Impact of location and forestry conditions on some physical and mechanical properties of northern Tunisian *Pinus pinea* L. wood

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Photo 1.
Pinus pinea trees located in the Northern Tunisia.
Photograph A. El Khorchani.

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RÉSUMÉ

IMPACTS DE LA SITUATION GÉOGRAPHIQUE ET DES CONDITIONS FORESTIÈRES SUR LES PROPRIÉTÉS PHYSIQUES ET MÉCANIQUES DU BOIS DE *PINUS PINEA* L. EN TUNISIE DU NORD

Les pins Pinea sont utilisés depuis l'ère préhistorique pour leurs pignons de pin comestibles. Plus récemment, ces pins ont été introduits en tant qu'essence ornementale dans les régions à climat méditerranéen, où ils sont fréquents dans les parcs et jardins. Cependant, dans le Maghreb, ils se sont naturalisés au-delà des villes au point d'être classés comme essence invasive. De par ses dimensions (au moins 15-20 m de hauteur et 30-40 cm de diamètre), *Pinus pinea* offre un potentiel intéressant comme source de bois d'œuvre en Tunisie. Cette étude visait à analyser les effets de la situation géographique et des conditions forestières sur certaines propriétés physiques et mécaniques du bois de *Pinus pinea* dans le nord de la Tunisie. Les échantillons analysés ont été recueillis dans quatre sites différents, sur 87 parcelles classées selon la densité des arbres et les paramètres de fertilité des sols. Des mesures de densité, de retrait et teneur en eau ont été effectuées sur chacun des échantillons, ainsi que des tests de résistance mécanique. Les premiers résultats indiquent un rapport stable entre les dimensions et la densité du bois de *Pinus pinea* tunisien. Cependant, le module de rupture (MOR) en flexion et en compression est plus faible que pour d'autres résineux en Tunisie, quelles que soient la situation géographique et la fertilité des sols. L'analyse de régression linéaire montre que la densité des peuplements est le seul paramètre ayant une influence significative sur la variabilité des propriétés du bois, à l'exception de la stabilité dimensionnelle et le retrait volumique. Nos résultats indiquent que la densité croissante des peuplements de *Pinus pinea* est un paramètre forestier déterminant pour les propriétés physiques et mécaniques du bois de cette essence. Il y aurait ainsi intérêt à améliorer les conditions forestières pour obtenir un bois de meilleure qualité.

Mots-clés: *Pinus pinea* L., bois d'œuvre, module de rupture (MOR), propriétés physiques et mécaniques, bois, Tunisie, forêt méditerranéenne.

ABSTRACT

IMPACTS OF LOCATION AND FORESTRY CONDITIONS ON SOME PHYSICAL AND MECHANICAL PROPERTIES OF NORTHERN TUNISIAN *PINUS PINEA* L. WOOD.

Pinea pines have been used and cultivated for their edible pine nuts since prehistoric times. More recently, *Pinus pinea* L. has been introduced as an ornamental tree in Mediterranean regions, and is now often found in city parks and gardens. However, it has become naturalized outside North African cities to the point that it is now classified as an invasive species there. Its size (more than 15-20 m in height and 30-40 cm in diameter) makes *Pinus pinea* a good candidate eco-resource for construction materials in Tunisia. The focus of this study was to analyze the effects of geographical location and forestry conditions on several physical and mechanical properties of Northern Tunisian Pinea pine wood. The *Pinus pinea* wood samples studied were collected from four different geographical locations, divided into 87 plots according to tree population density and soil fertility class. Density, shrinkage and moisture content were measured and mechanical tests were performed on each wood sample. Preliminary results showed that Tunisian Pinea pine wood has very good dimensional stability in relation to its density. However, the modulus of rupture (MOR) in bending and compression strength is lower than in other Tunisian softwood species, whatever the geographical situation and soil fertility. A linear regression analysis showed that only tree population density seems to have a significant impact on the variability of Pinea wood properties, except for dimensional stability and volumetric shrinkage. Our findings suggest that the growing population density of *P. pinea* trees is the most important forestry parameter determining its mechanical and physical wood material properties. It could therefore be of interest to improve forestry conditions to obtain better wood quality.

Keywords: *Pinus pinea* L., structural material, modulus of rupture (MOR), physical and mechanical properties, wood, Tunisia, Mediterranean forest.

RESUMEN

IMPACTOS DE LA UBICACIÓN Y DE LAS CONDICIONES FORESTALES EN LAS PROPIEDADES FÍSICAS Y MECÁNICAS DE LA MADERA DE *PINUS PINEA* L. EN EL NORTE DE TÚNEZ

Los pinos Pinea se emplean desde tiempos prehistóricos por sus piñones comestibles. Más recientemente, estos pinos fueron introducidos como especie ornamental en regiones de clima mediterráneo, en donde abundan en parques y jardines. Sin embargo, en el Magreb se han ido naturalizando fuera de las ciudades hasta ser considerados como una especie invasora. Por sus dimensiones (más de 15-20 m de altura y 30-40 cm de diámetro), *Pinus pinea* presenta un interesante potencial como fuente de madera de construcción en Túnez. El objetivo de este estudio era analizar los efectos de la ubicación geográfica y de las condiciones forestales en algunas propiedades físicas y mecánicas de la madera de *Pinus pinea* en el norte de Túnez. Las muestras analizadas se tomaron en cuatro sitios distintos, en 87 parcelas clasificadas según la densidad de los árboles y los niveles de fertilidad de los suelos. En todas las muestras, se efectuaron mediciones de densidad, contracción y contenido de humedad, así como pruebas de resistencia mecánica. Los primeros resultados muestran una relación estable entre las dimensiones y la densidad de la madera del *Pinus pinea* tunecino. Sin embargo, el módulo de ruptura (MOR) a flexión y compresión es menor que en otras coníferas de Túnez, independientemente de su ubicación geográfica y de la fertilidad del suelo. El análisis de regresión lineal mostró que la densidad de los rodales es el único parámetro que influye significativamente en la variabilidad de las propiedades de la madera, exceptuando la estabilidad dimensional y la contracción volumétrica. Nuestros resultados indican que la creciente densidad de los rodales de *Pinus pinea* es un parámetro forestal determinante para las propiedades físicas y mecánicas de la madera de esta especie. Sería, pues, interesante mejorar las condiciones forestales para lograr una madera de mayor calidad.

Palabras clave: *Pinus pinea L.,* madera de construcción, módulo de ruptura (MOR), propiedades físicas y mecánicas, madera, Túnez, bosque mediterráneo.

Introduction

Pinea pine, *Pinus pinea* L., is one tree species which is found around the Mediterranean basin (Sbay, 2000; Khaldi, 2009). This wood species (figure 1) was successfully introduced in Tunisia at the beginning of the 20th century along the Mediterranean coast line in order to stabilize the littoral dunes of Bizerte, situated in the north and along the north-eastern coast around the Cap Bon region (Hasnaoui, 2000). The success of these first plantations incited foresters to use this species to stabilize the littoral dunes of northwest Tunisia as well (Sghaier *et al.,* 2006). Today, *P. pinea* accounts for over 21,000 ha of the Tunisian forest area (El Khorchani, 2010) and has become one of the most valuable species in Tunisian reforestation programs (Lesnino, 1997), not only for wood production (Polge, 1978) and paper pulp manufacturing (Hasnaoui, 2000), but also for its nuts which are widely enjoyed and used in many traditional Tunisian dishes (Khouja, 2003).

Natural regeneration is difficult to achieve in Tunisia. Cone yield and the amount of available seeds together with other limiting factors such as livestock and overgrazing often result in the failure of *P. pinea* stands to regenerate naturally. *Pinus pinea* is now listed as an invasive wood species (Agrimi and Ciancio, 1994). For these reasons, various appropriate ways to use *P. pinea* wood and its fruits should be found and the trees subsequently regenerated through sustainable management of *P. pinea* tree population and its fruit supply. Due to its tree dimensions (more than 15-20 m long and 30-40 cm diameter), *P. pinea* could also be a good potential green resource for structural material in Tunisia (Khaldi, 2009). In spite of the large interest in using this wood species in structure, there remains a great lack of knowledge about the properties of the wood material. This present study is part of a Tunisian forest development program, conducted by the National Institute of Agricultural Engineering Research, Water and Forestry (INRGREF) in Tunis. The aim of this work consists in analyzing the impacts of geographical location and forestry conditions on several physical and mechanical properties of Northern Tunisian Pinea pine' wood. Wood samples were collected from four different geographical locations divided into 87 plots according to *Pinus pinea* population density and the soil fertility class. Density, shrinkage and moisture content measurements as well as mechanical test (bending and compression strength) were performed on each wood sample. The results from these physical and mechanical tests were correlated to the tree growing conditions such as population density, soil fertility and geo-localization. These results could form a data base of Pinea pine' wood properties in order to have a preliminary idea of recoverable ways of this invasive Tunisian softwood species.

Material and methods

Wood sample data collections

This study was carried out on *Pinus pinea* trees from four different regions of northwest Tunisia which are presented on figure 2: the region of Bizerte (37°1N, 9°52E), the Garaa Sejnane Watershed (37°05N, 9°12E), the coastal dunes of Nefza-Tabarka (36°57N, 8°45E) and the Aïn Draham area (36°46N, 8°41E).

The climate of the North-West region covered by this study is wet and temperate. Annual rainfall varies, according to altitude from 640 mm/year on the coast to 1,572 mm/year in the region of Aïn Draham. Average annual temperatures range from 14.9 °C to 18.5 °C. The average of maximum temperature of the warmest month can reach more than 30 °C and the average maximum of the coldest month is around 4 °C. The soil is poorly developed in coastal dunes and leached brown forest in the mountains (Rejeb *et al.,* 1996). Table I describes the topographic, climatic and soil characteristics from each selected area.

Each region was divided into several plots according to the *P. pinea* trees population density. These sections (6 ares of circular area) were classified into 6 density ranges from 500 to 3,000 trees/ha. Table II shows the plot repartition, according to area and tree population density.

Wood sample selection

The number of Pinea pine wood samples is also shown in table 2 & figure 2 according to its source region: 39 samples from Bizerte, 15 from Sejnane, 14 from Nefza-Tabarka and 20 from Aïn Draham. The selected trees have diameters (at 1.30 m from the ground) comprised between 25 and 35 cm.

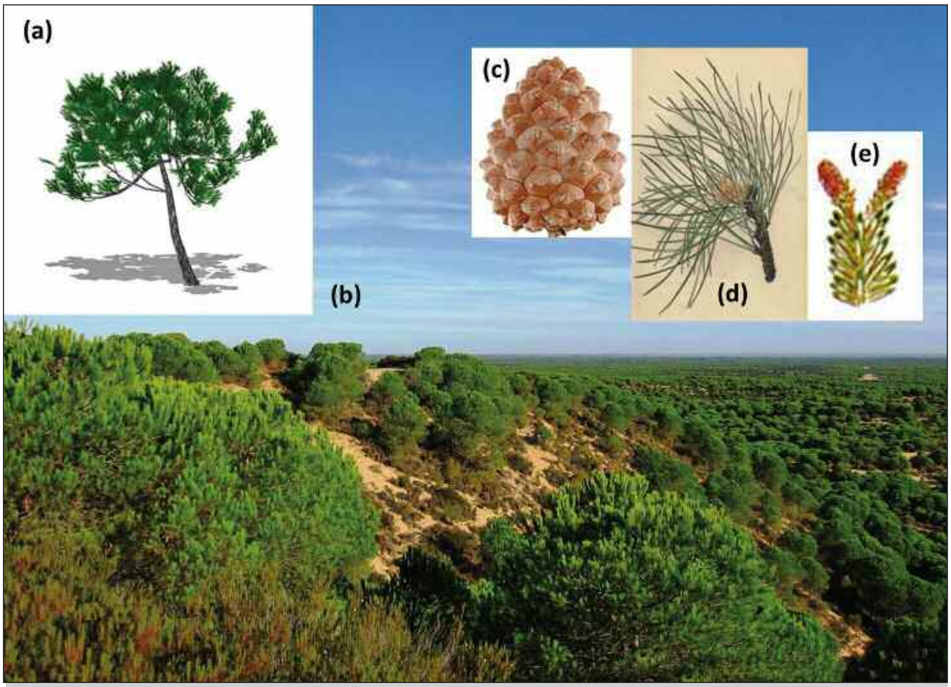

Figure 1.
Description of *Pinus pinea* L. tree.
(a) *Pinus pinea* tree; (b) Recent plantation of stone pine in the region of Sejnane; (c) Cone from stone pine ; (d) Male inflorescence; (e) Female inflorescence.

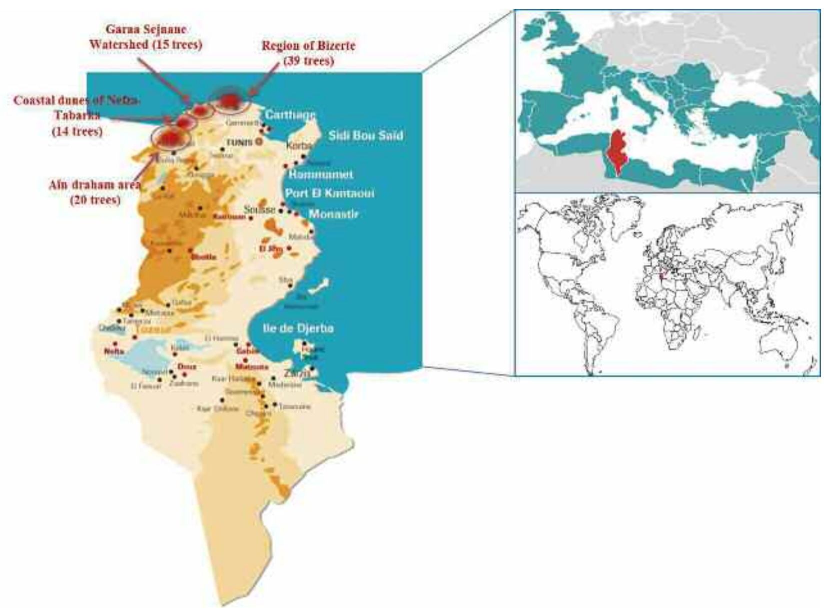

Figure 2.
Location and tree quantities of *Pinus pinea* L. wood samples.

Relating to the method developed by Oger and Leclercq (1977), one tree without defects (knots, biotic and abiotic alterations) and with perfect rectitude was selected for each section (table II), providing one wood sample per section, making a total of 87 Pinea pine wood samples. To perform physical and mechanical tests, a wooden disk 50 cm in thickness was cut at 1.30 m from the ground for each selected tree.

Physical properties

To avoid errors during sampling, extreme cases such as excessively knotty trees or the presence of reaction wood or slope grain were taken into account (ISO 4471, 1982). From each disk, 12 samples of 3 cm width from bark to bark were cut. These samples were then cut into strip 2 cm thick. Moisture Content, basic density, Air-dry density (after conditioning in a climatic room at 20 °C and 65% RH) and oven dry (after conditioning in an oven at 103 °C) density (D_{m12}, D_{m0}) (ISO 13061-2, 2014), shrinkage (β) [tangential (βt), radial (βr), longitudinal (βl), volumetric (βv)] (ISO 4469, 1981) of the wood samples were determined according to International Organization for Standardization (ISO) Standards using wood specimens of 2 × 2 × 3 cm (along the grain). The shape factor (β t/ β r) was the ratio between tangential and radial shrinkage.

Table I.
Topographic, climatic and soil features of the different areas (El Khorchani, 2010).

Region	**Bizerte**	**Sejnane**	**Nefza-Tabarka**	**Aïn Draham**
Series	**Béchateur, Corniche, Remel, Ras Djebel and Raf Raf**	**Choucha, Aïn Elkarma, Tamra**	**Ouechtata II, Mekna I, II, III, IV**	**AD II, III and X, Oued Ezen, Tegma I and II**
Area (ha)	1521,5	1415	695,6	1060
Number of sections	38	15	14	20
Altitude (m)	95-325	60-401	12	739
Slope (%)	15 to 60%			
Exposition	N and N-E, S and SW	SW-NE	NW	SE-NW
Bioclimatic stage	MoistMild winter/ Warm and dry summer	Moist	MoistWarm and slight variations	Moist Moderate variations
Pluviometry (mm)	640	800	1,032	1,572
Dry time (Months)	4	From 4 to 5	‹ 3	‹ 3
Mean annual temperature	18,5	18	17,9	14,9
Wind	N-W, 200 days/year speed = 34,4 m/s	——	S, 365 days/year	N-W, 365 days/year
Soil	Light humus	Hydromorphous	Raw mineral soils, poorly developed soils and hydromorphic soils	Calcimorphic soils, vertisols, brown leached soils and leached podzolic soils

Table II.
Plots repartition according to area and tree population density

Region	District	Plot numbers according to tree population density (trees/ha) < 500	[500-1,000[	[1,000-1,500[	[1,500-2,000[	[2,000-2,500[	[2,500-3,000[	Sections/Districts
BIZERTE	Béchateur	0	3	5	3	3	1	16
	Corniche	0	4	0	1	0	0	5
	Remel	3	5	3	1	0	0	12
	Rasjebel	0	3	0	0	0	0	3
	RafRaf	0	0	1	1	1	0	3
	Subtotal	3	15	9	6	4	1	39
SEDJENANE	Tamra	1	2	2	0	1	0	6
	Mhibes	0	1	3	0	0	0	4
	Choucha	0	1	0	0	0	0	1
	Sejenane	0	1	0	0	0	0	1
	A. El karma	0	3	0	0	0	0	3
	Subtotal	1	8	5	0	1	0	15
NEFZA	Ouchtata	1	2	0	1	0	1	5
	Mekna III	0	5	0	0	0	1	6
TABARKA	Mekna IV	0	0	1	2	0	0	3
	Subtotal	1	7	1	3	0	2	14
A.DRAHAM	A.DII	1	1	1	0	1	0	4
	A.DIII	0	0	1	1	0	0	2
	A.DX	0	0	2	1	1	0	4
	O.Z I	0	0	1	0	2	0	3
	Tegma I	0	0	2	1	0	0	3
	Tegma II	0	1	3	0	0	0	4
	Subtotal	1	2	10	3	4	0	20
	Overall	6	32	25	12	9	3	87

Moisture content was calculated by the following equation (1):

$$EMC\,(\%) = 100 \times \frac{(m_h - m_0)}{m_0} \quad (1)$$

Where m_h is the humid mass of the initial sample and m_0 is the oven-dried mass of the wood sample.

The densities were determined by the gravimetric method (Haygreen and Bowyer, 1996) (2).

$$D_b = \frac{m_0}{V_h} \ (1)\ ;\ D_{m0} = \frac{m_0}{V_0} \ (2)\ ;\ D_{m12} = \frac{m_{12}}{V_{12}} \ (3)$$

Where D_b is the basic density of wood (g.cm^{-3}), D_{m0} is the oven-dried density of wood (g.cm^{-3}) and D_{m12} is the Air-dried density of wood (g.cm^{-3}). V_h is the green volume of the specimen (cm^3), V_0 is the oven-dried volume of the sample and V_{12} is the air-dried volume of wood sample. m_0 and m_{12} are the oven-dried and air-dried weight of the sample (g), respectively.

Volumetric shrinkage was measured by the following equation (3):

$$\beta_v = \frac{(V_h - V_0)}{V_h} \times 100 \ (4)$$

Similar operations were used to determine tangential (βt), radial (βr) and longitudinal (βl) shrinkage, using dimensional variation of the respective orientation.

Determining mechanical strength properties

In order to assess the effect of *P. pinea* growing conditions and locations on mechanical properties, three point bending (MOE, MOR) and compression tests were carried out for each of the selected wood tree samples, and results were compared. An INSTRON 4467 Universal Mechanical Test Machine was used for the measurements. Samples were conditioned in a climate-controlled room with 65% RH and at 22 °C for the time required to stabilize the samples weights.

Bending test

Three point static bending tests were carried out according to the EN 408 (2003). The sample size was 400 x 20 mm x 20 mm^3 (L x R x T). The moving head speed and span length were 0.09 mm.s^{-1} and 260 mm, respectively. The load deformation data obtained were analyzed to determine the modulus of elasticity (MOE) and the modulus of rupture (MOR). The tests were replicated on 20 samples from each selected *P. pinea* tree.

Compression strength parallel to grain

Compression tests were carried out according to the EN 408 (2003). Deviating from the norm, a reduced specimen size of 30 x 20 x 20 mm^3 (L x R x T) was used. The moving head speed was 0.09 mm.s^{-1} to ensure wood sample rupture within 1.5 to 2 minutes. The load deformation data obtained were analyzed to determine the MOR. 20 specimens per selected tree were tested.

Statistical analysis

Physical and mechanical results were compared to *Pinus pinea* growth conditions as tree population density in the section (DEN), altitude (ALT), exposition (Expo) and region, using a linear regression statistical analysis. Such analyses attempted to model the relationship between two variables by fitting a linear equation to the observed data. One variable was considered an explanatory variable, while the other was considered to be a dependent variable.

Results

Moisture content

Several studies have demonstrated that *P. pinea* growing has a high sensitivity to climatic conditions (Campelo *et al.*, 2006; Mazza and Manetti, 2013) and more particularly to the geographical variability in rainfall which most influences tree ring formation (Mazza *et al.*, 2014). Both rainfall and humidity have an important impact on the anatomical structure of the wood and on its physical and mechanical properties (Skaar, 1988).

Based on the Moisture Content measurements (figure 3), the climatic conditions were similar to each other whatever the tree growing regions. However, it appears that the MC (%) of *P. pinea* issued from Aïn Draham (69.1%) and Bizerte (64.7%) are slightly higher than those of trees from the Sejane region (60.2%) and the Nefza-Tabarka (60.9%). These results are in agreement with the ratio between rainfall quantity and dried periods of each harvesting site (table I). In addition, the average MC value of northern Tunisian woods tested in this study was 64.3%, which means that *P. pinea'* wood among those timbers with low initial humidity (Hasnaoui, 2000) thus make it possible to converting it to in material by reducing the duration of the drying process and limiting the risk of dimensional material deformations and cracks.

Dimensional variations

According to the shrinkage analyses, the results figuring in figure 3, which shows the tangential (βt), radial (βr) and volumetric (βv) shrinkage values of *P. pinea'* woods, are very similar to each other, irrespective of the tree's origin and forestry conditions. These various average shrinkage values are 7.2% (βt), 4.7% (βr) and 11.9% (βv), respectively. According to Campredon (1967), *P. pinea'* timbers tested in this study can be classified as low wood volumetric (5% ‹βv‹ 10%) and middle wood linear (7% ‹βt‹ 11%; 4% ‹βr‹ 7%) shrinkages. In addition, *Pinus pinea'* wood generally seems to have a lower anisotropic ratio (βt/βr = 1,53) than those of other softwood species (USLPF, 1974; Azzouzi, 1995) such as *Pinus pinaster* (2), *Pinus sylvestris* (1.7) or *Pseudotsuga menziesii* (1.7), making it a wood relatively easy to dry before being used (Thibaut *et al.*, 1992).

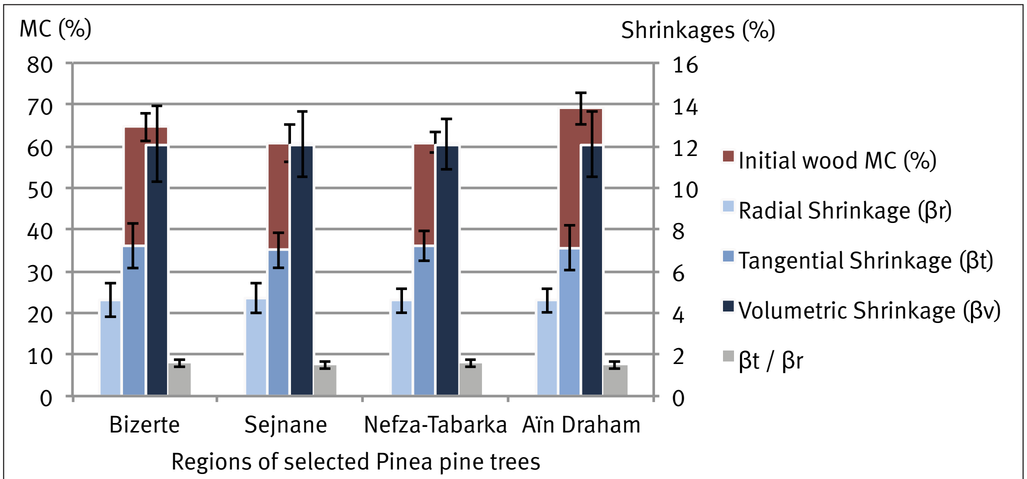

Figure 3.
Moisture Content (MC %) and shrinkages in different orientations of *Pinus pinea* woods according to their source regions.

Mechanical properties

The mechanical test results of each wood sample issued from the four regions and conditioned at a temperature of 20 °C and 65% RH are shown in figure 4. Elasticity modulus (MOE) implies that deformations produced by

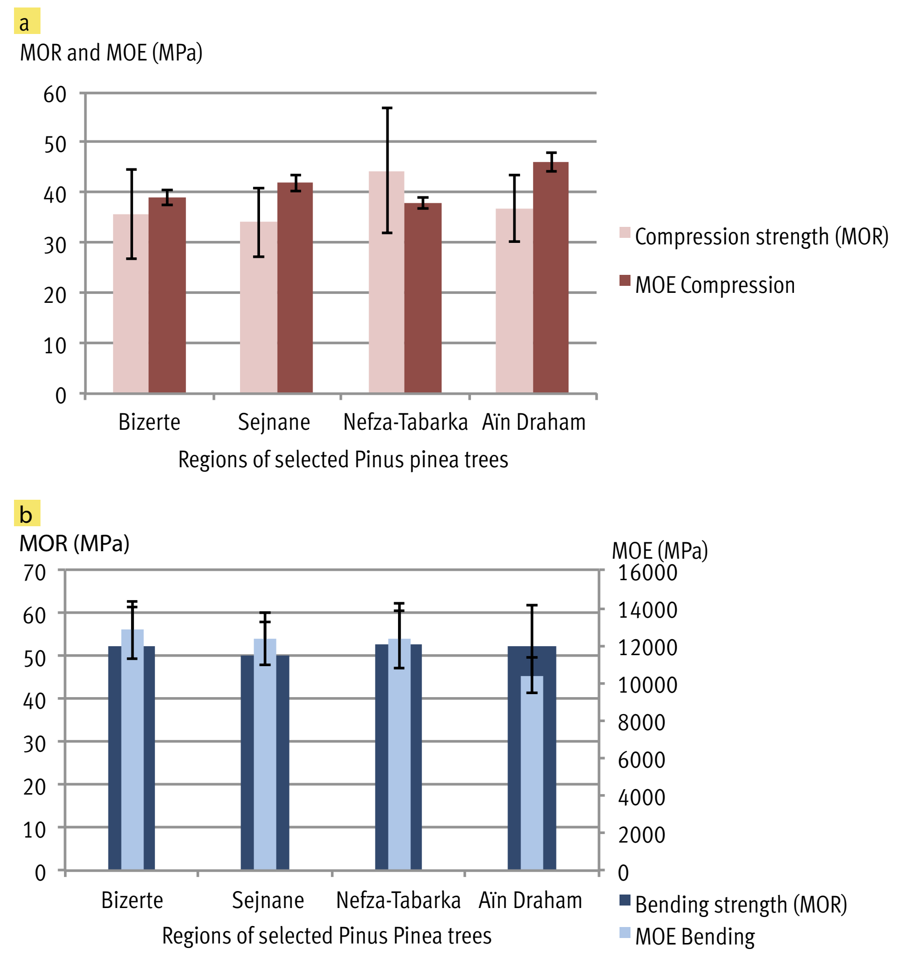

Figure 4.
The modulus of elasticity (MOE) and the modulus of rupture (MOR) in bending (a) and compression (b) of *Pinus pinea* woods related to their sourcing regions.

low stress are recoverable after removing the load. Modulus of rupture (MOR) reflects the maximum capacity in bending or in compression and is proportional to the maximum moment borne by a sample. MOE is the ratio of stress to strain in compressing or bending deformation.

Based on the MOE in bending and in compression strength measurements (figure 4), tree growing area does not have a significant impact on *P. pinea* wood mechanical properties. The MOE average values in bending and in compression of northern Tunisian woods tested in this study were 11 980 MPa and 41 MPa, respectively.

Based on the MOR in bending and in compression strength measurements (figure 4), tree growing area does not have a significant impact on *P. pinea* wood mechanical properties. The MOR average values in bending and in compression of northern Tunisian woods tested in this study were 52.37 MPa and 37.26 MPa, respectively. These results show that the Northern Tunisian *Pinus pinea'* wood can be classified as having medium static bending strength (75 MPa ‹ MOR ‹ 110 MPa) and low axial compressive strength (30 MPa ‹ MOR ‹ 40 MPa) (Collardet and Besset, 1998).

Wood densities

Air-dried Density (D_{m12}) is commonly used to compare different woods. Basic Density (Db), Oven-Dried Density (D_{m0}) and Air-dried Density (D_{m12}) have been measured on each wood sample. The results did not find any effect of the tree growth area on these densities. However, tree population density has an impact on wood material density (figure 5a). Table III presents the average values of the different densities.

According to Campredon (1967), *Pinus pinea* timbers which have been tested in this study can be classified as a light heavy weight wood ($0.5 < D_{m12} < 0.6$).

Discussion

To show the impact of forestry conditions on physical and mechanical properties, a linear regression analysis has been performed using the results cited above. The results from this statistical analysis are presented in table IV. Zobel and Van Buijtenen (1989) suggest that large structure variations are produced by changes in climate, site and management characteristics, due to the influence of these extrinsic factors on various activities. Our study indicated that there are no significant differences among wood coming from different growing areas in terms of wood mechanical properties, wood density, wood shrinkage variations and static bending properties. Table IV shows the coefficients of correlation between forestry conditions (Tree population density, Growing Area, Altitude), physical properties (Wood basic density – Db, volumetric shrinkage – βv) and mechanical strengths (Bending and compression strength – MOE and MOR) which were measured in this study.

Positive correlations were found between wood basic density, bending strength and compression strength. These results support previous studies (Zhang and Zhong, 1997; Betkas *et al.*, 2002; Heräjärvi, 2004). More interesting correlations were found between tree population density, wood density and mechanical properties. These results (figure 5) show that, in this study, the most important parameter does not depend on climatic and geological conditions of tree growth, but more particularly on forestry conditions which were characterized by tree population density.

Generally, width of annual ring was inversely correlated with density of wood in softwood (Erten and Sözen, 1997). Because, while width of annual ring was getting increase, the latewood zone which is heavy portion of wood was getting

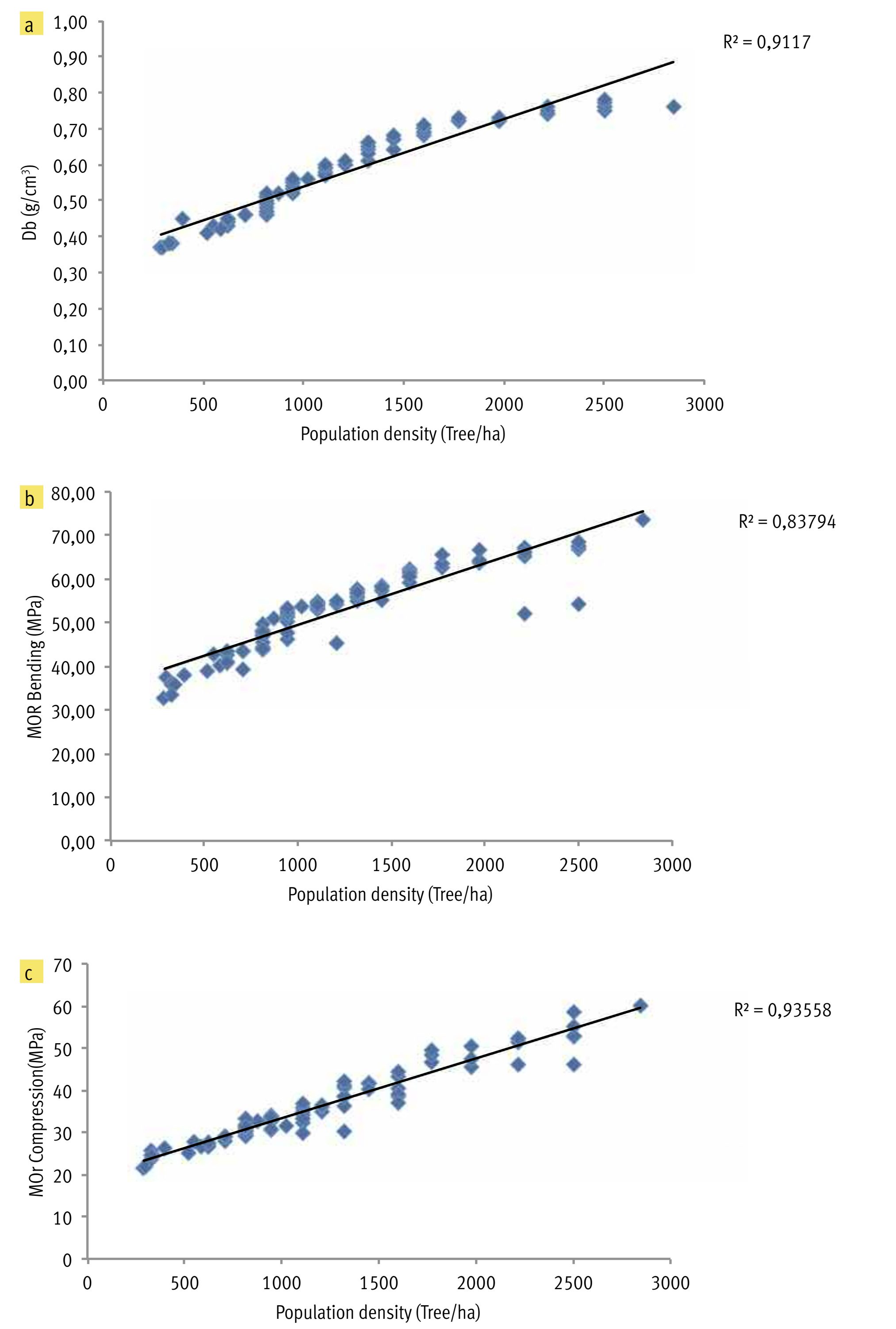

Figure 5.
Correlation between *Pinus pinea* tree population density, respective wood Basic density (a) and wood mechanical strength [MOR in bending (b) and compression (c)].

decrease (Berkel 1970). Indeed, some authors have reached similar findings by underscoring that an increase in tree plantation density results in a decrease in annual rings width (Nepveu, 1994; Pardé and Bouchon, 1988). According to Demirkir *et al.* (1997), mechanical and physical properties of softwood and hardwood species were affected from width of annual ring. Growth rate influences wood density due to the changes in the relative proportions of secondary cell walls and void volume (*e.g.* cell lumen) (Mäkinen *et al.*, 2002; Saranpää, 2003) as well as in the relative amounts of chemical components of the cell wall (Saikku, 1975). These chemical changes and structural modifications impact wood mechanical properties. It is obvious that rapid growth rate due to a low population density results in low wood density with low mechanical strength properties (Saranpää, 2003). The trends observed in figure 5 show that the higher the tree population density, the greater the wood density and mechanical strength.

Finally, tree population density may have an effect on the concurrence between trees, assuming that the tree ages are comparable (trees age is comprised between 30 and 40 years old), and therefore a negative effect on ring width. Negative correlations were often reported between ring width and wood density for coniferous trees (Berkel, 1970); it would not be surprising to observe an indirect positive correlation between tree population density and wood density. However, it is very surprising that we obtain such a strong correlation between trees population and wood basic density. Results from this study should therefore not be considered as a generality.

Table III.
Average values of basic, anhydrous and air-dried densities of Northern Tunisian *Pinus pinea* woods.

	Basic Density (D_b)	Anhydrous Density (D_{m0})	Air-dried Density (D_{m12})
Average Value (g/cm³)	0.46	0.52	0.54
COV*	0.13	0.15	0.13*

Coefficient Of Variation calculated by the ratio between the standard deviation and the average value.

Table IV.
Correlation matrix of all forestry conditions and physical/mechanical properties of the Northern Tunisian *Pinus pinea* wood sampled.

	Tree population density	Growing area	Altitude	Db	v	Bending MOR	Compression MOR
Tree population density	1.000						
Growing area	0.154	1.000					
Altitude	0.122	0.804	1.000				
Db	0.912	0.197	0.161	1.000			
v	0.077	0.003	0.023	0.121	1.000		
Bending MOR	0.838	0.115	0.054	0.885	0.134	1.000	
Compression MOR	0.936	0.157	0.085	0.889	0.105	0.896	1.000

Conclusion

The study focused on moisture content, densities, dimensional variations and mechanical properties of Northern Tunisian Stone pine woods issued from Bizerte, the Garaa Sejnane Watershed, Nefza-Tabarka and Aïn Draham areas. The physical and mechanical properties of these woods appear to depend more mainly on forestry population density than climatic conditions in all of the regions investigated. Indeed, results from the linear regression highlighted that the tree population density is the factor which has the greatest influence on *Pinus pinea'* wood basic density and mechanical properties. For most wood species, it appears that the denser the tree population, the higher the density and mechanical strength. In Tunisia, *P. pinea'* wood is mainly used for building boats, stilts, wood mines, lumber and poles. It is also used to produce of cellulose and mechanical pulp (Hasnaoui, 2000). Despite its physical and mechanical properties comparable or even superior to those of Spain, Tunisian Pinewood is mainly used in the crushing industry and to manufacture pallets.

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