuals. This ecological mosaic has had a major influence on radial and sugary growth over time.

The *Quercussuber* L. of western Algeria follows a totally different trend from that of the Center and the East of the country from which the notion of provenance imposes itself as a sine qua non condition before any study. Indeed, through the results obtained on the 100 cork samples representing ten provenances from the Algerian North, we conclude that:

- Calibers vary significantly from one source to another ($p <0.001$).
- The caliber loses 26% of its growth in western provenances (Hafir, Zarieffet and M'Sila) as those of the Center and the East, an average of the order of 24.21mm against 32.53 mm.
- The mean annual increases of the 10 provenances differ very significantly ($p <0.000$) between the Eastern Region samples (3.14 mm year-1: El Taref, Jijel, Skikda, Guelma and Mila) 19mm year-1: TiziOuzou and Bejaia) and the Western Region (2.64 mm year-1: M'Sila, Zarieffet and Hafir). In the provenances of the Mountain Zone, the increases are reduced by 12% compared to those of the Littoral Zone ($P <0.01$).
- The growth indices were stable in the samples of provenance 1, the variations appear remarkably by evoking the concept of provenances 2 and 3.
- Eastern and Central provenances are characterized by rapid growth rate indices while those of the West are of medium type.

These findings support the observations and the results obtained in the past by a large number of authors who have worked on Algerian oak forest including Lamey (1893), Saccardy (1937) and Boudy (1950). All these authors align themselves with the fact that the growth of cork is much correlated with the vegetative and climatic situation of the Algerian North which goes in crescendo from the Western Region to the Eastern Region.

Studies and disciplines can be incorporated to explain the mechanism of cork growth and the suberous activity of the phellogen. We cite specialties in relationship with soil moisture retention, electrical resistivity of surface horizons), regeneration and genetic improvement of elite trees by somatic embryogenesis, study of micro-propagation of cork oak, study of diet minerals of trees and the study of cork technology (quality) in relation to the ecophysiology of the tree.

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