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Wood anatomy and properties of Maritime pine (*Pinus pinaster* Ait.) after gravitropic responses

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1. ABSTRACT

Maritime pine (*Pinus pinaster* Aiton) is the conifer which major volume of wood is obtained in Spain. Quality and productivity of wood in Maritime pine is low due to the tendency of this specie to exhibit a lack of stem straightness. In addition, stem flexuosity produces an increase in the cost of transport and manufacturing of the row material.

Compression wood (CW) is formed on the lower side of branches and bent stems. Wood formed on the other side of branches and bent stems is called opposite wood (OW). There are big differences between CW and OW in conifers, for all physical and mechanical properties, for example higher density. A problem associated with compression wood include the difficulty of working the hard timber, besides, the higher levels of lignin also increase cost for the pulp and paper industry.

With this study we tries to answer the following questions: (1) How wood functional anatomy is modified by tree postural control necessities in stem and roots of several populations of maritime pine? (2) Are there differences between roots and trunk respect of structure of compression, opposite and normal wood?

Ten provenances, five with typically straight-stemmed plants and five with twisted-stemmed plants, of *P. pinaster* were subjected to stem inclination (45º) to assess genotype response to mechanical stressor. This response was evaluate through anatomical features ,cross sectional area (Total A) , compression wood area(CWA), major (R) and minor radius (r) of the section , eccentricity (Ecct) and porosities(P1, P2, P3 and P4), measured in different parts of the tree, trunk and root. The results of this thesis show that measured part (trunk and root) had a significantly role in all variables. Provenance only were a significant effect in total cross-sectional area and in major radius, however the interaction between provenance and part had significant role in Total A, P1, P3 and P4. There were not significant differences among straight and twisted provenances. Total A and r (minor radius) decreases as we descend from the apex of the plant stem towards extreme of root. There were not significant differences among trunk and root in porosities. However, in trunk as well as the part of the root closest to the root collar, the zone within the cross section where porosities were measured, had a significant role.

The conclusion from this study are that some qualitative and quantitative anatomical differences between stem wood and root wood exist in hardwood species, besides, the hypothesis about a genetic control about the typical stem form is reinforced. With this study we tried to observe that characteristics are responsible for the differences found in the provenances and which provenances showed greater efficiency in postural control by forming compression wood.

1. RESUMEN

El pino marítimo (*Pinus pinaster* Aiton) es la conífera de la que se obtiene mayor volumen de madera en España. La calidad y productividad de la madera del pino marítimo se ve disminuida debido a la tendencia de esta especie de exhibir una falta de rectitud del fuste, además de producirse un aumento en los costes de transporte y manufacturación de la materia prima.

La madera de compresión (CW) se forma en el lado inferior de las ramas y tallos que han sido dobladas. La madera que se forma en el otro lado de ramas y tallos inclinados se denomina madera opuesta (OW). Existen grandes diferencias entre CW y OW en coníferas, para todas las propiedades físicas y mecánicas, por ejemplo una mayor densidad en CW en comparación a OW. Un problema asociado con la madera de compresión incluye la dificultad trabajar la madera dura, además, los niveles más altos de lignina también aumentan el costo para la industria de la pulpa y el papel.

Con este estudio se intenta responder las siguientes preguntas: (1) ¿Cómo las necesidades de control postural de los árboles modifican la anatomía funcional de la madera en tallos y raíces en varios genotipos de pino marítimo? (2) ¿Existen diferencias entre raíces y tallos con respecto a la estructura de la madera de compresión, opuesta y normal?

Diez procedencias, cinco con un crecimiento recto del tronco y cinco con una tendencia a sinuidad del tronco, de *P. pinaster* fueron sometidos a una inclinación del tallo (45 º) para observar la respuesta del genotipo al estrés mecánico. Esta respuesta fue evaluada a través de características anatómicas ,área de la sección transversal, área de la madera de compresión, radio mayor y menor de la sección, excentricidad y porosidades, medidas en diferentes partes del árbol, tronco y raíz, así como en diferentes zonas dentro de la misma sección transversal. Los resultados de este trabajo mostraron que la parte analizada (tronco y raíz) tuvo un papel significativo en todas variables. La procedencia solo tuvo un efecto significativo en el área de la sección transversal y en el radio mayor, sin embargo la interacción entre procedencia y parte del árbol tuvo un papel significativo en el área total, P1, P3 y P4. No hubo diferencias significativas entre procedencias rectas y torcidas. El área de la sección transversal y el radio menor decrecen a medida que descendemos desde el ápice del tallo de la planta hacia el extremo de la raíz. No se encontraron diferencias significativas entre el tronco y la raíz para las porosidades, sin embargo, en el tronco, así como en la parte de la raíz más cercana al cuello, la zona dentro de la sección transversal donde se analizó la porosidad tuvo un efecto significativo.

Como conclusión podemos destacar la existencia de diferencias cualitativas y cuantitativas entre la madera del tallo y la madera de las raíces, además, se refuerza la hipótesis de la existencia de un control genético sobre la rectitud del fuste para esta

especie. Con este estudio se ha intentado observar que características son responsables de las diferencias encontradas dentro de las procedencias y que procedencias presenta mayor eficacia en el control postural mediante la formación de madera de compresión.

2. INTRODUCTION

Maritime pine (*Pinus pinaster* Aiton) is a conifer from the western Mediterranean Basin with a distribution that exceeds 4 million ha under different origins and environmental conditions (Fernandes and Rigolot, 2007). In this area is located the transitional zone between a sub-oceanic climate, with regular precipitations from the polar front, and a subtropical arid climate, with high pressures. As consequence, there are clearly differentiated zones in the Iberian Peninsula, with Atlantic and Mediterranean influence, and several climatic regions: arid, semi-arid, semi-humid and humid.

This species has a high economic value due to the characteristics of the wood, besides, annually fifth of the total timber cut in Spain, come (derived) from *Pinus pinaster*. However, this value is seriously affected by the existence of a tendency to exhibit a lack of stem straightness. The commercial value of *Pinus pinaster* is determined by multiple factors, in addition of the lack of stem straightness other problems exist as a result of the eccentricity of the cross section or the formation of compression wood. All this makes the quality of the final product suffers a significant deterioration (Zobel and Van Buijtenen, 1989). The economic importance of stem straightness has led to include it as a selection trait in most of the genetic improvement programs of this species (Garrido et al., 2015).

Previous studies assume the idea that there is a genetic control about the typical stem form (straight or twisted) representative of the population in the test plant's places of origin, demonstrating genetic control of this trait (Alía et al., 1995; Sierra de Grado et al., 1999). Tree stem flexuosity shows large natural variability in *P. pinaster* populations from different geographic regions (provenances), in this species, toppling problems usually occur when the trees reach a height of approximately 90 cm, during the first 2–5 years after planting (Lario and Ocaña, 2004; Ocaña et al., 2001). Crémière, (2003) studied the causes of instability in conifer plantations, indicating root quality and genotype as primary factors, among others.

Stem form can be affected by many environmental factors (wind, landslides, snow, etc.). Wood stiffness and strength provides trees with a efficient "skeletal motor" (Moulia et al., 2006), however this is not the only mechanical function of wood fibres. The other biophysical function of wood is to provide stems with the ability of performing movement, i.e. a "motor" system (Darwin and Darwin, 1880; Martone et al., 2010; Moulia et al., 2006; Moulia and Fournier, 2009; Wilson, 1984). Stem reorientation is necessary for plants to adapt to their environment, for example to recover from mechanical perturbations or maximize light interception (Alméras et al., 2009). Detailed biomechanical studies have been conducted on artificially inclined *P. pinaster* seedlings (Fournier et al., 1994; Loup et al., 1991) and both the kinetics and the gravitropic and autotrophic components of the stem straightening process after tilting are well known. A previous study looked at stem straightness in maritime pine from different provenance regions of Spain (Sierra-De-Grado et al., 2008). One of the key observations was that the compression wood developed in response to leaning in plants from different provenances appeared to have different levels of efficiency to straighten the stem. Some provenances became straighter with time compared to others but seemed to do so by laying down very similar levels of compression wood.

Tree anchorage strength is governed by several factors, e.g. root architecture (Danjon et al., 2005; Dupuy et al., 2005) soil, physical and mechanical properties of the roots (Moore, 2000; Nicoll et al., 2006), the depth, shape and weight of the root–soil plate (Coutts, 1986). Mechanical stress can play a fundamental role in the development of root structures, causing significant changes to the allocation rules that act to optimize tree stability (Stokes et al., 1997). A relationship between stem straightness and anchorage has also been noted by Danjon et al. (1999), who considered a low shoot: root ratio and a high proportion of deep roots to be promoters of straightness in *P.pinaster*. Important acclimation processes also occur when the trees experience mechanical stimuli such as wind, which affect the root system and, in turn, stability (Coutand et al., 2008; Danjon et al., 2005). Mechanical properties of roots have been investigated and linked to tree behavior under wind loading (Hathaway and Penny, 1975; Stokes et al., 1997a), however little is known about root wood formation during mechanical stress (Fayle, 1968).

The structure of the wood from the root and stem of arboreal species is important because it indicates the adaptations of the tree to the environment (Longui et al., 2012). Because the growth environment is different between root below ground and stem above ground, anatomical differences between them are recognizable within a tree (Bowyer et al., 2007; Schweingruber, 2006; Timell, 1986). In earlier studies, some qualitative and quantitative anatomical differences between stem wood and root wood were found in hardwood species (Ewers et al., 1997; Lee and Eom, 2011; Machado et al., 2007; Palhares et al., 2007; Psaras and Sofroniou, 1999; Stokke and Manwiller, 1994) and root wood was considered to be subject to great anatomical variability due to extremely variable soil conditions.

The use of wood properties from large databases has had great success in plant trait analysis. Density has long been understood to be the main factor affecting the mechanical properties of wood. Simply speaking, the denser the wood the stronger and stiffer it is. When properties are compared between species, this factor is of primary importance compared to other structural parameters such as microfibril angle (MFA) or chemical composition. However, although density is the first order factor affecting properties when comparing species or trees, the relationship becomes less clear when comparing properties in a single tree and especially when studying reaction wood. Thus compression wood, although denser than normal wood, is less stiff. In hardwoods, the relationship between density and stiffness is also disturbed, with large changes in stiffness occurring without concomitant changes in density (Clair and Thibaut, 2014b).

2.1 REACTION WOOD

The Committee on Nomenclature of the International Association of Wood Anatomists (IAWA, 1989) has defined Reaction wood (RW) as "Wood with more or less distinctive anatomical characters, formed typically in parts of leaning or crooked stems and in branches and tending to restore the original position, if this has been disturbed. It is divided in two types: tension wood (TW) in dicotyledons and compression wood (CW) in conifers". Generally, CW is formed on the lower side of branches and bent stems while TW is formed on the upper side of branches and bent stems. Wood formed on the other side of branches and bent stems is called opposite wood (OW) (Gardiner et al., 2014). In the most common tree species, the main driving force of bending arising from the maturation of new cells during radial growth is the asymmetry of wood properties between opposite wood and reaction wood.

Very often, successive growth events are used by trees "to solve" some mechanical problem, in addition to building of the prescribed structure, in order to restore the posture of an inclined tree (Moulia et al., 2006; Thibaut et al., 2001), to search for the light, to change the tree architecture after death of a major axis, and so on. RW is a solution for a drastic and sudden change in the existing wooden structure of the tree. It is commonly use by all trees, particularly in the juvenile stage. RW is created very locally in answer to a global mechanical problem for the tree. According to modeling simulations, the curving efficiency of asymmetrical stressing of the axis using RW is nearly five times higher than the best solution using normal wood asymmetry alone (Alméras and Fournier, 2009).

The most important single climatic influence on reaction wood formation in trees is wind, although snow loading can also be important. The research of Dunker and Spieker (2008), shows that the direction of the prevailing wind is more important for determining the location of compression wood formation than slope direction. Wind has also been found to influence tree lean in hardwoods and to lead to tension wood formation (Sorensen and Wilson, 1964). In Germany, where south-west and west winds predominate, conifer stems take on an elliptical form with the long axis of the ellipse parallel to the wind direction and greatest growth on the leeward side of the stem. Similarly they noted that in leaning conifer stems, greatest growth occurred on the lower side. Thus the tree presents its least flexible profile to the prevailing stress. It was also noted that those roots aligned with the direction of the stress, whether wind or gravitational pull, also developed an elliptical profile. They proposed that this helped to prevent the stem from falling over (Gardiner et al., 2014).

Reaction wood impacts tree ecology in different ways; first, it has indirect effects because it modifies other wood traits that are linked to tree physiological functioning, it changes the pre-stress system in wood which is designed to prevent the tree from breaking (Mattheck and Kubler, 1995), and finally it is the main motor of posture control. Growth eccentricity is a complementary but second order effect often associated with reaction wood formation (Alméras et al., 2005). Eccentric growth without a clear modification of wood structure has mentioned by (Fisher and Marler, 2006) in *Cycas micronesica*. It is precisely those properties which enable reaction wood to carry out its function in the tree that render it a problem for the timber industry. When Jaccard, (1983) cut loops in which reaction wood had formed, the curvature immediately changed as internal stresses were released.

Many of the characteristics that can lead to increased levels of reaction wood formation are relatively heritable (Timell, 1986). The hereditability of CW has been reported to be significantly high ranging from 0.3 to 0.9 (Shelbourne et al., 1969; Apiolazaet al., 2011). Other factors that could mitigate the impact of reaction wood may also be heritable, such as longitudinal shrinkage and fiber length, so that it may be possible to breed for fiber characteristic that reduce the impact of reaction wood in service (Gonzalez and Fisher, 1998).

Therefore, the traits involved in this process, including reaction wood presence and properties, should be studied as part of general plant strategies more or less expressed according to genotypes and condition of stress, competition or disturbance (and not only in extreme conditions of disturbance) (Fournier et al., 2013). Long-term observations in permanent plot studies, for example of survival probabilities of young trees as a function of the performance of their posture control function are necessary for a better integration of reaction wood studies in tree ecology (Gardiner et al., 2014).

In general any action that leads to unstable roots systems, stem sweep or lean, unbalanced root to shoot biomass allocation, eccentric crowns or increased wind or snow loading is liable to produce increased reaction wood. The difficulty for forest managers, timber buyers and timber processors is that it is extremely difficult to be sure which trees will have the greatest levels of reaction wood. The key for managers is to manage their stands "subtly", to not enforce large scale changes and to remove during thinning those trees with the highest probability of containing reaction wood whenever possible (Gardiner et al., 2014).

2.2 COMPRESSION WOOD

The macroscopic appearance of compression wood is often described as darker in color, varying in different species from brown to dark reddish brown. Its occurrence is associated with eccentricity of the stem, the pith being further away from the side containing compression wood.

Compression wood shows big differences from normal wood in conifers, for all physical and mechanical properties: higher density and axial crushing strength but lower modulus of elasticity, far higher axial shrinkage but lower radial and tangential shrinkage, sometimes even lower than the axial shrinkage (Clair and Thibaut, 2014b). In cross section compression wood tracheids are typically rounded in appearance and many intercellular spaces can be seen between individual cells; this appearance contrasts with the more rectangular to hexagonal cross section of non-reaction wood tracheids and the complete lack of intercellular spaces (Fig. 1). The thick and heavily lignified wall of compression wood tracheids also often show craks. Donaldson and Turnes (2001), observed the absence of an S3 layer in the compression wood of *Pinus radiata.* This last feature seems to be particularly related to severe forms of compression wood (Singh and LA, 1999). The occurrence of a highly lignified outer S2 layer that is continuous around the perimeter of the cell is also related to severe compression wood. It seems that the presence of cavities in cell corners may be common to both mild and severe compression wood (Gardiner et al., 2014). In the majority references is it stated that compression wood tracheids are shorter than those of non-reaction wood from the same tree (Dadswell and Wardrop, 1949; Lee and Eom, 1988). In longitudinal section of compression wood the most striking feature is the presence of spiral markings or spiral checks in the cell walls. These structures give a define indication of the cell wall organization, as it has been shown that they follow the microfibril orientation in the S2 layer of the secondary wall, which varies considerably depending on the severity of the compression wood (Gardiner et al., 2014).

Compression wood is almost always denser than normal wood. Timell (1986), cites numerous publications which all confirm this tendency. In more than 75% of the studies described by Timell, a ratio of density of CW/NW of 1.1-1.8 was found with some extreme cases showing up to 2.2. In 16% of the studies the ratio was between 1 and 1.1. The high increase in macroscopic density is linked to the fact that the cell wall is much thicker in compression wood that in normal wood (Clair and Thibaut, 2014a).

In the case of the gymnosperm loop, in which compression wood had former on the convex side of the lower curve, and the concave side of the upper curve, the effect of cutting the loop was to increase the radius of curvature of the lower section and decrease the radius of curvature of the upper section. Other problems associated with compression wood include the difficulty of working the hard timber. Büsgen, Münch, and Thomson (1929), commented that is very difficult to drive a nail into it. The higher levels of lignin also increase cost for the pulp and paper industry since lignin is expensive to remove and was hitherto difficult to dispose of.

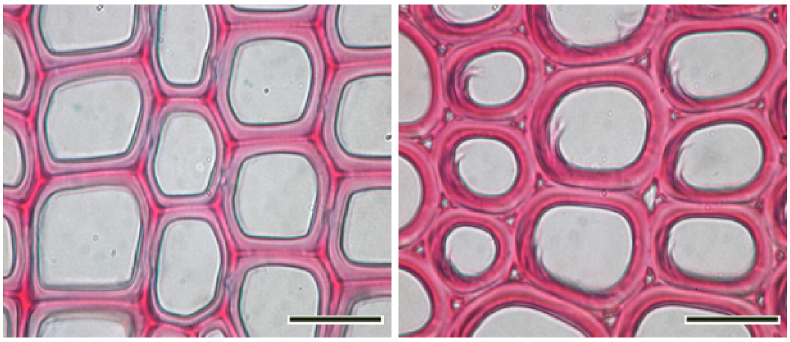


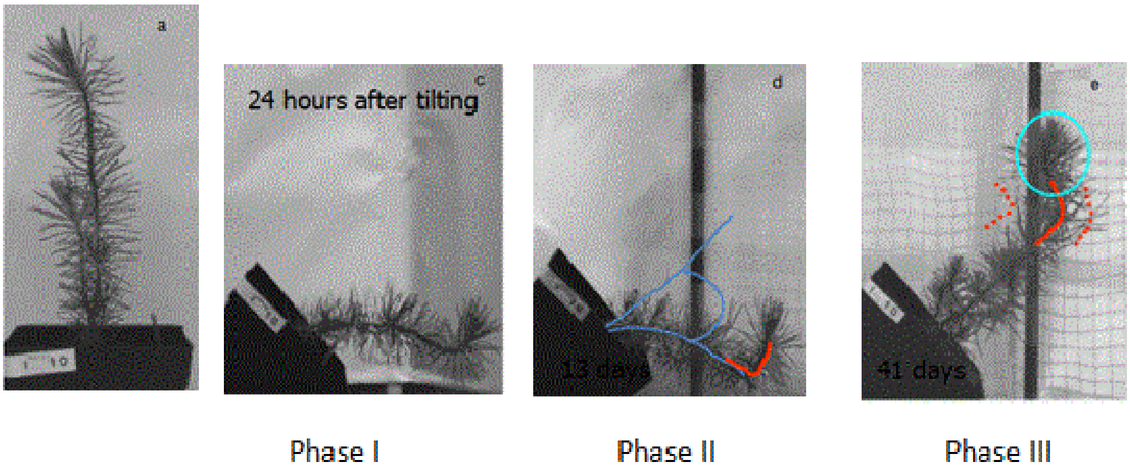
Fig. 1. Normal (left) and compression wood (right) tracheids of Pinus pinaster (scale bars 25µm)

At present, biological detection and classification offers the most detailed grading of compression wood and discrimination against normal wood. Chemical analysis complements these methods in providing quantitative measures of compression wood severity though losing its orientation in space. According to the specific problem encountered an appropriate compression wood detection method can be selected until a new and better method is developed which is likely to combine the strengths of these principle approaches (Duncker, 2014).

2.3. STRAIGHTENING PROCESS

Fig 2. illustrates movements observed in experiments where gravitropism is stimulated by tilting, where it is possible to observe different processes (Sierra-De-Grado et al., 2008).

- A primary gravitropic reactions, very fast (in hours) in the apical segment. **Phase I.**
- Gravitropic secondary reaction, slower, in the in the basal segment. **Phase II.**
- In both cases, the gravitropic curve, continues with a counter-curvature, called autotropic reaction which produce the straightening of the stem. **Phase III.**



Phase I

Phase II

Phase III

Fig. 2. Gravitropic and autotropic reactions in the apical and basal segment

This occurs as a result of two processes, the first one, the curvature of the apical segment, occurs as a result of primary growth which is produced by a differential cell elongation in the upper and lower face of the stem at the base of the apex. And second, the curvature of the basal segment, due to secondary growth resulting an asymmetric production of reaction wood in both sides of the stem (Moulia and Fournier, 2008).

As noted by the Darwins, the tropic movement involves spatio-temporal changes in the local stem form (Darwin and Darwin, 1880). A 3 cm long coleoptile from a grass seedling, a 50 cm dicot stem or a young 2 m high tree all share some obvious similarities: active tropic bending is distributed along the growing zones of the organs and all the stems tend to curve and de-curve in different places over time to reach a vertical and mostly straight form at the end of the movement. These spatio-temporal changes in the distribution of curving and growth make it difficult to characterize gravitropic movements via any single global measurement at the whole-organ level. This means that a significant issue in the study of tropism is how to relate local changes in angles all along the organ to the global change in its shape during the movement, to understand the role played by growth and the underlying biological control (Firn et al., 1981; Tasaka et al., 1999).

Previous experiments with *Pinus strobus* observed that tying of vertical shoot axes and lateral branches provoked significant bending movements, which tend to restore the initial position and was associated with compression wood formation, this study demonstrated that reaction wood is not a simple response to gravity or mechanical stimuli, but is associated with the more complex regulatory function of posture restoration (Sinnott, 1952).

Understanding the impact of forest management on reaction wood formation in trees is a complex and difficult process. The interaction between climate, site and genetics and the interactions between competing individuals within the forest or stand, make it difficult to give anything other than generic observations regarding how to forest management affects reaction wood formation in trees (Gardiner et al., 2014).

In spite of the importance of the roots in the economy of the tree control over their growth these has received little attention. In this context, the pattern of intra-individual variability, related to the formation of compression wood and differences in anatomical features in different heights of the tree (stem and roots), was studied. The question remains whether genotypes showed greater efficiency in postural control by forming compression wood and whether it is possible to assess these genotypes at very early ages.

As a basis for identifying possible characters which could be used for early selection, comparisons between straight and twisted-stemmed populations were performed**.**

3. OBJETIVE:

The specific objectives of this study are:

- Analyze how wood functional anatomy is modified by tree postural control necessities in stem and roots of several genotypes of maritime pine seedlings from straight and twisted-stemmed populations.
- Comparing roots and shoots in respect to the question of structure of compression, opposite wood and normal wood.

4. MATERIALS AND METHODS

4.1. PLANT MATERIAL

According to the straightness classification based on data from five provenance trial sites in Spain (Alia et al. 1995), ten seed sources with different straightness were studied (Fig 3), five of them from typically straight-stemmed provenances and five from typically twisted-stemmed provenances (five provenances chosen for their high straight-stemmed and five chosen for their twisted-stemmed.). Hereafter, we refer to the studied provenances using the acronyms defined in Table 1.

Table 1. Studied populations: from 01 to 05, twisted-stemmed populations; 06 to 10, straight-stemmed populations

Provenance region	Location	Stem form
01ONA	Sierra de Oña	Twisted
02NIEVA	Meseta Castellana	
03ESPA	Sierra de Espadán	
04ALMI	Sierra Almijara-Nevada	
05SEGU	Sierra de Segura-Alcaraz	
06ALMO	Serranía de Cuenca	Straight
07NOINT	Noroeste Interior	
08BUSO	Montaña de Burgos-Soria	
09GRE	Sierra de Gredos	
10LEIR	Leiria	

Fig. 3. Studied populations: twisted-stemmed populations (red) and straight-stemmed populations (green).

4.2. EXPERIMENTAL PROCEDURES

The plants were sowed on July 16, 2008 in the nursery of the Tragsa Company in Maceda (Ourense). Round pots 30 cm in diameter and 30 deep were used. The substratum was composed by a mixture of peat and perlite, 80:20. The plants were placed outdoor in May 2009, and they were distributed on a frame of 3x3 m according to a randomized complete block design with 10 blocks and one plant per provenance and block. In total, 100 plants included 10 provenances.

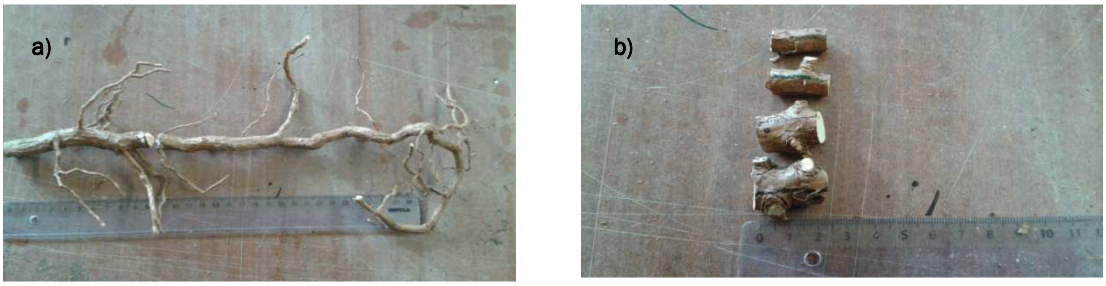
Germination and the first growing season of the plants were conducted under a shade cloth where these were irrigated by sprinkling while outdoors, they were irrigated by dripping. The Osmocote Exact standard NPK 15-9-11-2.5 MgO was used to fertilize the plants. On the plot an iron specially structures were installed for the experiment, these served to tip the pots with a 45º from the vertical, always pointing toward the south (to minimize interactions with phototropic effects; Sierra-de-Grado et al., 1997). A 45° tilt is severe compared with natural inclinations in forests (except after catastrophic events). However, studies with *Cryptomeria japonica* (L. f.) have demonstrated that RW formation (maturation strains and resulting internal bending moment) increase almost linearly from 0 to 30° and then reached a plateau (Yamashita et al., 2007). We reasoned, therefore, that a 45° tilt would enable us to characterize the maximum response. This process was performed between June 11 and June 17 2009. Throughout the experiment the stems were allowed to grow freely while the pots remained tilted. In this way, it was expected the main plane of the straightening reaction (N-S) to be perpendicular to the prevailing winds during the experiment. Shoots had an average length of 12.5 cm, at the moment of the tilting.
We began to extract the plants block by block, at the end of October 2009 to be processed immediately. The last block was extracted in February 2010 so that all samples were taken during the dormancy period. To facilitate analysis we separated the aerial part of the plants from the root, and the roots were cleaned to remove the substrate. Te branches were separated from the stem. Root structure measurements were performed on the taproot and the coarse second-order roots were stored for future analysis.

Roots used in this experiment were sent to "The Institut national de la recherche agronomique (INRA)" in Nancy-Lorraine (France). In this centre the preparation and analysis of the samples was performed, during a period of four months, thanks to a mobility internship.

Different zones were marked, at the end of the main root and near to the root collar. A 2cm diameter wooden cylinder was obtained from each of these zones (Fig 4; Fig 5). Subsequently, these wooden cylinders were taken to support the microtome for cutting. The samples obtained were used to perform studies of anatomy (cross-sectional area, compression wood area, major and minor radius, eccentricity and porosity). The areas were cuts were made were subject to the shape of the main root, its twisted structure made it difficult to obtain samples from the zones of interest. A band saw was used to perform these cuts in roots.

Besides, a wooden cylinder was obtained in the middle of the main root. This sample will be used to analyzed the grain angle and microfibril angle in cell (MFA). These data will be used in future studies.

Fig. 4. Root system. a, before cutting. b, after cutting.



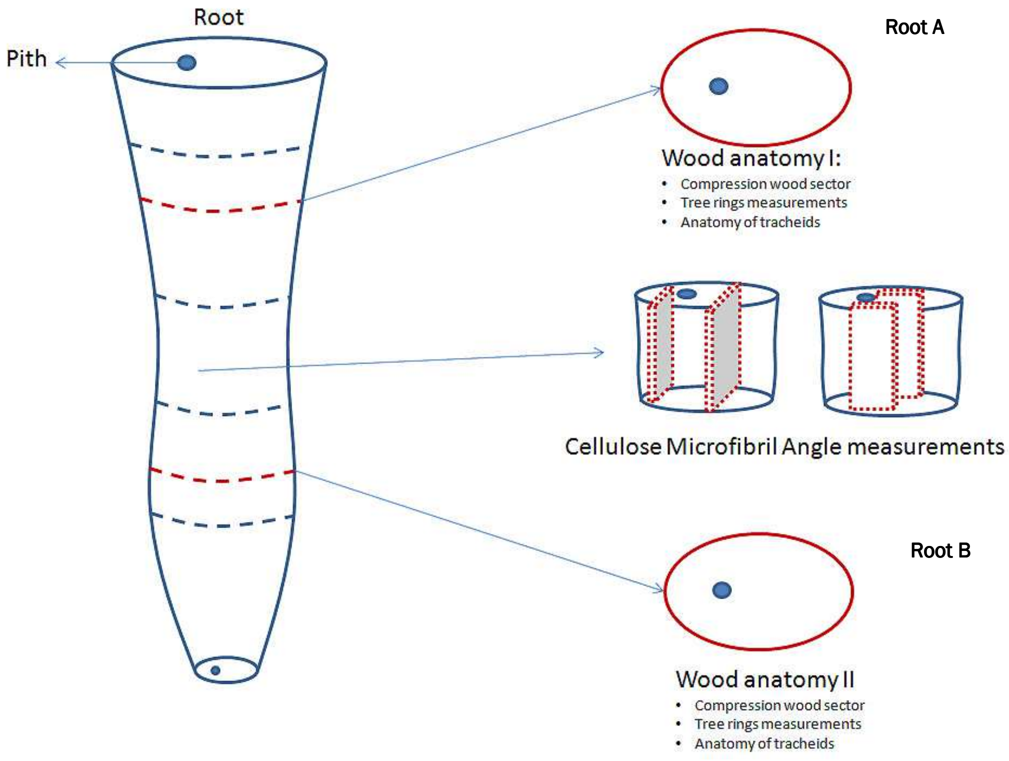


Fig. 5. Root sampling. Close to the root collar and at the end of the main root for anatomical studies and in the middle of the main root for analysis of microfibril angle and grain angle.

The samples that were obtained using the above explained methodology were used for the anatomy study. First, each sample was dipped inside distilled water containers for one week. Secondly, the distilled water was replaced by a solution of polietilenglicol (PEG) 30%, for a period of 24 to 48 hours. Thirdly, this PEG 30% solution was substituted by a similar solution but with a higher PEG concentration, 50%, for the same period of time, 24 to 48 hours. In these concentrations, PEG is found in liquid form at room temperature. Given its liquid state, it can flow through the cavities left by the cellulose in the cell wall and ensure these cavities are adequately thickened. This process is called “prepreg”, once PEG has been cooled to room temperature, it solidifies inside the timber acting as the support structure of this. Prepreg is necessary because wood is mainly composed by water which otherwise would evaporate leaving gaps within the structure of the cell wall and causing significant cracks in the wood. During this process, the containers with samples were introduced in a vacuum desiccator which, as its name indicates, was used to suction the air and create vacuum inside them. This allows the root sample to absorb the PEG solution. Finally, the samples with pure PEG were deposited inside a stove for a period of 24 to 48 hours as well. Pure PEG must be heated to reach liquid estate, therefore it is introduced in the stove to be heated so it can reach liquid form while vacuum is been created. After this impregnation process, samples were dried, bagged and labeled (block and source) to, subsequently, study their anatomical characteristics.

A 15 µm cross section was cut from each sample using a sliding microtome. A blade inclination of 20 degrees was used for all cuts. Once cut, sections of the samples were collected with a brush and were smeared on a glass slide. Safranine and Blue Astra were used to color the sections. Blue Astra has some specificity for cellulose, and stain non-lignified cell walls blue, as for Safranine, it is the classic wood coloring. After staged dehydration with alcohol 70%, alcohol 90% and pure alcohol, the section was mounted on a glass slide.

Samples were identified for subsequent measurement using their source of origin, block and part of the root which each sample belonged to (near the root collar and at the end of the section of the main root). During samples preparation, some of these were excluded because they were broken during the cutting and tinted process.

4.3. ANALISIS OF HISTOLOGICAL SECTIONS

Samples were photographed using a modified LEICA Wild M420 microscope with an attached camera used to obtain a picture of the whole section as well as of the compression wood area. Compression wood was only seen in the trunk section. These photographs were then used to measure the cross-sectional area and the compression wood area as well as the different radius used for analysis, major and minor radius (Table 2; Fig. 6).

In addition to that, the camera was attached to an Axio Imager microscope which allows to take pictures with higher contrast and resolution. Using this microscope, photographs were taken in different zones, obtaining a longitudinal area and a transversal area of the sample. In these areas, a porosity measurement was performed (Table 2; Fig. 6). For each samples, the different analysis were measured using the image analysis program ImageJ (Abramoff et al., 2004).

Table 2. Acronyms and short descriptions of the studied traits. Units are indicated in brackets; otherwise, the variable is dimensionless.

Variable acronym	Description
Total A	Total cross-sectional area (µm^2)
CWA	Compression Wood Area (µm^2)
R	Major radius (µm)
r	Minor radius (µm)
Ecct	Cross-sectional eccentricity (%)
P1	Porosity (lumen area/ total area) in zone 1 (%)
P2	Porosity (lumen area/ total area) in zone 2 (%)
P3	Porosity (lumen area/ total area) in zone 3 (%)
P4	Porosity (lumen area/ total area) in zone 4 (%)

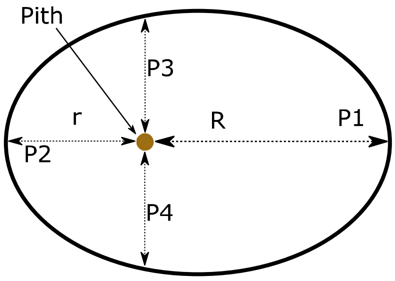


Fig. 6. Different measurements performed at the cross section.

Eccentricity was measured like a percentage of the distance between the pith and the center of the ellipse, with respect to the length of the major diameter (Equation 1).

$$Ecct\ \% = \frac{R - D/2}{D} \times 100 \qquad \text{(EQUATION 1)}$$

To analyze the porosity, color adjustment and contrast were performed for each image using the image analysis program ImageJ. In this way we got an image with two colors, black and red (Fig 7). Red color corresponds to the area belonging to the cell lumen and black color corresponds to the area belonging to the cell wall.

After that, we select an area within the image and divides the color red area between the total selected area. So, we could calculate the percentage belonging to the lumen of the analyzed area (Equation 2).

$$Pi = (\text{lumen area } (\mu m^2) / \text{Total area } (\mu m^2)) * 100 \qquad \text{(EQUATION 2)}$$

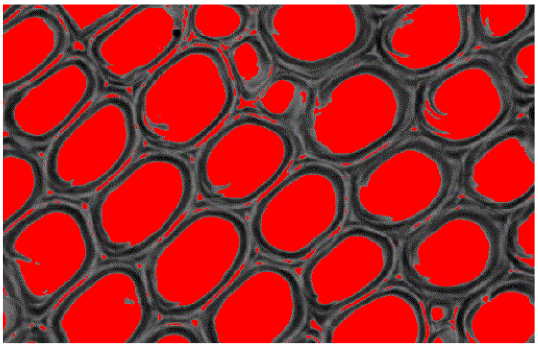


Fig 7. Adjustment and image contrast. Red color corresponds to lumen area and black color corresponds to cell wall area.

P1, P2, P3 and P4 are de different porosities measured in the cross section. P1 was measured in the zone where compression wood is formed (in trunk) and in the zone with major radius in roots (Zone 1). P2 was measured in the zone where opposite wood is formed (trunk) and in the zone with minor radius in roots (Zone 2). P3 and P4 were measured where normal wood is formed (Zone 3 and Zone 4) (Fig. 8).

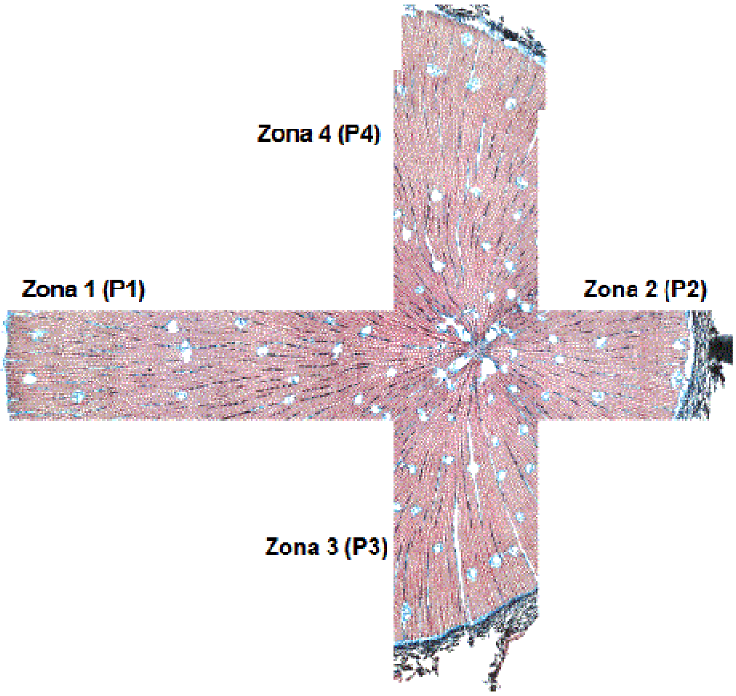


Fig 8. Measurement of porosities in different zones in root. Sample GRE-ARE B5

4.4. DATA ANALYSIS

The influence of provenance, block and part factors on total cross-sectional area (Total A), radius (R and r), cross-sectional eccentricity and porosity (P1, P2, P3 and P4) were studied by adjusted repeated measures ANOVA according to a PROC MIXED model, where the repeated measures represent the part of the tree (trunk, root A and root B). Provenance was considered a fixed factor. Block was considered a random factor with trees rested within it. Restricted maximum likelihood (REML) variances were calculated for each provenances.

Repeated measured ANOVA model, is used to study the effect of one or more factors when, at least one of them, is an intra-subject factor. An intra-subject factor or a factor with repeated measures are characterized by the fact, that all levels of the factor are applied to the same subjects. According to Carrero et al. (2008), the methodology of mixed models allows to analyze correctly and efficiently the data of the experiments with repeated measurements by modeling the covariance structure, which considers the correlations between repeated measurements.

To study the variables, the model has been:

$$y_{i,j,k} = \mu + B_i + P_j + S_k + P_j * S_k + \varepsilon_{ijk}$$

Where µ represents the effect of overall average; B_i represents the effect of the block factor, with i = 1,…,10; P_j represents the effect of the provenances, with j = 1,…, 10; S_k represents the effect of the part of the tree, with k = "trunk", "roots A", "roots B" and ε_{ijk} is the random error checking that $\varepsilon_{ijk} \rightarrow N(0, \sigma j^2)$ and independent. Total. A, R, r, Ec, P1, P2, P3 and P4 are the dependent variables.

Compression wood area was studied with a mixed-model ANOVA with provenance as fixed factor and block as random factor due to this variable was measured only in one part of the tree, the trunk, removed in this way, the effect of repeated measures. Errors were normally distributed and independent. Restricted maximum likelihood (REML) variances were calculated for each provenance. In this case, the model is:

$$y_{i,j} = \mu + B_i + P_j + \varepsilon_{ij}$$

Where µ represents the effect of overall average and random effects are block with $B_i \rightarrow N(0, \sigma_i^2)$; and provenances with $P_j \rightarrow N(0, \sigma_j^2)$; ε ijk is the random error checking that $\varepsilon_{ijk} \rightarrow N(0, \sigma j2)$ and independent. CWA is the dependent variable.

At this point in the analysis, we thought in the possibility a relation between the variables obtained in this study and variables measured in previous work with the same individuals. To observe this relation we choose PHI angle from previous studies. This angle was the estimated angle from Fournier's Model (Fournier et al.,1994). It was calculated considering the amount and position of compression wood and represents the angle recovered by a tilted stem due to the developed compression wood. Hernandez 2010, performed the necessary calculations to obtain this angle in her thesis master. This model has been applied to plants used in this experiment according to the methodology explained in Sierra de Grado et al (2008). CWA and R were the variables used to study the relation with PHI angle. To analyze this variables a linear model was performed:

$$PHI = \mu + \beta_0 * Log\,(CWA) + \beta_1 * R + \varepsilon$$

Log (CWA) was used due to problems of heteroscedasticity in the residuals.

According to this model, the dependent variable (*PHI*) is interpreted as a linear combination of a set of two dependent variables (CWA and R) each of which will be accompanied by a coefficient (β_0 and β_1) indicating the relative weight of that variable in the equation. The model includes a constant (µ) and a random component (residuals: ε) which includes everything that the independent variables are not able to explain.

All statistical analyses were done using the R statistical package called "nlme".
To check normality in residuals model, Kolmogorov Smirnov test of the "nortest" R package was used.
A LSD test of multiple comparisons was performed in all variables that showed significant differences between provenances using a significance level of 0.05. LSD test allows to compare the means of the t-factor levels after refusing the null hypothesis of equal means. "Predictmeans" was the R statistical package used to do this statistical analyses.

5. RESULTS

5.1. ANATOMY

Data summary statistics are shown in Table 1. These data show that “Total A” presents great variability, with a minimum of 5.63 µm^2 and a maximum of 175.76 µm^2. P1, P2, P3 and P4 have similar means, however P1 shows a wider range and a higher value of coefficient of variation (29.16 %) than the rest of porosities. Total observations on “CW A” were lower due to this variable was only measured in trunk.

Table 3. Basic summary statistical by the variables studied.

Variable	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se	cv
Total Area	238	62.79	39.03	58.95	59.66	45.40	5.63	175.76	170.13	0.58	-0.44	2.53	62.16
CWA	51	6.05	4.04	4.85	5.61	3.47	1.11	21.05	19.94	1.22	1.79	0.57	66.78
R	238	5.03	1.72	4.92	4.97	1.95	1.52	9.88	8.36	0.27	-0.56	0.11	34.19
r	238	3.56	1.37	3.60	3.52	1.64	0.60	7.33	6.73	0.21	-0.73	0.09	38.48
Ecct	238	1.49	0.45	1.39	1.44	0.31	0.76	5.95	5.19	4.52	40.31	0.03	30.20
P1	236	48.25	14.07	51.86	49.62	10.62	5.79	77.03	71.24	-0.88	0.12	0.92	29.16
P2	237	47.56	12.91	50.94	48.67	9.21	7.34	70.48	63.14	-0.84	-0.11	0.84	27.14
P3	234	47.37	13.17	50.61	48.49	10.18	9.28	74.91	65.63	-0.78	-0.16	0.86	27.80
P4	233.	47.57	12.98	50.64	48.61	9.49	9.28	74.91	65.63	-0.74	-0.12	0.85	27.29

07NOINT and 04ALMI provenances showed the greatest value for the mean in cross-sectional area (Total A) with 75.78 and 72.05 µm^2 while BUSO was the provenance with the minimum value for cross-sectional area, 50.62 µm^2.
For the straight provenances, 07NOINT and 10LEIR had the highest mean in the R variable (5.8 µm and 5.52 µm) on the contrary, 04 ALMI, belonging to the twisted provenances, had the greatest value for minor radius (3.87 µm). On the other hand,07NOINT was the provenance that showed highest mean for Ecct (1.63 %). Finally 07NOINT and 09GRE were the provenances with higher porosities in every studied zone, P1, P2, P3 and P4 (Fig 19).

Provenances have significantly role ($p<0.05$) in Total A and R, whereas differences through provenances were not observed in the rest of measured variables, r, Ecct and porosities, P1, P2, P3 and P4 (Table 4). However, the part of the plant was significant in all studied variables (p-value<0.0001).

The significant interactions provenance by part in Total A (p-value = 0.0386) P1 (p-value = 0.0006), P3 (p-value=0.0231) and P4 (p-value = 0.0413) indicates an association between provenance and the studied parts of the tree in these variables.

Table 4. P-values of mixed models for variables measured on trunk and roots in the different studied provenances.

Variable	Provenance	Part	Provenace * Part	Contrast Straight-vs. Twisted-stemmed provenances
Total Area	0.0035**	< 0.0001***	0.0386*	0.6979
R	0.0088**	< 0.0001***	0.1918	0.4004
r	0.1628	< 0.0001***	0.3852	0.9538
Ecct	0.0893	< 0.0001***	0.8735	0.0814
P1	0.1958	< 0.0001***	0.0006***	0.5871
P2	0.3537	< 0.0001***	0.1975	0.3523
P3	0.2132	< 0.0001***	0.0231*	0.5920
P4	0.4113	< 0.0001***	0.0413*	0.3024

$^*p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$

Kolmogorov Smirnov test applied to residual models, show that the distribution of these variables follow a normal distribution in all measured variables (Table 5).

Table 5. Kolmogorov-Smirnov test results for residuals.

Variable	Kolmogorov Smirnov
Total A	0.925
R	0.885
r	0.496
Ecct	0.290
P1	0.758
P2	0.437
P3	0.934
P4	0.140

$^*p<0.05$

None measured variables showed significant differences between twisted and straight provenances (Table 4). However, the five twisted provenances showed great similarity in Total A and R, whereas the straight populations showed great variability (Table 6 and 7) for these variables. Besides, the interaction provenance by part had also significant differences in straight provenances, with a p-value of 0.0104 for Total A and a p-value of 0.0243 for R (Table 6 and 7).

Table 6. . P-values of mixed models for total cross-sectional area (Total A) on trunk and roots in both twisted and straight provenances.

TWISTED	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	60	259.887	<.0001***
Part	2	60	115.421	<.0001***
Provenance	4	34	1.077	0.3833
Provenace * Part	8	60	1.449	0.1951

STRAIGHT	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	62	207.249	<.0001***
Part	2	62	119.377	<.0001***
Provenance	4	36	7.406	0.0002***
Provenace * Part	8	62	2.7945	0.0104*

*p<0.05, **p<0.01,***p<0.001

Table 7. P-values of mixed models for total Major radius (R) on trunk and in both twisted and straight provenances.

TWISTED	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	60	753.553	<.0001***
Part	2	60	86.652	<.0001***
Provenance	4	34	0.698	0.5984
Provenace * Part	8	60	0.409	0.9109

STRAIGHT	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	62	823.662	<.0001***
Part	2	62	84.509	<.0001***
Provenance	4	36	8.262	0.0001***
Provenace * Part	8	62	2.417	0.0243*

*p<0.05, **p<0.01,***p<0.001

Figure 9 and 10 shows the means of Total A, R, r and Ecct for each part of the tree (Trunk, Root A and Root B). It is observed that the mean of Total A decreases as we descend in height within the tree, with a maximum value of 97.49 µm^2 in trunk and a minimum of 28.65 µm^2 in Root B. This trend is repeated for the variable r. However, the mean of the R variable is very similar in trunk and Roots A with 5.95 and 5.96 µm respectively, decreasing significantly in the lower part of the tree, with a mean of 3.57 µm. There were significant differences in Ecct between Roots (A and B) and Trunk, p-value = 0.0001. We can observe these differences in the graph which is shown in the Figure 10.

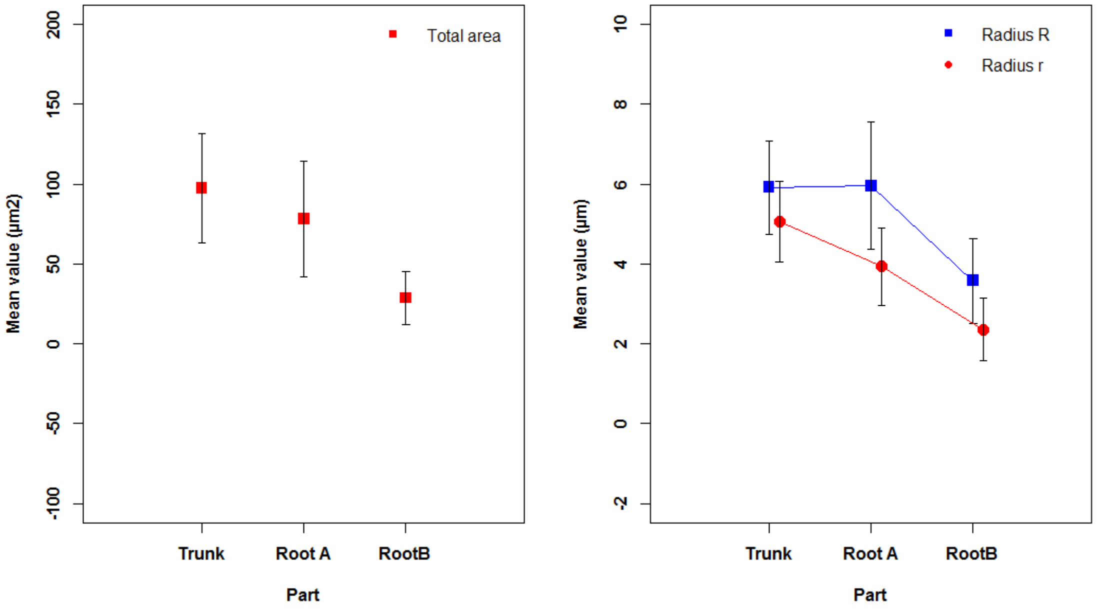


Fig. 9. (a) Mean plot for total cross-sectional area in different part of the tree, Trunk, Root A and Root B. (b) Mean plot for major radius (R) and minor radius (r)

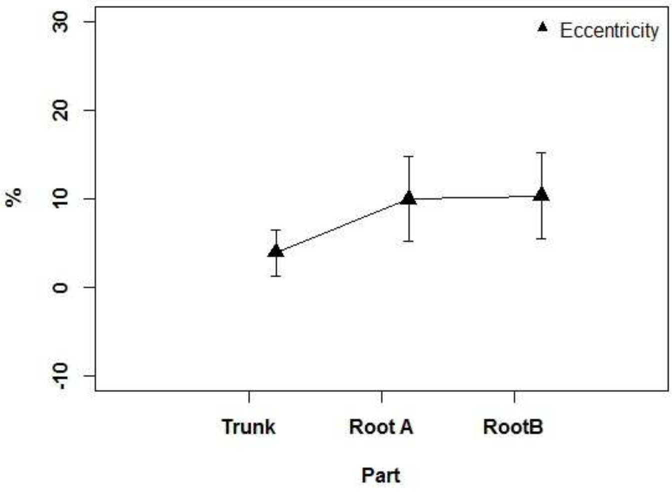


Fig. 10. (a)Mean plot eccentricity in different part of the tree, Trunk, Root A and Root B.

After significant differences in Total A and R for different studied provenances existence were proven, Fisher's Least Significant Difference (LSD) Test was performed null hypothesis of equal means, averages of t-levels were Refused and compared with LSD test, adjusted by "Bonferroni" method. As a result of this test, significant differences at different levels have been obtained, p-value ≤0.01; 0.01 < p-value ≤ 0.05 and 0.05 < p-value ≤ 0.1 (Fig. 11).

The provenances 07NOINT and 08BUSO show significant differences (p-value ≤0.01), for Total A and R, with different levels of significance, p-value ≤0.01 for Total A and 0.01 < p-value ≤ 0.05 for R, these differences also appear in 07NOINT and 06ALMO provenances. Both variables have significant differences in 07NOINT and 02 NIEV, however R has a lower level of significance (0.05 < p-value ≤ 0.1) than Total A (0.01 < p-value ≤ 0.05). Besides, total A presents also differences between provenances 08BUSO and 09GRE with p-value 0.01 < p-value ≤ 0.05 (Fig. 11).

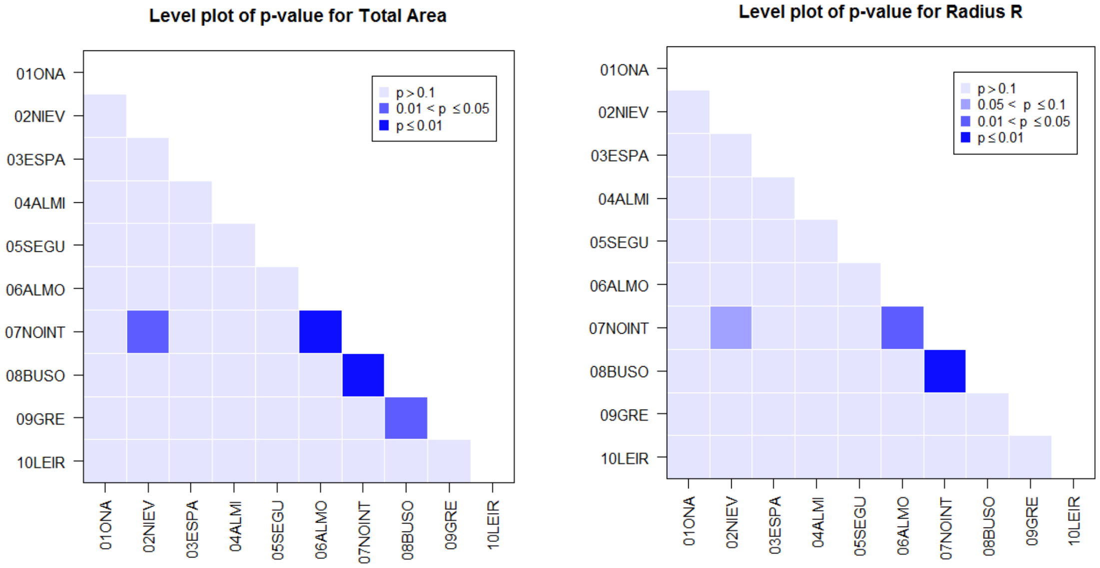


Fig. 11. LSD test for Total cross-sectional area (Total A) and Major radius (R).(Variable = Provenance)

Repeated measured ANOVA showed that existed significant differences for the interaction between tree's provenance and part (trunk, root A and root B) in Total A, P1, P3 and P4 (Table 3).

For this reason, the LSD test was used to analyze this interaction between tree's provenance and part in these variables. By using this test, it was possible to observe the effect provenances played in each part of trees (Fig. 12, and Fig. 13).

In Total A we can see, it exists more variability in trunk than in roots. Results into the trunk, the provenance 07NOINT showed the maximum value, with a mean of 140.36 µm^2 for LSD test, while 08 BUSO showed the minimum value with mean of 72.50 µm^2. This variable is more uniform in root (between 17.50 µm^2 and 33.13 µm^2) than in trunk.

P1, 07NOINT showed the maximum value in all parts of the tree, with mean of 26.28% in trunk, 54.05% in root A and 55.56% in root B. 10 LEIR obtained the highest mean in roots B, 60.15%, however in the rest of parts, is one of the provenances with lower mean, 53.11% in root A and 10.17% in trunk. Based on the mean values for the different parts of the tree for each provenance, the variability between trunk and the two parts of roots was higher than the variability between roots A and roots B. A similar pattern was observed in each of the porosity analyzed. P3 and P4 had the same behavior than P1, being 07NOINT the highest provenance mean in trunk; root A and root B with 10LEIR as the highest provenance mean in roots B and the lowest mean in roots A and trunk. In all zones analyzed (P1, P3 and P4), the mean of porosity showed a significant decrease in trunk part.

Average LSD show the confidence interval, which should be associated with each average calculated for each provenance in all studied parts of the tree.

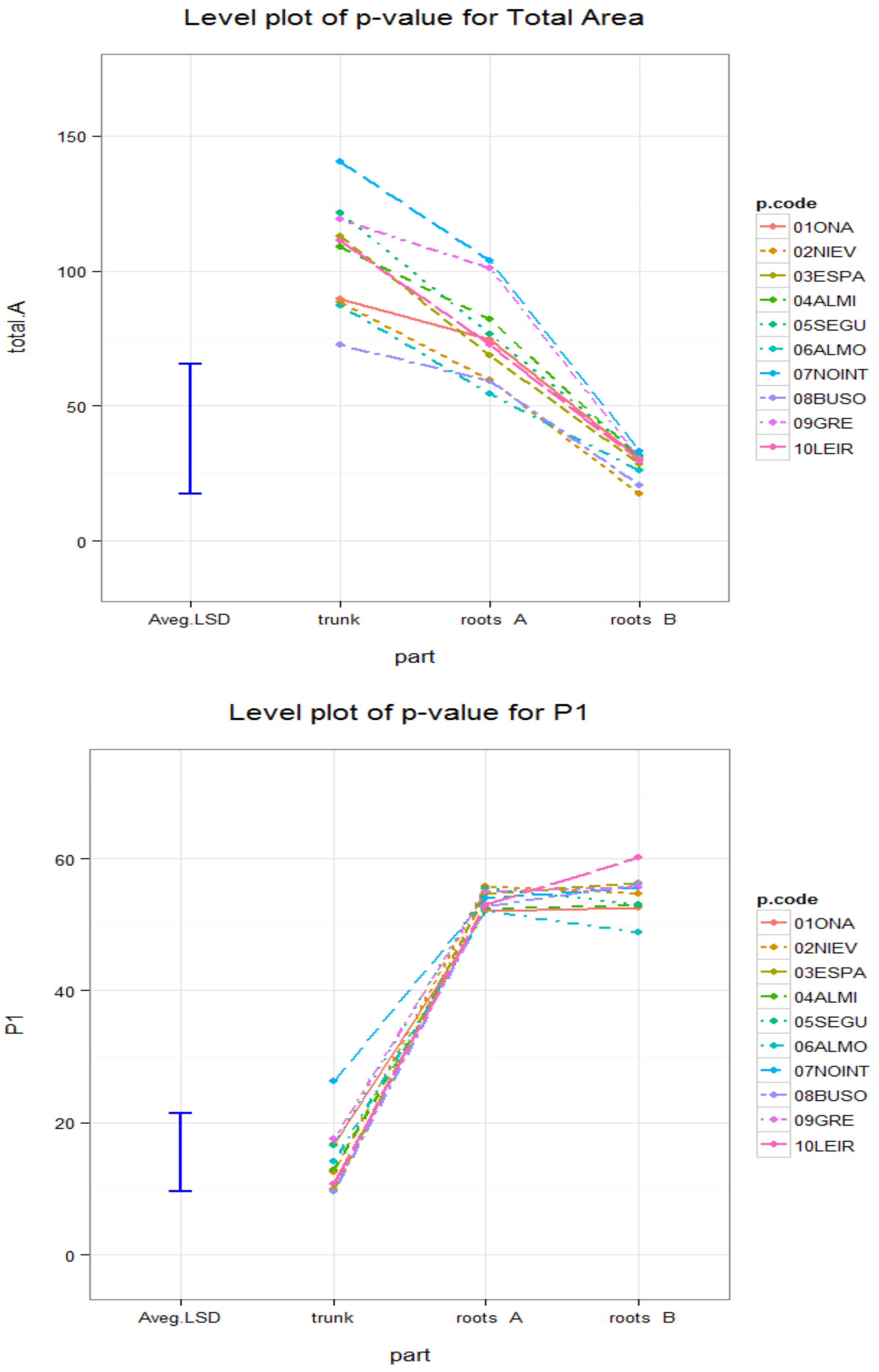


Fig. 12. LSD test for Total cross-sectional area (Total A) and Major radius (R).(Variable = Interaction provenance and part).

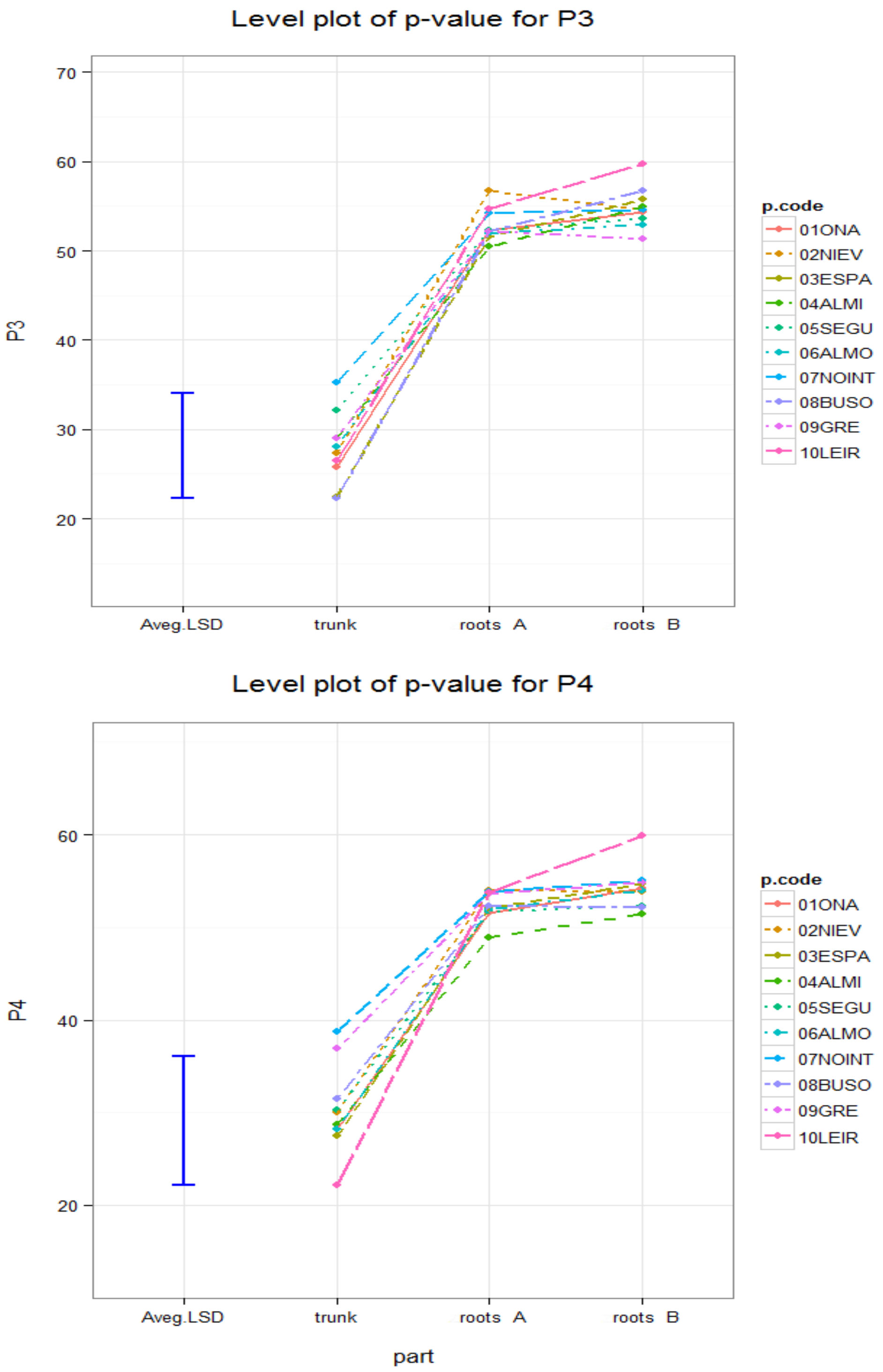


Fig. 13. LSD test for Porosity in zone 3 and Porosity in zone 4 (Variable = Interaction provenance and part).

5.2. COMPRESSION WOOD

This variable was measured only in trunk, due to compression wood area was not possible to measure in roots. Since, we have not repeated measurements on the same tree for this case, two parameters ANOVA (provenance and block) was used to analyze this variable.

To study CWA in our plants, we calculated the percentage of CWA which existed in the whole section, this way, was possible to observe the provenance which produced more amount of compression wood according to the size of its cross section.

Analysis of variance showed differences in compression among wood area and provenances (p-value 0.0246), however, the difference in CWA between the straight and twisted provenances was not significant (Table 21). The five twisted provenances (on the left side of Table 22 and Fig 14) showed a great similarity in compression wood area (p-value 0.5294) whereas the straight provenances (on the right side) showed a great variability (p-value 0.0211) for this variable.

08BUSO and 10LEIR were the provenances with highest percentage of CWA with 8.13% and 11.11% respectively, whereas 01ONA and 06ALMO were the provenances with the lower percentage of compression wood area, 4.4% and 3.89%. It is interesting to note that 04ALMI showed the highest value for coefficient of variation, 89.59%, 01ONA and 06 ALMO had also high values for this coefficient, 72.50% and 84.32 % respectively. On the contrary 08BUSO was the provenance which got the lowest value for this coefficient of variation, 37.64%.

These results indicate that 04ALMI was the provenance that showed greater heterogeneity of the compression wood values, while 08BUSO was the provenance which showed lowest variability in the formation of this type of wood, confirming the variability in compression wood formation for the different studied provenances. Kolmogorov Smirnov test applied to residuals model shows that the distribution of the model follows a normal distribution (p-value 0.523). Therefore, null hypothesis of equal means was not refused.

Table 8. P-values of mixed models for compression wood area measured on trunk in the different studied provenances.

Variable	Part	Provenance	Contrast Straight-vs. Twisted-stemmed provenances
Compression Wood Area (%)	Trunk	0.0246*	0.1052

*p<0.05, **p<0.01,***p<0.001

Table 9. P-values of mixed models for Compression wood area on trunk in twisted provenances and straight provenances.

Twisted	numDF	denDF	F-value	p-value
(Intercept)	1	15	70.745	0.001***
Provenance	4	15	0.659	0.5294

Straight	numDF	denDF	F-value	p-value
(Intercept)	1	15	92.796	0.001***
Provenance	4	15	3.815	0.0218*

*p<0.05, **p<0.01,***p<0.001

In Fig 14, it is possible to observe the variability within the two groups of provenances, whereas twisted provenances have more homogeneous distribution, with values between 4 % and 6.5 % of compression wood in the cross section. The percentages obtained by straight provenances showed more variability, between 4%-11%. This results agree with the two parameters ANOVA results that indicated significant differences in straight provenances.

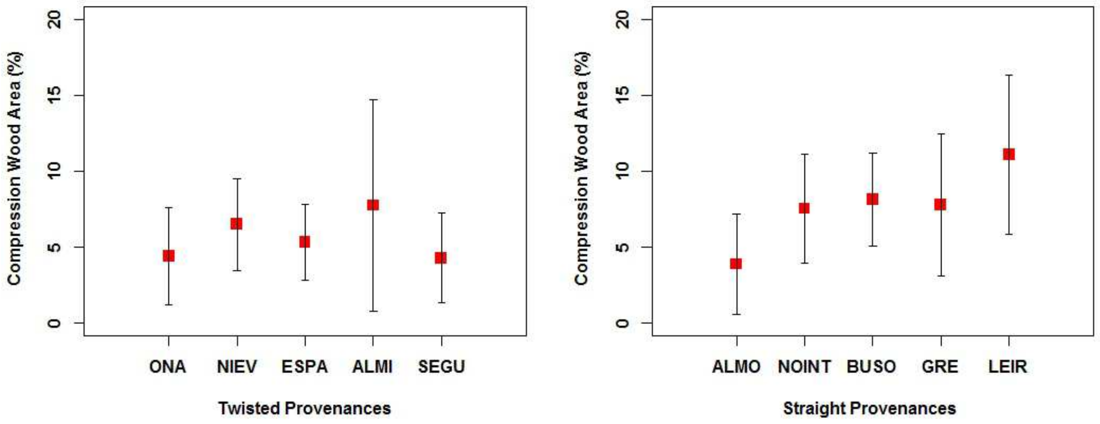


Fig. 14. Mean plot for Compression Wood area in twisted provenances and straight provenances.

Using LSD test (Image 15), significant differences at different levels have been obtained, (0.01 < p ≤ 0.05; 0.05 < p ≤ 0.1 and p > 0.1) for the different studied provenances. Differences in percentage of CWA were significant among the straight provenances 10LEIR and 06ALMO (p-value 0.0281).

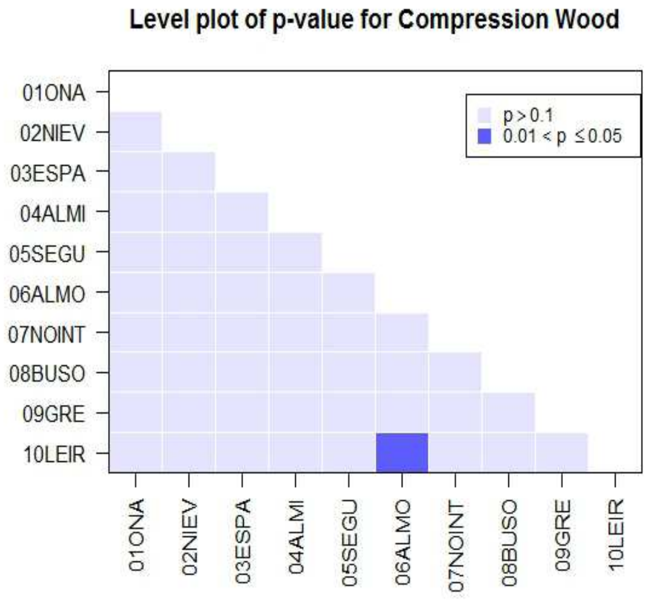


Fig. 15. LSD test for the percentage of Compression wood area (Variable = Provenance)

5.3. POROSITY

In this case, porosity have been studied in different zones inside the same part of the tree, in order to analyze porosities in the same cross section. P1, was measured in the zone where compression wood is formed (in trunk) and in the zone with major radius in roots (Zone 1). P2, was measured in the zone where opposite wood is formed (trunk) and in the zone with minor radius in roots (Zone 2). P3 and P4, were measured where normal wood is formed (Zone 3 and Zone 4) (Fig. 6).

Repeated measured ANOVA, with provenance and zone as fixed factor, showed that the difference in porosities in provenances was not significant at any of the measured parts. Besides, the contrast between straight and twisted provenances showed that these differences were not significant (Table 10).

In the part of trunk as well as root A, the zone where porosities were measured inside the cross section (P1, P2, P3 and P4) had a significance role, with lower level of significance in root A (p-value = 0.0435) compared to trunk (p-value < 0.0001). On the contrary, the lowest part of the tree analyzed, root B, did not show significant differences between the measured zones (Table 10). The significant interaction provenance * zone (p-value = 0.0001) in the part of trunk indicates an association between provenance and the zone where porosities were measured.

Table 10. P-values of mixed models for porosity on trunk and roots in the different zones of the sample (P1, P2, P3 y P4).

Variable	Part	Provenance	Zone	Provenance * Zone	Contrast Straight-vs. Twisted-stemmed provenances
Porosity	Trunk	0.3290	<0.0001***	0.0001***	0.9593
	Root A	0.4015	0.0435*	0.5937	0.7875
	Root B	0.2161	0.4359	0.2468	0.4434

*$p<0.05$, **$p<0.01$,***$p<0.001$

A new, kolmogorov Smirnov test was used to analyzed the residuals statistical model with a level of significance of $\alpha = 0.05$. As the table 11 shows, the residuals of the model performed with the different parts of the tree, follow a normal distribution.

Table 11. Kolmogorov-Smirnov test results for residuals.

Part	Kolmogorov Smirnov
Trunk	0.112
Root A	0.085
Root B	0.279

*$p<0.05$, **$p<0.01$,***$p<0.001$

Both twisted and straight provenances showed significant role in the part of trunk for the different measured porosities, (p-value<.0001). Besides, in twisted provenances, significant differences was possible to observe in roots A, with p-value 0.0308 (Table 12). The interaction zone*provenances was more important in straight than in twisted provenances (Table 12). In straight provenance it was possible to observe high level significant differences in trunk (p-value 0.0003) and roots B (p-value 0.0095). However, in twisted provenances significant differences were only observed in trunk (p-value 0.0189).

These results confirm it exists greater variability in straight provenances than in twisted provenances.

Table 12. P-values of mixed models for porosities (P1, P2, P3 and P4) on trunk and roots in twisted provenances and straight provenances.

Form	Zone	Zone (p-value)	Provenance (p-value)	Zone * Provenace (p-value)
Twisted	Trunk	<.0001***	0.0772	0.0189*
	Roots A	0.0308*	0.1831	0.8215
	Roots B	0.3588	0.5618	0.3350
Straight	Trunk	<.0001***	0.4015	0.0003***
	Roots A	0.6006	0.6279	0.3169
	Roots B	0.9400	0.1861	0.0095**

*p<0.05, **p<0.01,***p<0.001

Image 16 shows the variability between the different porosities inside of each part of the tree. As the measured repeated ANOVA showed, in the part of trunk it is observed more variability than in roots.

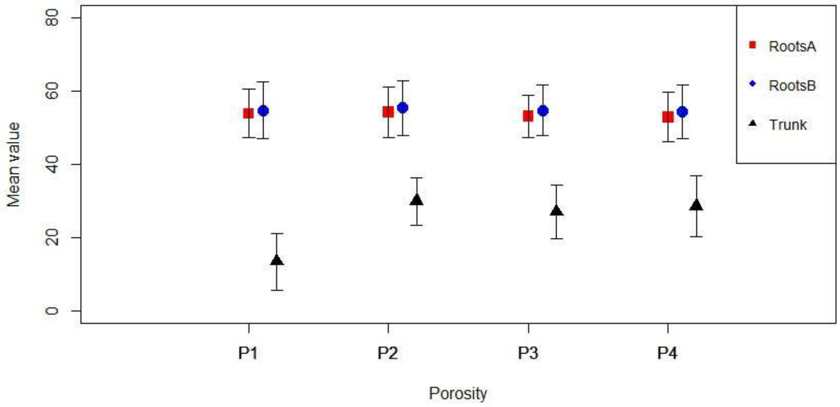


Fig. 16. Mean plot for porosities in different parts of the tree. Red squares: Roots A; Blue circles: Roots B; Filled triangles: Trunk. Error bars represent the standard deviation

With high level of significance (p ≤ 0.01), LSD results showed high significant differences (p ≤ 0.01) between the porosity measured in the zone where compression wood was formed (P1) and the rest of porosities (P2, P3 and P4) in the part of trunk. In the graph shown above, is possible to observe this results in where we can see that P1 had a lower mean than the rest of porosities in trunk.

For root A, differences between P2 (the porosity measure, where opposite wood was formed) and P4 (the porosity, where normal wood was formed) were found. The significance was lower than found differences in trunk.

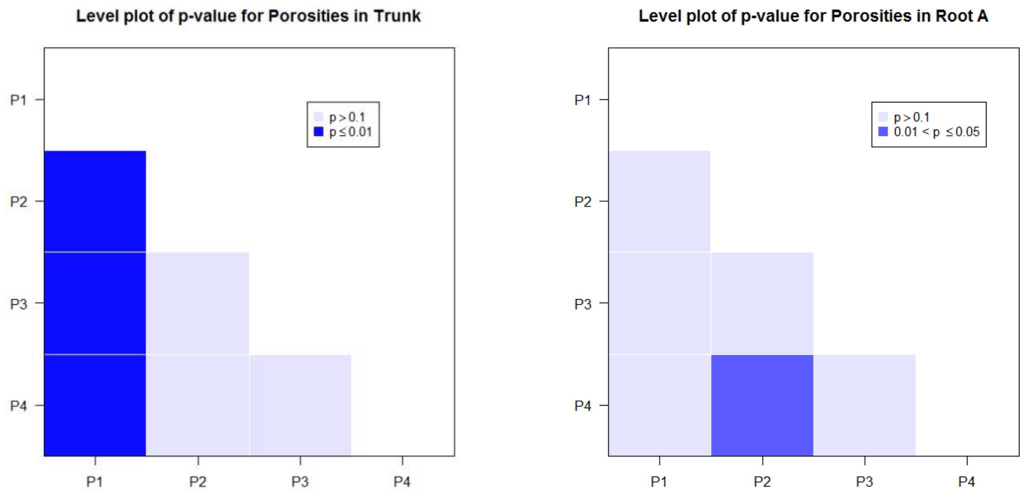


Fig. 17. LSD test for porosities in trunk and root A.(Variable = Zone)

Results of repeated measured ANOVA indicated there exist significant differences for the interaction between provenance and zone for porosities measured in the part of trunk. Therefore, LSD test was used to analyze this interaction (Fig. 18).

07NOINT, within P1,was the high mean provenance (26.13%). Similarly in P3 and P4, the highest values averages of porosities obtained for this provenance were 35.22% and 34.23% respectively. However, 07NOINT within P2, showed the lowest mean, 26.13%. The provenance 05SEGU showed high means in all zones studied, whereas the provenances with lower values were 03ESPA and 04ALMI. In general, all provenances showed lower values for P1, except 07NOINT which had a similar value in P1 and P2.

It was possible to observe different trend for the studied provenances (Fig. 18). Some of these, like 01ONA, 02NIEV, 03ESPA, 08BUSO and 09GRE showed a decreased in the value of porosities analyzed in P3. Others, like 04 ALMI, 05SEGU and 10LEIR had lower means in P3 and P4 than in P2. 06ALMO provenance showed a constant value through the porosities measured in P2, P3 and P4 whereas 07NOINT had similar values for the porosities measured in P3 and P4.

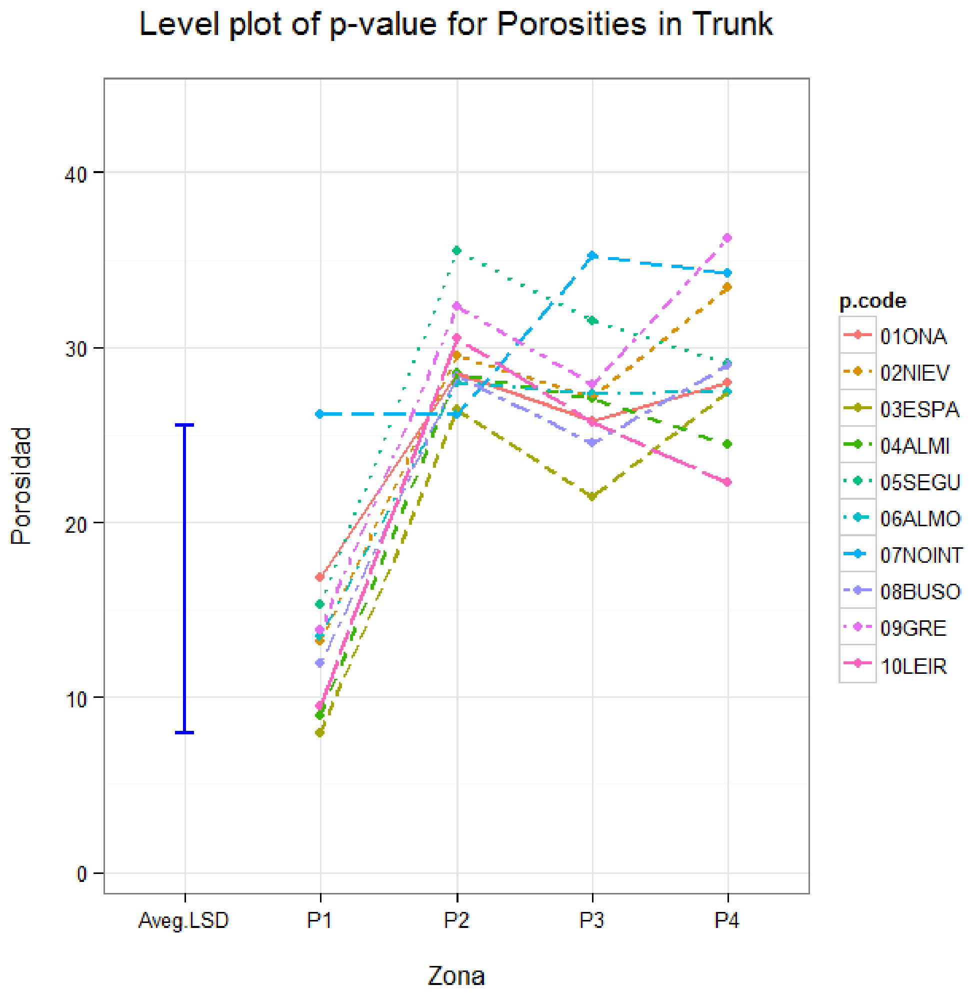


Fig. 18. LSD test for porosities measured in the different analyzed zones (Variable = Interaction provenance and zone).

Despite provenances did not show significant differences. Graphic was performed in order to know which are the mean distribution and the mean relation measures in porosities for the different studied provenances (Fig. 19).

It is observe that in all analyzed zones obtained values for measured porosities in trunk were smaller than obtained values in roots. The average values in P1, P2, P3 and P4 for the different studied provenances showed more homogeneity in roots A and roots B than in trunk.

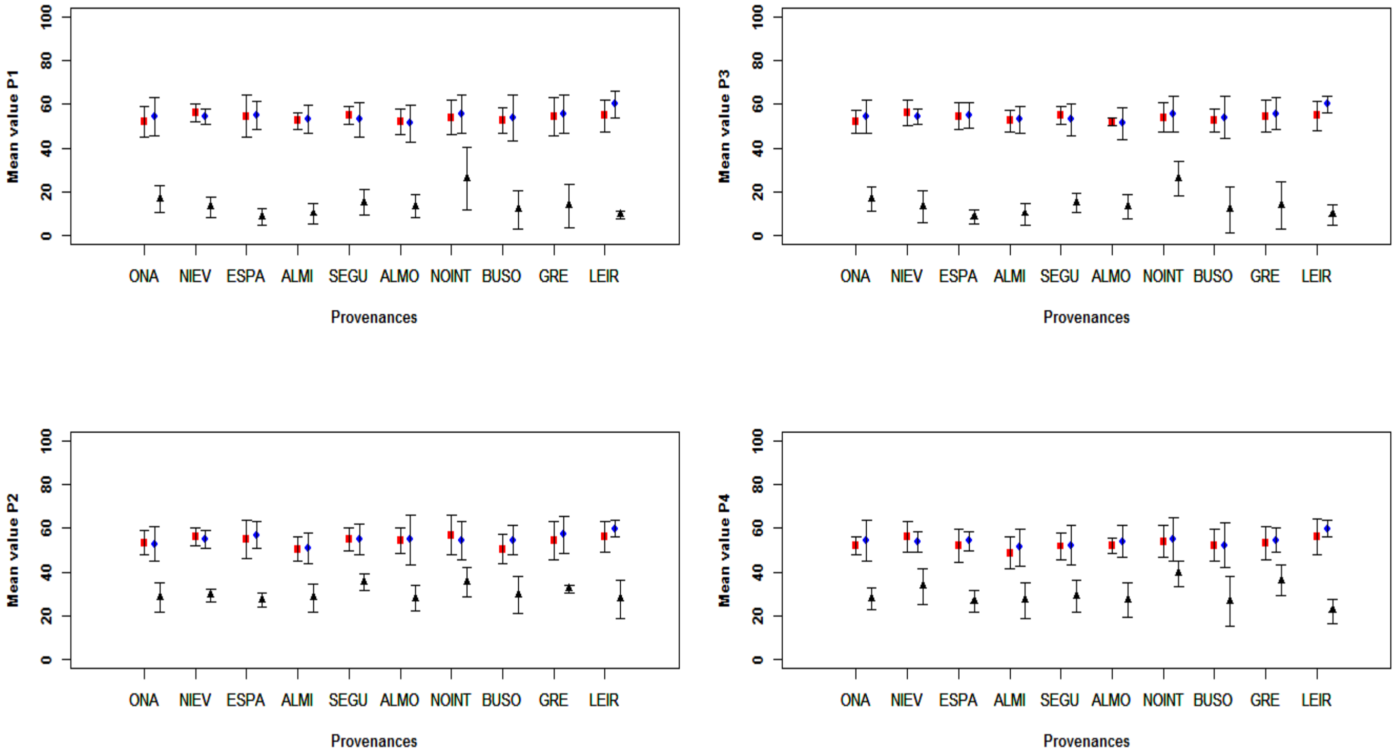


Fig. 19. Mean plot for Porosities measured in different zones for the different studied provenances. Red squares: Roots A; Blue squares: Roots B; Black squares: Trunk. Error bars represent the standard deviation.

5.4. LINEAR ADJUSTMENT

At this point of the analysis, we thought in the possibility to use variables obtained in previous studies performed with the same individuals. PHI was the estimated angle from Fournier's Model (Equation 3). It was calculated considering the amount and position of compression wood. The objective was to check if there was a relation between the obtained variables in this study and measured variables in different previous works.

To analyzed this relation a linear adjustment among PHI, *log*(CWA) and R was performed. Log (CWA) was used due to problems of heteroscedasticity in the residuals.

There was a strong correlation between PHI and log(CWA) (p-value = 3.51 e-6) and between PHI and R (p-value = 0.000586). The value for R^2 was 0.4461, this indicated, that CWA and R variables, explain the 44,61% of the variability of PHI. This model meets the assumptions of normality, p-value= 0.6433 for Kolmogorov-Smirnov test, and homoscedasticity (Table 13, Fig. 20).

Table 13. Linear adjustment results and Kolmogorov Smirnov test results for residuals.

	Coefficients				**Residuals**
	Intercept (p-value)	**Log (CW.A) (p-value)**	**R (p-value)**	**R^2**	**Kolmogorov**
PHI = *Log*(CW.A) + R	9.53e -11	3.51 e-6	0.000586	0.4461	0.643

p*<0.05, ***p*<0.01,**p*<0.001

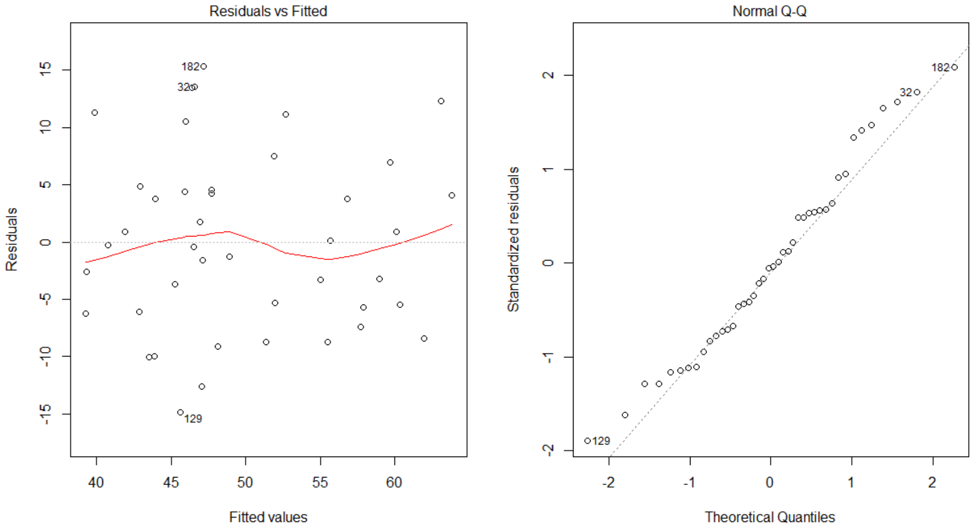


Fig. 20. Plots of residuals and fitted values and normal Q-Q.

The same model was performed dividing the variables in twisted and straight provenances (Table 14). R^2 value was higher in the model developed for straight provenances ($R^2 = 0.5013$) than in twisted provenances ($R^2 = 0.4041$).

Table 14. Linear adjustment results and Kolmogorov Smirnov test results for twisted provenances and straight provenances .

	Provenances	**Coefficients**				**Residuals**
		Intercept (p-value)	**Log (CW.A) (p-value)**	**R (p-value)**	**R^2**	**Kolmogorov**
PHI = Log(CW.A) + R	Twisted	4.72 e -05***	0.00715**	0.01175*	0.4041	0.2926
	Straight	1.02 e-06***	0.000489***	0.0249*	0.5013	0.1385

6. DISCUSSION

As we expected, a great variability between the different parts of the tree, trunk and root, was observed. These results contribute to previous studies in which some qualitative and quantitative anatomical differences between stem wood and root wood were found in hardwood species (Ewers et al., 1997; Lee and Eom, 2011; Machado et al., 2007; Palhares et al., 2007; Psaras and Sofroniou, 1999; Stokke and Manwiller, 1994).

Cross-sectional area (Total A) and minor radius (r) decreases as we descend in height inside the tree. However eccentricity was higher in roots than in trunk, Fig. 8 shows as the value of this variable increases with depth in all studied provenances.

Garrido et al., 2015, in previous studies performed with the same plants, found that the asymmetry was lost in the deeper cross sections of the root. This finding differ from our results where eccentricity increases with depth. The differences about the variation of cross sectional asymmetry depending on depth may be due to the use of different methods for calculating the eccentricity. In our case, we used the Equation 1, in which cross-sectional eccentricity was measured like a percentage of the distance between the pith and the center of the ellipse, with respect to the length of the major diameter. However, in the work performed by Garrido et al, (2015) the cross-sectional eccentricity was obtained as the ratio between the E-W/N-S diameters at each observed depth.

The porosity measured in the zone where compression wood was formed (P1) showed higher coefficient of variation (with values between 20-50%) in all populations, which could indicate that this porosity has greater variability than the rest. The significant anatomical differences showed by P1 (in trunk) regarding the rest of porosities, reinforce studies, like those made by Clair and Thibaut, 2014b, in which compression wood shows differences from normal wood in conifers, for all physical and mechanical properties.

6.1. VARIABILITY BETWEEN TWISTED-AND STRAIGHT-STEMMED POPULATIONS.

Straight provenances showed greater heterogeneity than twisted provenances in all studied variables. This pattern was reflected in the results of mixed models. All twisted provenances were quite similar in the following studied variables, Total A, R and CW.A, whereas straight populations combined the traits of size of the roots and trunk in a more variable way than the twisted population. This agrees with the observation finding by Garrido et al. (2015). In both cases, results suggesting a higher responsiveness in straight-stemmed provenances when they encounter mechanical stresses and a more effective modulation of the shape and size of their roots and trunks, although different strategy are showed by each provenance.

The contrast between straight and twisted provenances were not significant for total cross sectional area (Total A), major radius (R), minor radius (r), eccentricity (Ecct) or porosities (P1, P2, P3 and P4). NOINT, LEIR and GRE, all belonging to the group of straight provenances, were the populations with highest values in all the mentioned variables. A large root area is usually associated with good stability (Lindgren and Örlander, 1978), therefore, according our results NOINT, LEIR and GRE could be the provenance with greater mechanical stability.

Stem reorientation are necessary for plants to adapt to their environment, for example to recover from mechanical perturbations or maximize light interception. But stem straightness is related not only for stem reorientation but also by several factors, root architecture, shape and weight of the roots, physical and mechanical properties of the roots, etc. Ability of performing movement have be assume as better adaptation to their environment, for example to recover from mechanical perturbations or maximize light interception (Alméras et al., 2009). The results of the lineal adjustment performed with Phi angle, CWA and major radius (R), emphasizes the importance of a relation among different factors to understand the process of stem straightness.

Note also that the interaction between provenance and part had a significant effect in some of the studied variables, such as, Total A, P1, P3 and P4. If we analyzed these variables for the different provenances in the different parts of the tree, we can see that these provenances had different behavior according the part of the tree. For example, LEIR had the highest mean in roots B, however in the rest of parts is one of the provenances with lower mean. This finding emphasizes the importance of the difference between the structure of the wood from root and stem of arboreal species as an indicator of the adaptation of the tree to the environment (Longui et al., 2012).

6.2. Compression wood

Provenance showed a significant effect in the formation of compression wood , being 10LEIR the provenance which produce greater amount of this type of wood, with a percentage of 11.11% of compression wood area, and 06ALMO the provenance with lower percentage in the formation of compression wood, 3.89%. Percentage obtained by 10LEIR is similar to that obtained by Ladell et al. (1968) who found that even a good site in Painell, Township (Ontario), the mean compression wood content in trees of black spruce *(Picea mariana)* was 13.9%. Occurrence of 13–17% CW in rocked and straight plants has been reported (Apiolaza et al. 2011), apparently caused by the stem movement. Being these percentages very similar to those obtained in our study.

The variability in compression wood percentages among provenance can be assumed as a difference in the efficiency of the postural control by genotypes through compression wood formation. This observation is in agreement with data of Nanayakkara et al. (2014), where genotypes differed significantly in the amount of CW formed. Telewski and Jaffe (1986), observed that six-month-old *Pinus taeda* plants of different genetic background respond in slightly different ways to identical mechanical perturbations under similar environmental conditions.

As has been shown in this experiment, there were not significant differences among twisted and straight provenances in the formation of compression wood. This finding suggests that straight provenances are more efficient in the postural control, since, with the same formation of compression wood, straight-stemmed populations are able to respond more efficient than twisted-stemmed population. This conclusion is supported by the results obtained by Garrido et al. (2015), who described different population strategies in response to mechanical stress.

Compression wood can be classified from mild to severe on the basis of its anatomy. Severe compression wood is characterized by a rounded cell outline with intercellular spaces at the corners, a highly lignified outer S2 layer that is continuous around the perimeter of the cell, a thick secondary wall containing helical cavities, distorted bordered pit apertures, and the absence of an S3 layer. Mild compression wood can occur in a range of forms characterized by many different partial combinations of the complete set of compression wood features described above, forming a continuum between normal wood and severe compression wood (Singh and Donaldson, 1999). It is desirable, therefore, to also have detailed information on the characteristics of mild compression wood because the features of mild compression wood may also be very different from normal wood and are likely to impact upon the processing and utilization of wood (Singh 1996, 1997). The high values showed by several provenances (89 % for ALMI and 84% for ALMO) in the coefficient of variation for the percentage of compression formed in the cross section, could be associated with various compression wood types. Judging from the extent of variability observed in a range of characteristics within a small region of wood, it appears that several features in combination may often have to be considered in distinguishing mild compression wood from severe compression wood (Singh and Donaldson, 1999).

Growth eccentricity is a complementary but second order effect often associated with reaction wood formation (Almeras et al., 2005) . According to this theory it make sense that the provenances with major eccentricity be the provenances with major percentage of compression wood area.

As has been shown, compression wood was not observed in any of the cross-sections of all the roots examined, this effect are commonly observed in other studies performed about gymnosperm roots where compression wood can only form when the root is exposed to sunlight (Fayle, 1968). In this case, could be interesting deepen in microscopic features as well as the chemical properties of compression wood in the deepest areas of the tree. These results could provide information about the process of formation for different types of wood, compression, opposite and normal wood and their relationship in the straightening process.

Compression wood shows important differences from normal wood in conifers, for example, higher density. Density has long been understood to be the main factor affecting the mechanical properties of wood, and usually this factor is compared to other parameters when species or trees are examined. However, when we wish to study these parameters in a single tree, the relationship becomes less clear and specially when studying reaction wood (Clair and Thibaut, 2014b).

The term wood density refers to macroscopic measurement, and depends on the amount of the cell wall compared to void volume ,fibre and vessel lumina, for example, (Clair and Thibaut, 2014b). If we calculated porosity as a ratio of lumen area between total analyzed area, we could understand this variable like a indicator related with the density since higher value for the thickness of the cell walls produces a lower value for porosity (Equation 2). The mean values obtained for porosities measured in the part of trunk were smaller than the mean values obtained in roots, this results might indicate a higher density in the part of trunk compared with the density in roots. In the case of trunk , the results of repeated measured ANOVA showed significant different in the zone where compression wood is formed (P1) regarding the rest of zones, P2, P3 and P4. If we compared the means of the four zones in the cross section, we observe that porosity measured in P1 have a lower mean (13.49 %) that the porosities analyzed in the rest of zones of the cross section (29.87, 26.95 and 28.75%), these values indicates that the density in the in the zone where compression wood is formed is higher than in the zones where opposite and normal wood is formed, which is commonly observed in other studies, as those performed by Timell (1986).

Coefficient of variation had a higher value in the case of P1, with a value of 56.41% compared with the porosities measured in other zones in the cross section, whose values are between 20% and 30% (see Table 3, Appendix). This variability in the coefficient of variation for the different analyzed porosities only was possible to observe in trunk, since, porosities measured in the different zones of the cross sections belonging to roots, both root A as root B, showed values for coefficient of variation very similar (10-15%). These results about the coefficient of variation suggest that porosity measure in the zone where compression wood is formed (P1), is subjected to more variation regarding the rest of porosities measured in the rest of zones of the cross section (P2, P3 and P4).

On the contrary, in "root A", differences were found between the zone where opposite wood is formed (P2) and the zone where normal wood is formed (P4). However, in this case the significance was lower than differences showed in trunk. As has been shown before, the part of the tree that are being analyzed had a significant effect in the result obtained. This agrees with the observations performed in earlier studies in which anatomical differences between root and trunk are recognizable within a tree (Bowyer et al., 2007; Schweingruber, 2006; Timel, 1986).

6.3 STEM STRAIGHTENING AND MECHANICAL STABILITY

Downes ,(1993) observed that in terms of the speed of the reaction response, the families with bigger initial deformity were as effective in responding to the induced bend as those with smaller deformities. The stem size at the moment of leaning is crucial for the recovery process. For example, during the first years after planting, a small tree will be able to recover from a leaning position rather quickly (Little and Mergen 1966, Cremer 1998). As a consequence, limited compression wood formation can be expected. If the tree is larger, the process will take longer, thus leading to more compression wood formation (Warensjö and Rune, 2004). The limited dimension of the variability in the age of sample trees used in this study made difficult to observe the difference of the reaction response due to the stem size. For future studies, it could be interesting to combine different age of sample trees and to observe the difference in the reaction response through time.

Vertical growth may only be achieved by constant corrections of tendencies to lean under the influence of wind, whose direction may change from day to day (Barnet et al., 2014) or other stimuli. The strong correlation between PHI angle and log(CW.A) reinforce the observations performed by Sierra de Grado et al. (2008) , in which compression wood appeared to have different levels of efficiency in the postural control from different provenances and confirms the hypothesis which relates the efficiency of the different populations with stem straightness.

Trees as we know them could not have evolved without reaction wood, a fact which needs to be borne in mind by those working to improve wood quality (Barnett et al., 2014). Reaction wood presence and properties, involved in the gravitropic movements, should be studied as part of general plant strategies more or less expressed according to genotypes and conditions of stress, competition or disturbance. Besides, a combined study of the measurement of CW and cellular characteristic in roots would provide information as to how mechanical stress influences wood formation.

7. CONCLUSION

It is evident that differences between stem wood and root wood anatomy are recognizable in *Pinus pinaster.* This fact originating anatomical variations within the same tree, such as compression wood area or eccentricity of the section, among others, which could indicates different adaptations of the tree to the environment. Besides, these anatomical variations could be associated with changes in mechanical and chemical properties of the wood which occur along the tree growth.

Straight provenances appear to show more efficiency in the control postural, since with similar percentages of compression wood, these populations obtained a higher straightness of the stem. This is a very important factor to take into account, because it is possible to obtain wood with higher quality and lower amount of compression wood. Again, this finding , emphasizes the importance of genetic variability in the efficiency of the stem straightening process.

The results obtained in this study allows us to lay the foundations for future studies which will increase information about the role that mechanical stress play during straightening process and the function of compression wood as a strategy of the plant to adapt to mechanical stresses.

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9. APPENDIX

9.1. PINUS PINASTER

9.1.1. Biology and ecology

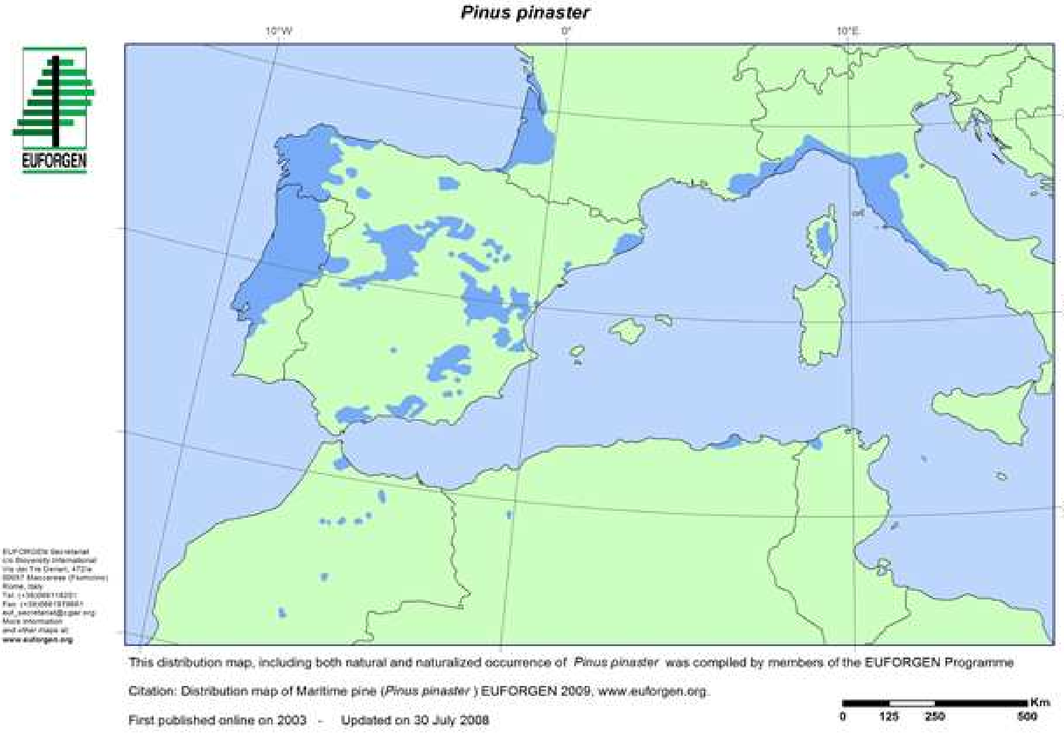
Maritime pine (*Pinus pinaster* Aiton) morphologically is similar to other species of the genera. The species display several adaptations to forest fires: early flowering (in some populations cones can be observed in 4-year-old seedlings), presence of serotinous cones, and a thick bark. Compared with other Mediterranean pines, Maritime pine has large cones (8-22 cm long) usually in groups of 2 or 3, and long needles (10-25 cm). Clear morphological differences exist among the different populations, resulting in the subdivision of the species into two subspecies (*atlantica* and *pinaster*), and into several geographical races (*atlantica, mesogeensis, corteensis, maghrebiana, renoui,* etc.), but a complete revision of the species does not exist. The species can be found in quite different environments: from sea level to 2100 m elevation in the High Atlas (Morocco); from areas with more than 1400 mm of annual rainfall and no dry season, to others with 350 mm and more than 4 dry months. The soil conditions are variable; mainly in acid soils, but also in basic soils and even in sandy and poor soils, where not many commercial species can grow.

Fig 1. Image of *Pinus pinaster* Aiton

9.1.2. Distribution

Maritime pine is a broadly distributed conifer in the western Mediterranean Basin, in Southern Europe and Africa, and the Atlantic coast in Portugal, Spain and France. The island distribution of the species is limited to Corsica, and to a very limited extent, northern Sardinia. There is a marginal stand in Pantelleria island, close to the Tunisian shore. Two main factors have affected the present natural distribution of the species, resulting in a high degree of fragmentation: the discontinuity and altitude of the mountain ranges causes isolation of even close populations, and the human impact. At present, the species is broadly distributed by forestation in different countries (within and outside the natural range). The differentiation of autochthonous and non-autochthonous stands is, in many cases, controversial. We can find regions with either a large or a limited human impact. This combination presents a unique opportunity to understand some aspects of forest management and its impact on the genetic resource conservation of broadly distributed conifers.

Its natural area, which are very dispersed by the Spanish geography, amount to around six hundred thousand hectares, and its reforestation, made it during 1940-82 period, exceed eight hundred thousand hectares (Fig 1) . Approximately, this specie occupies 1.200.000 as dominant species, according Second National Forest Inventory (Table 1).



This distribution map, including both natural and naturalized occurrence of *Pinus pinaster* was compiled by members of the EUFORGEN Programme

Citation: Distribution map of Maritime pine (*Pinus pinaster*) EUFORGEN 2009, www.euforgen.org.

First published online on 2003 - Updated on 30 July 2008

Fig 2. Distribution map, including natural and naturalized occurrence of *Pinus pinaster*. Source EUFORGEN 2009

Provincia	Superficie	Provincia	Superficie
Albacete	52056	Madrid	11216
Almería	10387	Málaga	14454
Ávila	54845	Murcia	6333
Badajoz	10223	Orense	78778
Burgos	35443	Asturias	47285
Cáceres	95100	Pontevedra	41913
Castellón	12774	Salamanca	29409
Ciudad Real	49259	Segovia	94738
La Coruña	127294	Soria	42644
Cuenca	47505	Teruel	29032
Granada	36930	Toledo	22483
Guadalajara	50816	Valencia	32551
Jáen	30513	Valladolid	17987
León	12381	Zamora	28329
Lugo	40380	Zaragoza	10861
TOTAL			**1173903**

Table 1. Area occupies by *Pinus pinaster* Ait. Source: Second National Forest Inventory.

9.1.3. Importance and use

Maritime pine is one of the most important forest species in France, Portugal and Spain. The main uses of the species are related to wood and resin production, recreation and soil protection. It can be considered a fastgrowing species (especially in the Atlantic region where rotation ages of 40-50 years are common). The main uses in these regions are pulp and paper production, construction, chipboards, floor boards and palettes. In the other regions, the rotation ages vary from 80 to 120 years, and trees produce either highquality (Corsica, some mountains areas in Central Spain), or lowquality timber, especially owing to the existence of very crooked trees (Castillian plains and several southern populations in southern Spain). One of the most traditional uses of the species is resin tapping. Maritime pines produce resin of high quality. The importance of this product has decreased over time, but recently the production has increased slightly in some regions (Castillian plains in Spain, Portugal). The development of new tools and extraction methods, combined with breeding programmes, could be of importance for this product. The ability of the species to grow in very poor soils, and under prolonged drought, is one of the reasons for its use in afforestation programmes for wood production or soil protection.

9.1.4. Genetic knowledge

Coniferous forest trees are windpollinated and typically have high proportions of outcrossed progeny (>0.80). In Mediterranean forests, pollen gene flow could be great owing to generally lowdensity stands and the lowfertility soils where Maritime pine grows. Maritime pine has an important genetic load. Because of its high commercial value, there have been many studies dealing with the genetics of Maritime pine. This species is one of the model species used worldwide for the discovery of genes related to wood quality and water stress resistance. Large genetic differences among populations have been reported at regional and wide-range spatial scales using various genetic markers (terpenes, isozymes, DNA markers) and common garden experiments. Especially important is the large genetic variation found between provenances in traits of importance for the adaptation of the species (drought and frost tolerance, insect resistance) and others of large importance for the use of the species (growth, stem form, polycyclism, branching habit). In general, clear geographic areas can be defined in terms of genetic diversity using different types of genetic markers, and within these areas, different adaptations are found. A clear geographic structuration of the diversity is found with the different genetic markers and adaptive traits.

9.1.5. Threats to genetic diversity

The main threats to the genetic diversity in maritime pine are similar to those of other Mediterranean species.

Forest fires. Mainly isolated stands or small populations have been affected. Fires have traditionally played an important role in modeling the genetic architecture of the species.

Land uses and plant cover changes. Transformation of forest land to agricultural or pasture areas has been a general trend in the Mediterranean region. Forest stands have been ploughed to introduce more productive species, or water-demanding crops have been introduced close to some pine forests. However, at present, the main threat comes from conversion of forested to residential areas.

Introduction of exotic species or genomes. Hybridization of maritime pine with other species is quite limited. The main threat is the introduction of material from exotic provenances close to natural populations. Because of advanced breeding programmes, selected material is widely planted in some countries (e.g. France). Pollen flow in this species is quite extensive and could impact local resources, leading to loss of local adaptivity, for example in sand dune areas where *P. pinaster* has a very important ecological role against habitat destruction by wind and waves.

Overexploitation. There is little information on the effect of silvicultural practices on the genetic resources of the forest species. In conifers, the effect seems to be of scant importance under normal forestry practices. The adoption of criteria and indicators of sustainable forest management in most European countries would diminish the importance of this factor in the near future.

Global climatic change. Most of the models predict a reduction and changes in the pattern of rainfall in the Mediterranean area, where *P. pinaster* is mainly found. We can expect a shift northward in its range, leading to changes in pollen flow, seed dispersal, recolonization dynamics and new possibilities for gene exchange with resources from breeding programmes.

Pests and diseases. A good example is the reduction in the natural area of Maritime pine in the Southern French Maures and Esterel mountain regions, caused by *Matsococcus feytaudy*. This insect caused the destruction of approx. 200 000 ha of *P. pinaster* forests in the 1960s. Resistant material, both local and from Spain and Morocco, is currently tested to understand the genetic determinism of the resistance and to reintroduce the resource. The presence of a nematode (*Bursaphelenchus xylophilus*) in Portugal is a risk not completely evaluated until now

9.1.6. Guidelines for genetic conservation and use

Seed source selection. Taking into consideration the important differences in growth, stem form and adaptation of the different populations, seed source selection has to be carefully analyzed based on the results of provenance trials. Selection is dependent on the main objective of the plantation (protection, wood production, etc.), and in most countries descriptions of the base material are available to assist in selecting the most suitable for afforestation.

In situ conservation areas. These are the best means of preserving the adaptive potential of the species in the long term. Given the breeding system of the species, special care has to be taken to establish conservation stands of sufficient size to reduce the effect of inbreeding and external contamination. As in other conifers, areas greater than 20 ha are necessary to ensure enough regeneration to maintain the genetic variability of the species. A network of conservation areas covering the most contrasting areas in the distribution range of the species would be a method to preserve the natural stands of the species.

Ex situ conservation. This form of conservation is based on different activities, such as clonal banks, seed banks and plantations using seeds from the threatened populations. Clonal banks are mainly used in populations with large economic (or ecological) value. Seed banks are very effective methods of preserving the adaptiveness of the target populations, because of the heavy seed production in

Maritime pine, and the possibility of conserving the seed (or pollen) for a prolonged period of time. At present there are many activities in different countries that could be considered as a starting point for the conservation of the species.

9.2. EXPERIMENTAL PROCEDURES

9.2.1. Plant material

Figure 3 shows the distribution of the 100 plants used in our study. As explained earlier, we used 10 provenances distributed into 10 randomized complete blocks. On the plot a iron specially structures were installed for the experiment, these served to tip the pots with a 45º from the vertical, always pointing toward the south. This process was performed between June 11 and June 17 2009. We began to extract the plants block by block, at the end of October 2009 to be processed immediately. The last block was extracted in February 2010 so that all samples were taken during the dormancy period.

Calendar	
Sowing	July 16, 2008
Tilting	June, 2009
Extraction	October (2009)-February (2010)

Table 2. Dates of the process of sowing, tilting and extraction.

Fig 3. Distribution of plants used in our study

9.2.2. Roots system

In the following images we can observe the roots belonging to each provenances and block. To facilitate analysis we separated the aerial part of the plants from the root, and the roots were cleaned to remove the substrate. Te branches were separated from the stem. Root structure measurements were performed on the taproot and the coarse second-order roots were stored for future analysis.

- Roots of straight provenances

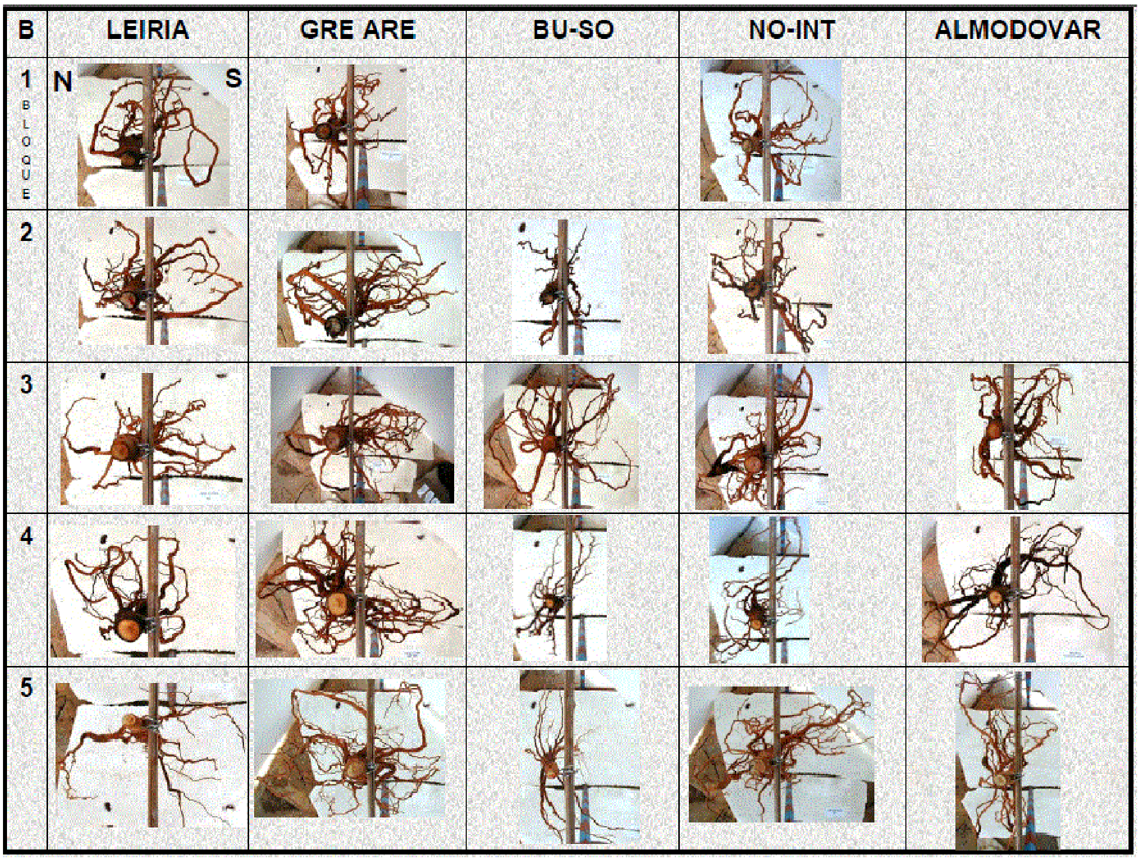


Fig 4. Root system in straight provenances B1-B5

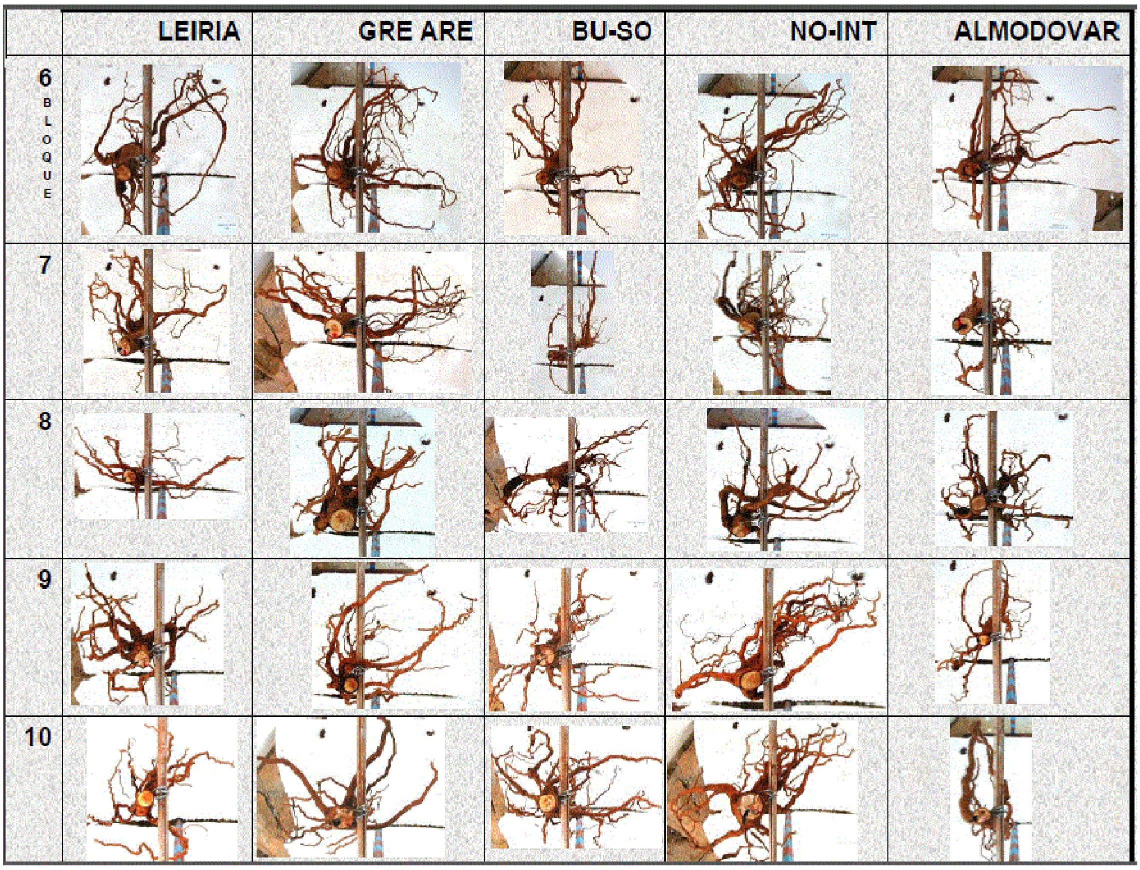


Fig 5. Root system in straight provenances B6-B10

- Roots of twisted provenances

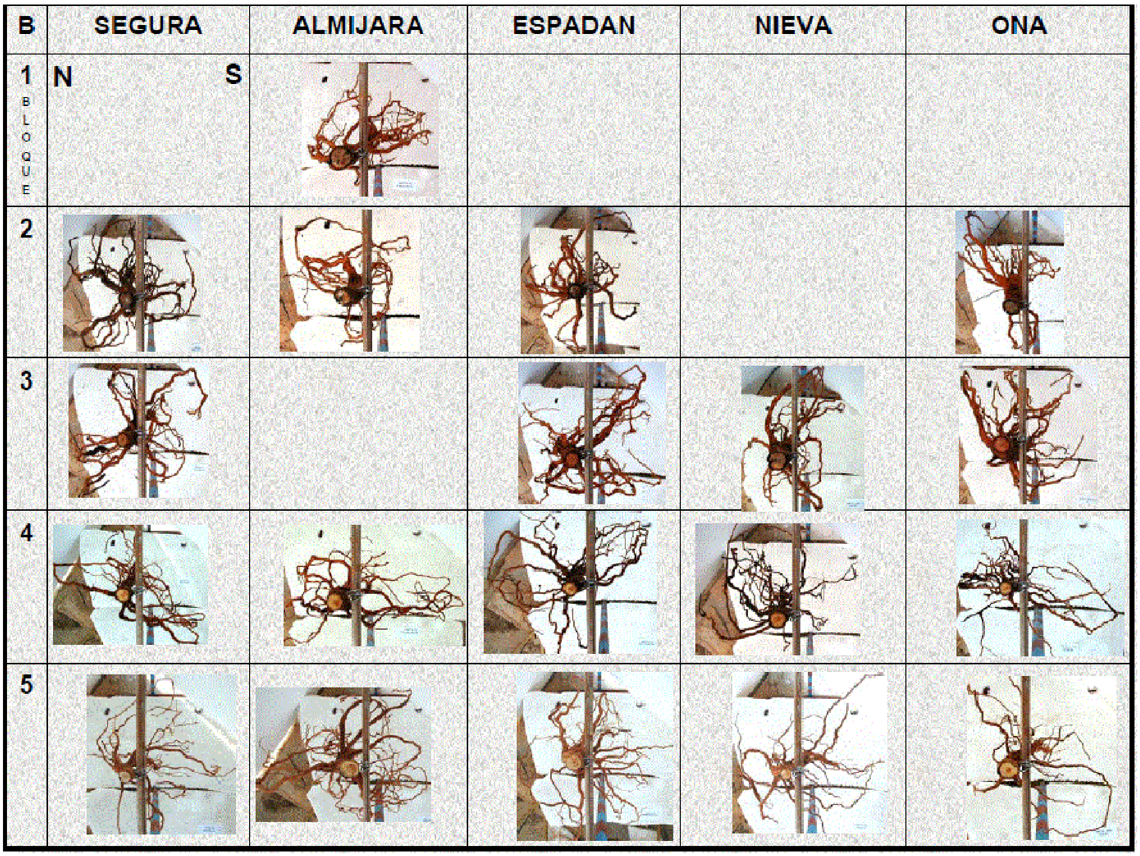


Fig 6. Root system in twisted provenances B1-B5

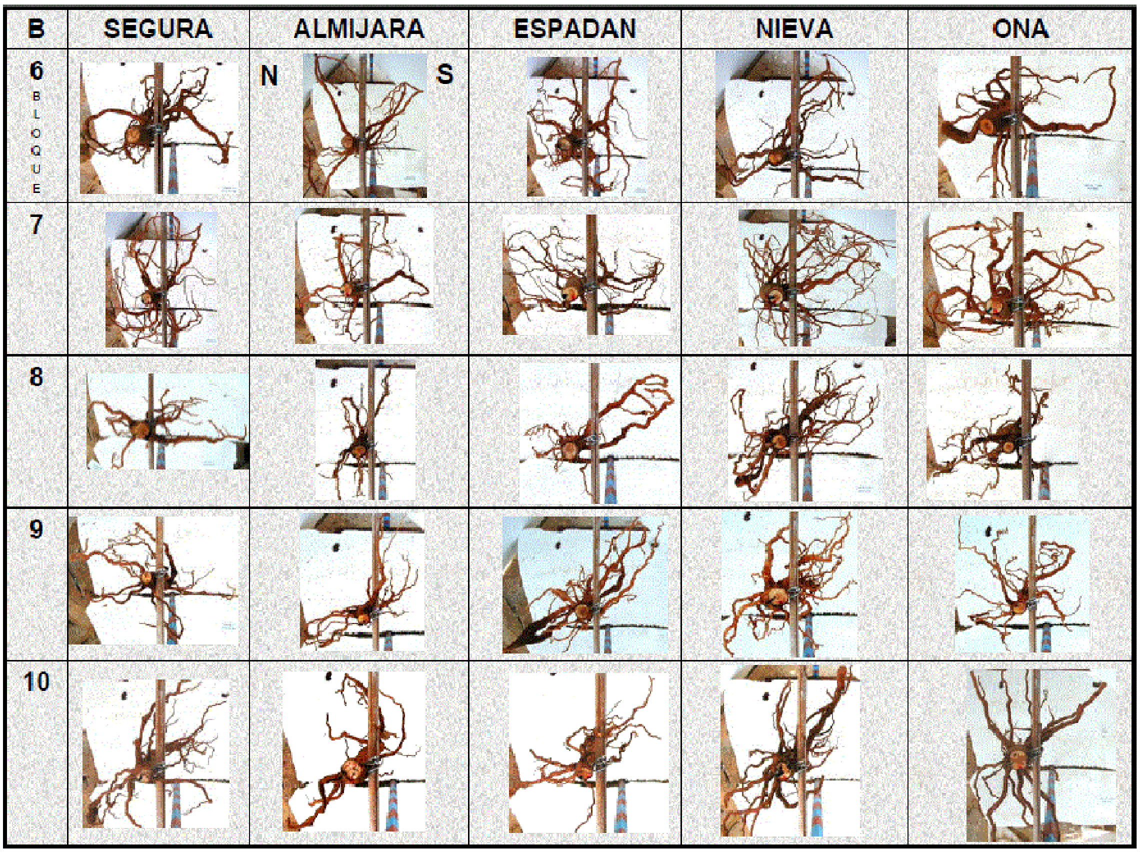


Fig 7. Root system in twisted provenances B6-B10

9.2.3. Sample Preparation

In this section images about the experimental procedures are shown. Besides, we explain which measures performed in each type of sample.

- Cutting samples

A 2cm diameter wooden cylinder was obtained from each of these zones. To obtain this wooden cylinder we used a band saw. Figure 8 shows shows an image of these samples

Besides, a wooden cylinder was obtained in the middle of the main root. This sample will be used to analyzed the grain angle and microfibril angle in cell (MFA). However, these data will be used in future studies.

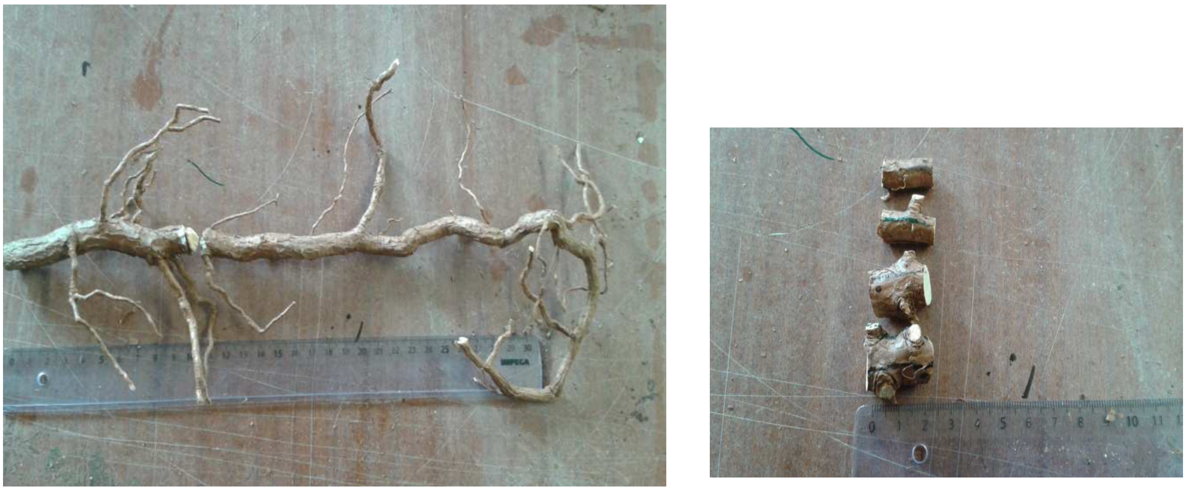


Fig 8. Root system before y after cutting

- <u>Impregnation of PEG by the root samples</u>

Each sample was dipped inside distilled water containers for one week. Secondly, the distilled water was replaced by a solution of polietilenglicol (PEG) 30%, for a period of 24 to 48 hours. Thirdly, this PEG 30% solution was substituted by a similar solution but with a higher PEG concentration, 50%, for the same period of time, 24 to 48 hours (Fig 9). In these concentrations, PEG is found in liquid form at room temperature. Given its liquid state, it can flow through the cavities left by the cellulose in the cell wall and ensure these cavities are adequately thickened. This process is called “prepreg”, once PEG has been cooled to room temperature, it solidifies inside the timber acting as the support structure of this. Prepreg is necessary because wood is mainly composed by water which otherwise would evaporate leaving gaps within the structure of the cell wall and causing significant cracks in the wood. During this process, the containers with samples were introduced in a vacuum desiccator which, as its name indicates, was used to suction the air and create vacuum inside them. This allows the root sample to absorb the PEG solution.

Finally, the samples were dipped inside pure PEG and were deposited inside a stove for a period of 24 to 48 hours as well. Pure PEG must be heated to reach liquid estate, therefore it is introduced in the stove to be heated so it can reach liquid form while vacuum is been created. After this impregnation process, samples were dried, bagged and labeled (block and source) to, subsequently, study their anatomical characteristics.

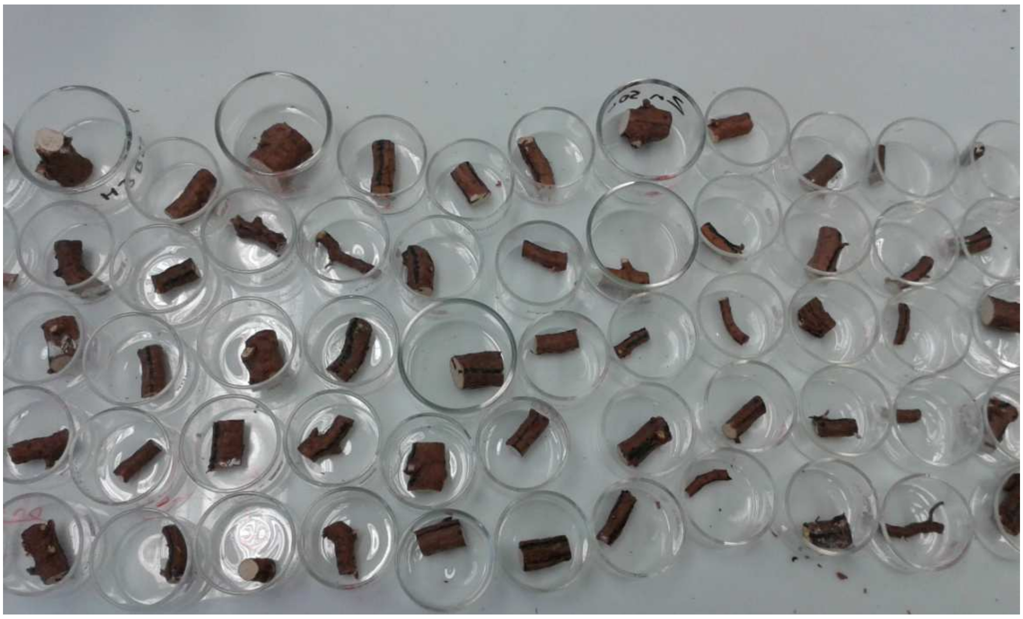


Fig. 9. Samples dipped inside containers for its impregnation of PEG.

- Cutting samples with sliding microtome

Using a sliding microtome, we obtained a 15 µm cross section from each sample. In total, 200 samples of roots (100 of each depth) were cut with the microtome to obtain a 15 µm cross section. A blade inclination of 20 degrees was used for all cuts.

Fig. 10. Image of the sliding microtome model used in our experiment and image of the cross section obtained for each sample.

- Tinted wood samples

Once cut, sections of the samples were collected with a brush and were smeared on a glass slide. Safranine and Blue Astra were used to color the sections. Blue Astra has some specificity for cellulose, and stain non-lignified cell walls blue, as for Safranine, it is the classic wood coloring. After staged dehydration with alcohol 90% and pure alcohol, the section was mounted on a glass slide using Entellan.

Fig. 11. Tinted wood samples with Safranine and Blue Astra

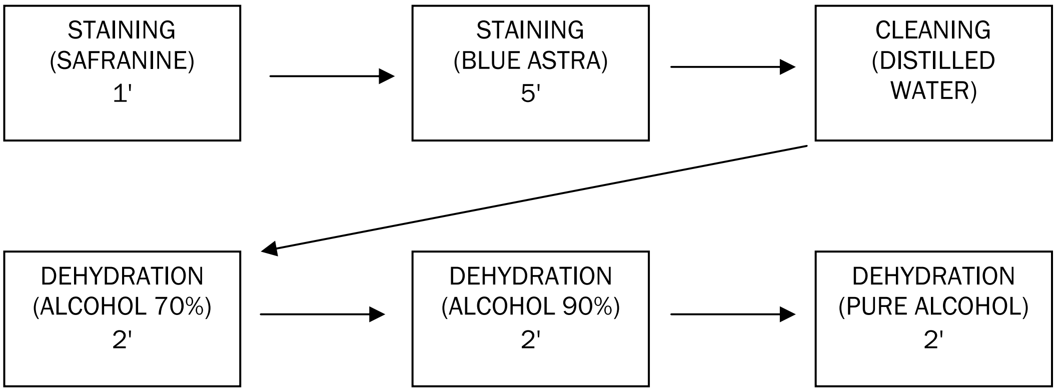


Fig. 12. Tinting process.

9.2.4 Photographed and measurement of roots sections

- Measures performed by LEICA Wild M420 microscope

Samples were photographed using a modified LEICA Wild M420 microscope with an attached camera used to obtain a picture of the whole section as well as of the compression wood area, but compression wood area was only seen in the trunk section.

Fig. 13. LEICA Wild M420 microscope

We used this images to measure the cross-sectional area and the compression wood area (in trunk) as well as the different radius used for analysis, major (R) and minor radius (r). With major and minor radius data, we calculated the eccentricity in each sample using the following equation (1).

(EQUATION 1)

$$Ecct\ \% = \frac{R - D/2}{D} \times 100$$

Where:

- R: Major radius
- D: Section diameter

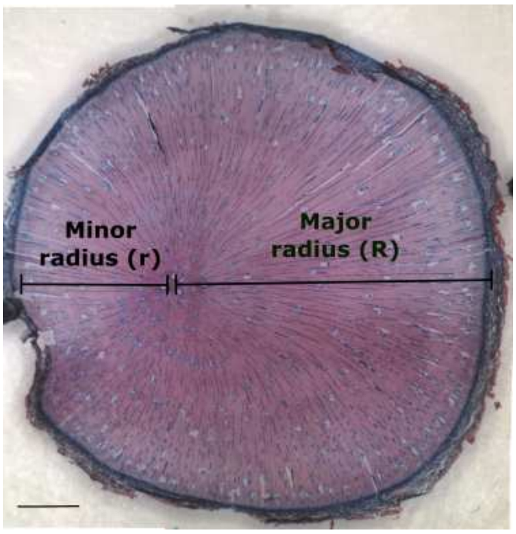


Fig. 14. Measurement of cross-sectional area, major and minor radius in root. Sample ALMI B1 (Scale bar 2mm).

- Measures performed by Axio Imager microscope

The camera was attached to an Axio Imager microscope which allows to take pictures with higher contrast and resolution. Using this microscope, photographs were taken in different zones, obtaining a longitudinal area and a transversal area of the sample. In these areas, a porosity measurement was performed (Fig 12).

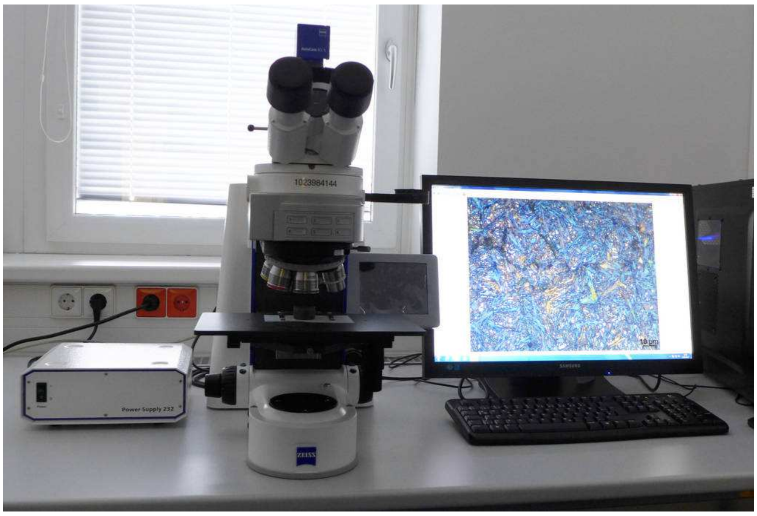


Fig 15. Axio Imager microscope with attached camera.

We used image analysis program ImageJ (Abramoff et al. 2004) to analyze the samples. To measure porosity we created a command which we could used with this program. This command contained the following instructions.

- Make an adjustment and image contrast; In this way we got an image with two colors, black and red. Red color corresponds to the area belonging to the cell lumen and black color corresponds to the area belonging to the cell wall.

- Select an area and divides the color red area belonging to the total area. So, we could calculate the percentage belonging to the lumen of the analyzed area (Fig 11).

$$\mathbf{Pi = lumen\ area\ (\mu m2)\ /Total\ area\ (\mu m2)} \qquad \text{(EQUATION 2)}$$

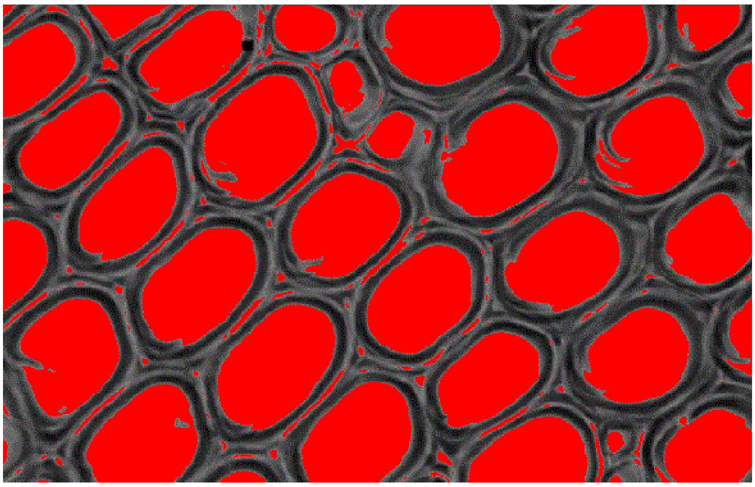


Fig 16. Adjustment and image contrast. Red color corresponds to lumen area and black color corresponds to cell wall area.

As we said, four zones were selected to calculate the porosities (Fig 12).

P1 : Measured in the zone where compression wood is formed (in trunk) and in the zone with major radius in roots.

P2: Measured in the zone where opposite wood is formed (trunk) and in the zone with minor radius in roots.

P3 and P4: Measured where normal wood is formed

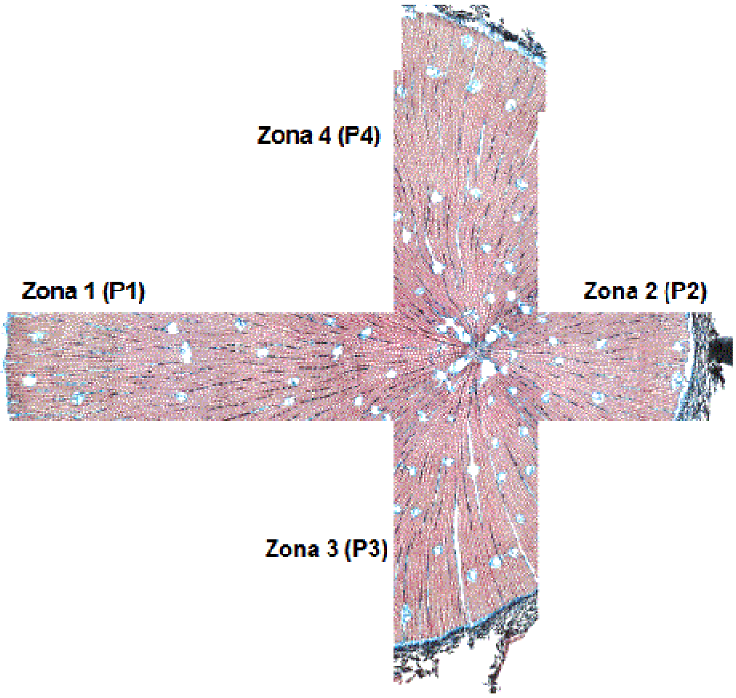


Fig 17. Measurement of porosities in different zones in root. Sample GRE-ARE B5

9.2.5. Photographed and measurement of trunk section

- Measures performed by LEICA Wild M420 microscope

In this case, in addition to measured the cross total section, major and minor radius, we could measured the compression wood area of the samples (Fig 12).

Sections belonging to the trunk were prepared for previous studies. For these reason, this samples show differences with the samples prepared by us, for examples, in this case, the people who prepared the samples did not use Safranine and Blue Astra to color the sections.

To calculate the eccentricity we used the same equation that in roots.

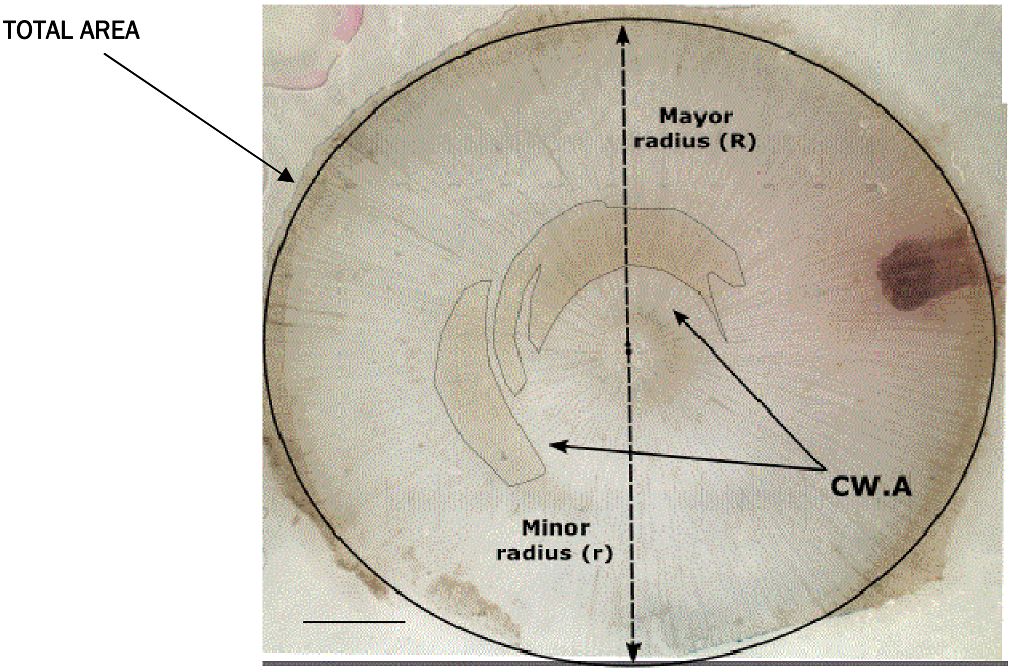


Fig. 18. Measurement of cross-sectional area, compression wood area, major and minor radius in trunk. Sample BU-SO B8 (Scale bar 2mm).

- Measures performed by Axio Imager microscope

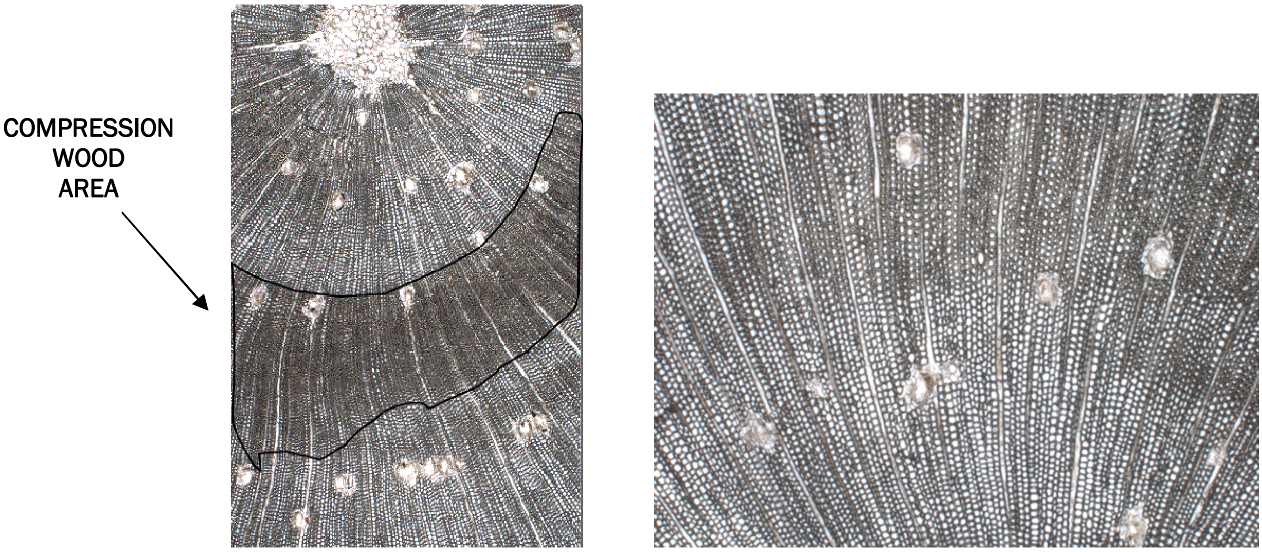


Fig. 19. Measurement of porosities in compression wood and opposite wood zones in trunk. Sample GRE-ARE B5.

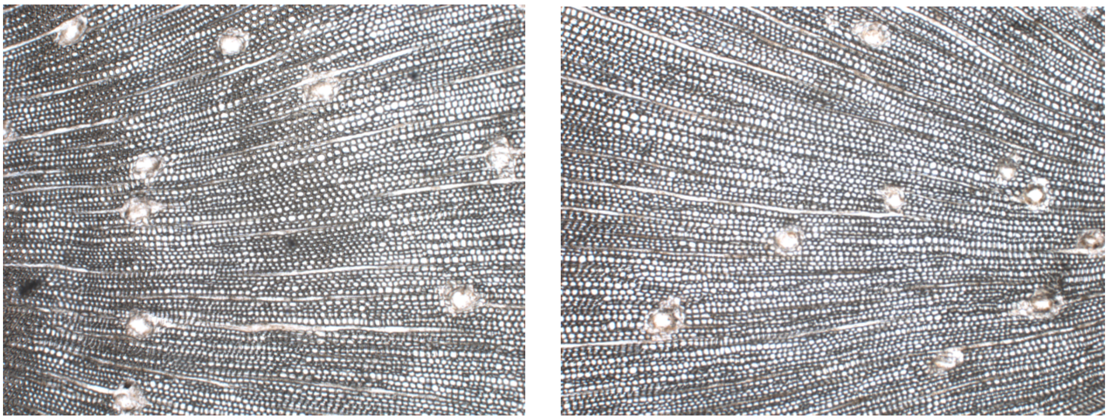


Fig 20. Measurement of porosities normal wood in trunk. Sample GRE-ARE B5

9.2.6. Data analysis

- Fournier's Model

With Fournier's model, we computed the integral effect of RW on stem leaning from measurements of the radial extension of RW in serial anatomical cross sections along the stem. The increment in longitudinal curvature at one location along the stem due to the occurrence of RW during growth, *dR*, of its cross section at time t can be modeled from mechanical principles. Assuming a sinusoidal distribution of maturation strains along the inner circumference of the cambium and neglecting eccentric growth and the differences in the modulus of elasticity between RW and NW, Fournier et al. (1994) found that the local curvature caused by RW formation and asymmetric maturation strains in a new layer of cells deposited by the cambium during secondary growth is (1) proportional to the thickness of the layer, *dR* (and thus to the growth rate in girth *dR/dt*), (2) proportional to the difference in maturation strains between opposite sides of the stem (2αj) and (3) inversely proportional to the square of the radius of the stem R(t) that resists the bending as:

$$\partial C = -4\,\alpha_j \frac{dR}{R^2} \qquad \text{(EQUATION 3)}$$

where ∂C is the change in local curvature of the stem (Moulia et al. 1994), α is half the difference in maturation strain between the upper side of the trunk and that of its OW, R is the radius of the stem at time t and at position j along the stem and the minus sign denotes the downward sector of RW inducing upward curving. If the stem is straight and not producing a sector of RW, then αj = 0

PHI angle was the estimated angle from Fournier’s Model (Fournier et al.,1994) , It was calculated considering the amount and position of compression wood and represents the angle recovered by a tilted stem due to the developed compression wood. This model has been applied to plants used in this experiment according to the methodology explained in Sierra de Grado et al, (2008).

9.3. STATISTICS

9.3.1. Exploration data

In this section the normal distribution is shown for each variable.

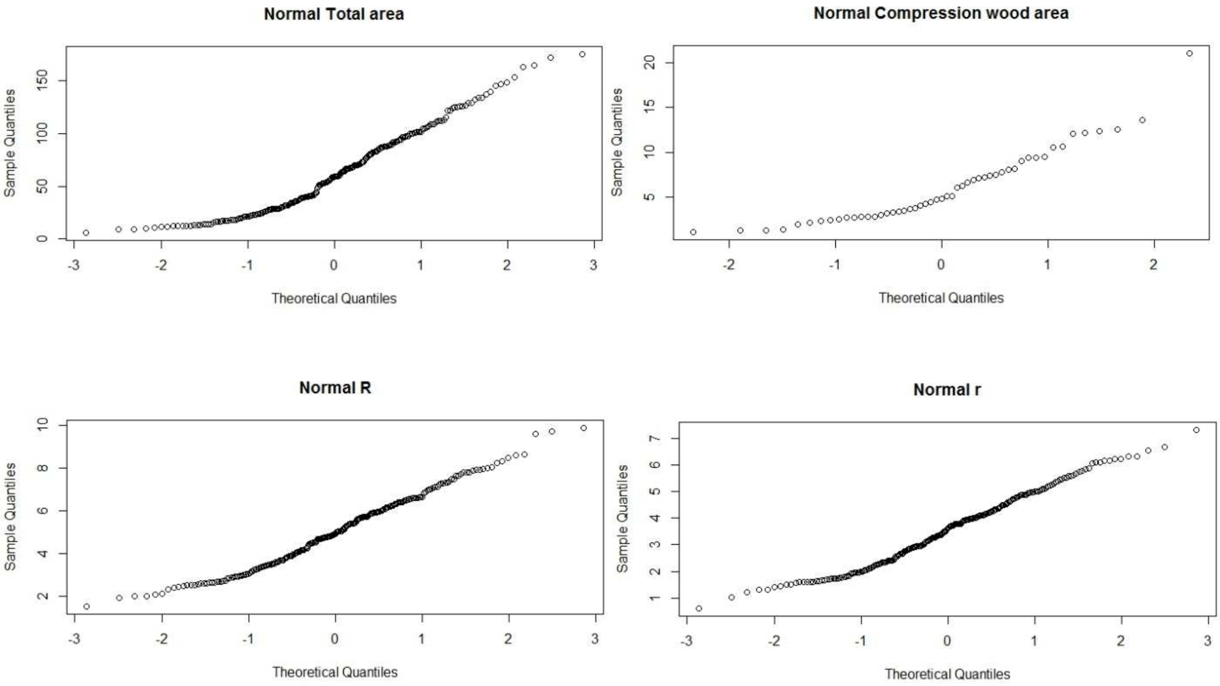


Fig 21. Normal distribution for cross section area, compression wood area, major radius (R) and minor radius (r)

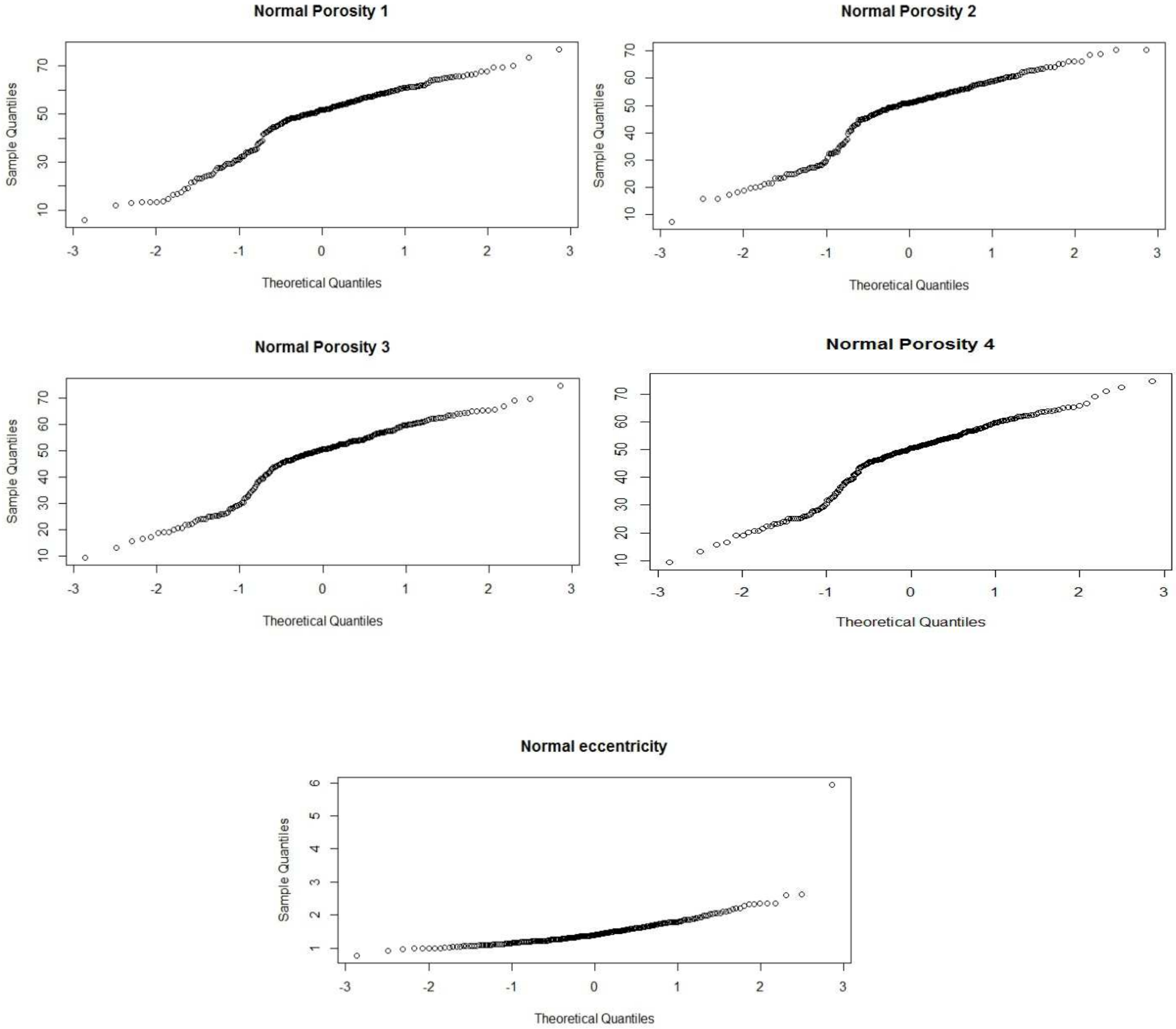


Fig 22. Normal distribution for porosities measured in zones; 1, 2, 3 and 4 and eccentricity.

- Summary statistical by provenances

Table 3. Statistical summary of all variables by provenances**.**

Variable	Provenance	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se	cv
Total Area (μm^2)	01ONA	27	63.67	41.22	62.86	60.85	43.6	9.49	153.8	144.35	0.6	-0.67	7.93	64.74
	02NIEV	23	53.64	33.81	40.12	52.58	34.84	5.53	112	106.34	0.26	-1.51	7.05	63.03
	03ESPA	24	63.44	40.38	57.97	61.39	44.32	11.33	145.4	134.06	0.38	-1.17	8.24	63.65
	04ALMI	21	72.05	44.01	67.06	68.91	40	12.3	172.3	159.98	0.54	-0.65	9.6	61.08
	05SEGU	24	62.47	36.16	61.39	61.93	47.21	8.64	126.5	117.86	0.19	-1.46	7.38	57.88
	06ALMO	27	52.59	30.94	40.91	50.41	33.12	10.94	128.9	117.97	0.61	-0.65	5.95	58.83
	07NOINT	21	75.78	45.77	77.71	71.7	34.22	12.7	175.8	163.06	0.4	-0.57	9.99	60.40
	08BUSO	27	50.62	30.51	43.62	48.69	23.51	8.68	125.2	116.47	0.63	-0.44	5.87	60.27
	09GRE	21	69.55	44.31	73.14	67.62	63.29	12.22	148.5	136.27	0.18	-1.43	9.67	63.71
	10LEI	23	70.21	41.99	59.36	67.56	53.85	12.51	164.9	152.37	0.42	-0.85	8.76	59.81
CWA (%)	01ONA	6	4.4	3.19	3.64	4.4	2.3	1.46	10.27	8.81	0.84	-0.92	1.3	72.50
	02NIEV	5	6.49	3.03	6.04	6.49	3.16	3.58	10.83	7.25	0.32	-1.87	1.36	46.69
	03ESPA	6	5.31	2.5	4.7	5.31	2.51	2.69	9.4	6.71	0.51	-1.5	1.02	47.08
	04ALMI	4	7.74	6.93	5.4	7.74	2.62	2.27	17.88	15.61	0.64	-1.75	3.46	89.53
	05SEGU	6	4.29	2.97	3.21	4.29	0.5	2.7	10.33	7.63	1.33	-0.13	1.21	69.23
	06ALMO	7	3.89	3.28	3.13	3.89	1.28	1.41	11.02	9.61	1.36	0.28	1.24	84.32
	07NOINT	4	7.53	3.61	7.21	7.53	3.11	3.48	12.22	8.74	0.19	-1.89	1.8	47.94
	08BUSO	7	8.13	3.06	7.54	8.13	2.95	3.55	12.2	8.65	-0.08	-1.61	1.16	37.64
	09GRE	3	7.78	4.65	7.33	7.78	5.86	3.38	12.64	9.36	0.1	-2.33	2.68	59.77
	10LEI	6	11.11	5.24	10.89	11.11	4.54	4.19	18.96	14.77	0.15	-1.61	2.14	47.16
R (μm)	01ONA	27	4.98	1.79	5.03	4.98	2.33	2.02	7.96	5.94	0.06	-1.26	0.35	35.94
	02NIEV	23	4.72	1.64	4.52	4.7	2.18	1.52	7.78	6.26	0.07	-0.97	0.34	34.75
	03ESPA	24	5.1	1.87	4.95	5.06	2.27	2.13	8.64	6.51	0.04	-1.23	0.38	36.67
	04ALMI	21	5.13	1.76	4.89	5.01	1.91	2.51	9.71	7.2	0.6	0.15	0.38	34.31
	05SEGU	24	5.03	1.65	5.26	5.02	2.18	1.94	8.03	6.09	0.02	-1.13	0.34	32.80
	06ALMO	27	4.61	1.23	4.67	4.61	1.68	2.31	7.11	4.8	0.03	-0.86	0.24	26.68
	07NOINT	21	5.8	2.07	6.35	5.76	2.28	2.55	9.88	7.33	-0.01	-1.05	0.45	35.69
	08BUSO	27	4.38	1.34	4.59	4.38	1.56	2.01	6.58	4.57	0.02	-1.15	0.26	30.59
	09GRE	21	5.3	1.87	5.38	5.27	2.79	2.49	8.31	5.82	0.01	-1.29	0.41	35.28
	10LEI	23	5.52	1.85	5.58	5.47	2.18	2.61	9.59	6.98	0.22	-0.87	0.39	33.51
r (μm)	01ONA	27	3.64	1.31	3.69	3.57	1.02	1.57	6.67	5.1	0.46	-0.37	0.25	35.99
	02NIEV	23	3.24	1.33	3.19	3.3	1.76	1.01	5.46	4.45	-0.03	-1.42	0.28	41.05
	03ESPA	24	3.63	1.46	3.5	3.53	1.55	1.49	7.33	5.84	0.63	-0.22	0.3	40.22
	04ALMI	21	3.87	1.59	4.24	3.93	1.82	0.6	6.32	5.72	-0.24	-92	0.35	41.09
	05SEGU	24	3.56	1.29	3.58	3.57	1.71	1.31	6.06	4.75	0.01	-1.08	0.26	36.24

Table 3 (cont). Statistical summary of all variables by provenances**.**

Variable	Provenance	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se	cv
	06ALMO	27	3.44	1.34	2.98	3.39	1.54	1.44	6.21	4.77	0.41	-1.03	0.26	38.95
	07NOINT	21	3.63	1.32	3.71	3.6	1.59	1.51	6.56	5.05	0.15	-0.8	0.29	36.36
	08BUSO	27	3.34	1.23	3.13	3.3	1.38	1.31	5.85	4.54	0.28	-0.85	0.24	36.83
	09GRE	21	3.65	1.61	3.92	3.62	2.54	1.22	6.22	5	0.1	-1.47	0.35	44.11
	10LEI	23	3.72	1.37	3.77	3.72	1.51	1.6	5.88	4.28	-0.12	-1.3	0.29	36.83
Ecct (%)	01ONA	27	1.38	0.25	1.3	1.36	0.27	1.08	1.99	0.91	0.89	-0.11	0.05	18.12
	02NIEV	23	1.54	0.34	1.49	1.49	0.24	1.08	2.36	1.28	1.04	0.39	0.07	22.08
	03ESPA	24	1.44	0.3	1.39	1.43	0.3	0.92	2.28	1.36	0.61	0.46	0.06	20.83
	04ALMI	21	1.35	0.35	1.27	1.3	0.36	0.99	2.21	1.22	0.94	-0.19	0.08	25.93
	05SEGU	24	1.46	0.32	1.42	1.45	0.42	1.06	2.1	1.04	0.38	-1.27	0.07	21.92
	06ALMO	27	1.43	0.35	1.37	1.39	0.25	1	2.62	1.62	1.43	2.61	0.07	24.48
	07NOINT	21	1.63	0.33	1.61	1.61	0.37	1.18	2.35	1.17	0.53	-0.84	0.07	20.25
	08BUSO	27	1.37	0.3	1.27	1.33	0.21	1	2.2	1.22	1.2	1.03	0.06	21.90
	09GRE	21	1.6	0.44	1.57	1.56	0.5	1	2.6	1.6	0.56	-0.8	0.1	27.50
	10LEI	23	1.54	0.3	1.56	1.52	0.34	1.12	2.33	1.21	0.6	-0.11	0.06	19.48
P1 (%)	01ONA	27	43.8	17.84	47.89	44.39	14.1	11.9	73.37	61.47	-0.64	-0.91	3.43	40.73
	02NIEV	22	45.77	18.51	52.92	48.17	7.73	5.79	60.64	54.85	-1.15	-0.48	3.95	40.44
	03ESPA	25	45.44	20.45	51.72	47.13	7.89	2.29	69.39	67.1	-1.02	-0.38	4.09	45.00
	04ALMI	19	43.69	19.09	50.63	44.97	10.45	5.36	60.35	54.99	-1.15	-0.38	4.38	43.69
	05SEGU	25	44.67	17.93	51.46	46.2	11.25	7.8	64.61	56.81	-0.93	-73	3.59	40.14
	06ALMO	25	40.75	18.63	46.28	41.65	11.42	5.94	69.7	63.76	-0.62	-1.03	3.73	45.72
	07NOINT	24	50.03	14.04	52.62	51.97	12.62	13.86	68.24	54.38	-1.19	0.97	2.87	28.06
	08BUSO	28	39.96	21.3	49.09	40.84	13.26	3.03	66.67	63.64	-0.59	-1.26	4.03	53.30
	09GRE	22	49.53	16.8	55.62	52.09	10.7	7.75	68.57	60.82	-1.28	0.78	3.58	33.92
	10LEI	24	45.37	22.03	51.55	46.88	13.19	6.23	68.08	61.85	-0.84	-1.01	4.5	48.56
P2 (%)	01ONA	27	46.75	12.73	50.07	47.3	9.92	19.97	68.91	48.94	-0.58	-0.69	2.45	27.23
	02NIEV	21	49.37	11.97	53.77	50.61	6.85	26.2	61.76	35.56	-0.91	-0.82	2.61	24.25
	03ESPA	24	49.75	13.97	52.67	50.56	10.94	23.28	69.96	46.68	-0.67	-0.86	2.85	28.08
	04ALMI	19	46.47	11.22	49.56	46.98	7.9	23.14	61.05	37.91	-0.8	-0.34	2.57	24.14
	05SEGU	24	50.05	10.25	51.24	50.61	12.27	30.65	64.12	33.47	-0.47	-1.16	2.09	20.48
	06ALMO	25	46.98	14.49	50.03	47	9.89	18.65	77.03	58.38	-0.15	-0.65	2.9	30.84
	07NOINT	24	52.32	11.28	50.84	52.89	12.03	29.34	69.3	39.96	-0.28	-0.98	2.3	21.56
	08BUSO	27	45.63	12.77	50.24	46.1	10.17	21.84	64.16	42.32	-0.55	-1.18	2.46	27.99
	09GRE	21	52.38	11.41	55.26	53.16	8.9	30.91	67.59	36.68	-0.65	-0.9	2.49	21.78
	10LEI	24	50.41	14.89	54.89	51.89	8.3	14.59	69.56	54.97	-0.94	-0.24	3.04	29.54
P3 (%)	01ONA	27	46.18	13.69	50.28	46.87	10.51	17.24	69.9	52.66	-0.64	-0.75	2.64	29.64
	02NIEV	22	49.34	13.43	54.38	50.9	8.12	18.58	65.14	46.56	-1.05	-0.19	2.86	27.22
	03ESPA	26	46.3	14.92	50.58	47.36	10.11	17.27	65.22	47.95	-0.83	-0.82	2.93	32.22

Table 3. Statistical summary of all variables by provenances**.**

Variable	Provenance	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se	cv
	04ALMI	21	46.67	12.26	49.52	47.51	6.57	21.41	63.42	42.01	-0.67	-0.72	2.67	26.27
	05SEGU	25	47.73	10.8	49.95	48.1	7.74	26.34	68.41	42.07	-0.46	-0.59	2.16	22.63
	06ALMO	27	46.61	12.8	50.71	46.88	2.7	20.5	70.48	49.98	-0.63	-0.46	2.46	27.46
	07NOINT	22	50.85	10.36	52.11	51.48	9.68	27.31	66.21	38.9	-0.49	-0.42	2.21	20.37
	08BUSO	27	43.47	15.97	50.71	44.51	11.98	7.34	64	56.66	-0.68	-0.85	3.07	36.74
	09GRE	22	48.41	11.13	51.08	49.74	10.23	15.79	62.86	47.07	-1.11	1.04	2.37	22.99
	10LEI	24	49.87	15.19	54.27	51	8.02	19.65	70.45	50.8	-0.82	-0.81	3.1	30.46
P4 (%)	01ONA	26	46.48	13.2	50.25	46.84	9.19	21.62	72.67	51.05	-0.41	-0.78	2.59	28.40
	02NIEV	22	50.09	11.23	53.92	50.97	6.58	25.24	71.2	45.96	-0.7	-0.12	2.39	22.42
	03ESPA	25	46.75	12.85	51.11	47.55	9.77	23.14	62.45	39.31	-0.73	-0.93	2.57	27.49
	04ALMI	21	44.64	12.54	47.31	45.5	12.32	19.16	63.62	44.46	-0.5	-0.62	2.74	28.09
	05SEGU	24	46.28	12.56	47.67	46.77	10.44	22.27	66.88	44.61	-0.4	-0.81	2.56	27.14
	06ALMO	26	46.11	13.09	49.49	46.94	6.52	15.66	63.64	47.98	-0.78	-0.49	2.57	28.39
	07NOINT	23	51.76	9.75	50.7	51.92	10.13	32.29	69.15	36.86	-0.07	-0.99	2.03	18.84
	08BUSO	27	43.76	15.41	46.55	44.56	15.08	9.28	65.83	56.55	-0.57	-0.8	2.97	35.21
	09GRE	21	51.45	9	52.84	52.09	5.75	28.26	65.25	36.99	-0.72	0.09	1.96	17.49
	10LEI	24	49.02	16.97	53.75	50.17	11.68	13.08	74.91	61.83	-0.78	-0.74	3.46	34.62

- Summary statistical By part of the tree

Table 4. Statistical summary of all variables by part of the tree**.**

Variables	Part	Vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	Kurtosis	se	CV
Total.A (μm^2)	Trunk	6.00	58.00	97.50	34.04	98.62	96.77	33.65	29.82	187.46	157.64	0.28	0.06	4.47	34.91
	Root A	6.00	94.00	78.11	36.20	73.14	74.89	31.84	20.69	175.76	155.07	0.73	0.18	3.73	46.34
	Root B	6	88	28.65	16.59	24.03	26.66	14.71	5.63	73.14	67.51	1.01	0.14	1.77	57.91
CW.Area (μm^2)	Trunk	7.00	54.00	6.13	4.03	5.00	5.73	3.45	1.11	21.05	19.94	1.17	1.60	0.55	65.74
R (μm)	Trunk	8.00	58.00	5.92	1.17	5.98	5.91	1.17	3.07	8.57	5.50	-0.02	-0.19	0.15	19.76
	Root A	8.00	94.00	5.96	1.60	5.94	5.93	1.91	2.52	9.88	7.36	0.18	-0.59	0.17	26.85
	Root B	8	88	3.58	1.07	3.39	3.51	1.1	1.52	6.31	4.79	0.54	-0.59	0.11	29.89
r(μm)	Trunk	9.00	58.00	5.06	1.01	5.00	5.05	1.02	2.92	7.56	4.63	0.12	-0.29	0.13	19.96
	Root A	9.00	94.00	3.94	0.97	3.93	3.90	0.85	1.80	6.67	4.87	0.46	0.35	0.10	24.62
	Root B	9	88	2.36	0.79	2.22	2.28	0.78	1.01	4.64	3.63	0.93	0.57	0.08	33.47
Ecct (%)	Trunk	12.00	58.00	3.90	2.61	3.74	3.76	2.79	-0.18	11.66	11.84	0.59	0.09	0.34	66.92
	Root A	12.00	94.00	9.94	4.78	9.95	9.91	5.13	-2.21	20.23	22.44	0.02	-0.44	0.49	48.09
	Root B	12	88	10.32	4.83	10.14	10.13	5.4	0.61	22.34	21.73	0.29	-0.42	0.52	46.80
P1 (%)	Trunk	14.00	58.00	13.49	7.61	13.29	12.58	6.21	2.29	39.62	37.33	1.32	2.12	1.00	56.41
	Root A	14.00	94.00	53.82	6.58	53.70	53.86	6.43	37.07	69.39	32.32	-0.08	-0.26	0.68	12.23
	Root B	14	93	54.7	7.79	54.89	54.66	8.2	33.98	73.37	39.39	0.01	-0.45	0.81	14.24
P2 (%)	Trunk	15.00	57.00	29.87	6.31	29.33	29.62	5.58	14.59	48.65	34.06	0.41	0.58	0.84	21.12
	Root A	15.00	94.00	54.27	6.91	53.84	54.41	5.97	34.11	69.56	35.45	-0.25	0.36	0.71	12.73
	Root B	15	90	55.11	7.5	55.01	54.96	8.21	41.44	77.03	35.59	0.25	-0.46	0.79	13.61
P3(%)	Trunk	16.00	58.00	26.95	7.13	26.39	26.87	7.31	7.34	46.10	38.76	0.12	0.20	0.94	26.46
	Root A	16.00	94.00	52.99	5.63	52.38	52.85	4.71	40.41	70.45	30.04	0.30	0.26	0.58	10.62
	Root B	16	90	54.64	6.86	54.2	54.6	6.74	35.31	70.48	35.17	0	-0.15	0.72	12.55
P4(%)	Trunk	17.00	58.00	28.70	8.29	27.54	28.47	7.23	9.28	48.94	39.66	0.33	-0.13	1.09	28.89
	Root A	17.00	92.00	52.88	6.68	51.76	52.64	5.60	38.24	74.91	36.67	0.49	0.62	0.70	12.63
	Root B	17	89	54.2	7.53	54.43	54.38	8.61	34.49	72.67	38.18	-0.2	-0.24	0.8	13.89

9.3.2.Repeated measures ANOVA

Repeated measures ANOVA is used when all members of a random sample are measured under a number of different conditions. As the sample is exposed to each condition in turn, the measurement of the dependent variable is repeated. Using a standard ANOVA in this case is not appropriate because it fails to model the correlation between the repeated measures: the data violate the ANOVA assumption of independence. Keep in mind that some ANOVA designs combine repeated measures factors and nonrepeated factors. If any repeated factor is present, then repeated measures ANOVA should be used.

- This approach is used for several reasons. First, some research hypotheses require repeated measures. Longitudinal research, for example, measures each sample member at each of several ages. In this case, part of the tree or zone in the cross section were a repeated factor.
- Second, in cases where there is a great deal of variation between sample members, error variance estimates from standard ANOVAs are large. Repeated measures of each sample member provides a way of accounting for this variance, thus reducing error variance.
- Third, when sample members are difficult to recruit, repeated measures designs are economical because each member is measured under all conditions.

Recall that, for all of the hypotheses specified above, you test the null hypothesis of no differences between population means. In most cases, some difference will occur in the sample between any levels of a factor. However you want to draw conclusions not about the sample, but about the larger population from which it was taken. F ratios and the analysis of variance were developed to enable you to do that. A large F value yields a correspondingly small p value. The p value is the observed significance level, or probability of a Type 1 error: concluding that a difference between population means exists when in fact there is no difference. This type 1 error is also known as alpha error.

An Repeated measures ANOVA was performed to compare the differences between provenances, part of the tree and their interaction.

- Repeated measured ANOVA for Total Area

The result shown below is a summary of the original script.

```
Linear mixed-effects model fit by REML
  Data: datos.TA
  Log-restricted-likelihood: -952.5337
  Fixed: total.A ~ part * p.code
            (Intercept)            partroots B
              74.538102             -44.080102
              parttrunk            p.code02NIEV
              15.128805             -14.882487
           p.code03ESPA            p.code04ALMI
              -5.875102               7.385304
```

```
             p.code05SEGU              p.code06ALMO
                 2.164012                -20.220102
            p.code07NOINT              p.code08BUSO
                29.029171                -15.248102
              p.code09GRE              p.code10LEIR
                26.317228                 -1.965289
 partroots B:p.code02NIEV    parttrunk:p.code02NIEV
                 1.933798                 13.577410
 partroots B:p.code03ESPA    parttrunk:p.code03ESPA
                 4.085134                 29.130631
 partroots B:p.code04ALMI    parttrunk:p.code04ALMI
                -6.866453                 11.679996
 partroots B:p.code05SEGU    parttrunk:p.code05SEGU
                -1.186012                 29.692827

 partroots B:p.code06ALMO    parttrunk:p.code06ALMO
                15.973102                 17.657789
partroots B:p.code07NOINT   parttrunk:p.code07NOINT
               -26.351978                 21.668452
 partroots B:p.code08BUSO    parttrunk:p.code08BUSO
                 5.238697                 -1.911477
  partroots B:p.code09GRE     parttrunk:p.code09GRE
               -26.185270                  3.295315
 partroots B:p.code10LEIR    parttrunk:p.code10LEIR
                 1.186979                 23.586456

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:    10.25012

Formula: ~1 | tree %in% block
        (Intercept) Residual
StdDev:    15.90322 17.70793

Number of Observations: 233
Number of Groups:
          block tree %in% block
             10              97
```

- Repeated measured ANOVA for Major radius(R)

```
Linear mixed-effects model fit by REML
  Data: datos.R
  Log-restricted-likelihood: -352.3104
  Fixed: R ~ part * p.code

            (Intercept)               partroots B
             5.99760000               -2.76692390
              parttrunk             p.code02NIEV
            -0.19887870               -0.75208099
           p.code03ESPA             p.code04ALMI
            -0.18110000               -0.31958478
           p.code05SEGU             p.code06ALMO
             0.04926596               -1.01050000
          p.code07NOINT             p.code08BUSO
             1.32300000               -1.06440000
            p.code09GRE             p.code10LEIR
             1.01941409                0.55811411
 partroots B:p.code02NIEV    parttrunk:p.code02NIEV
             0.41958033                0.70528038
 partroots B:p.code03ESPA    parttrunk:p.code03ESPA
             0.51153517                1.01059995
 partroots B:p.code04ALMI    parttrunk:p.code04ALMI
             0.72434056                0.63165191
 partroots B:p.code05SEGU    parttrunk:p.code05SEGU
             0.48435794                0.66319820
 partroots B:p.code06ALMO    parttrunk:p.code06ALMO
             1.39952390                0.67784930

partroots B:p.code07NOINT   parttrunk:p.code07NOINT
            -0.74066204                0.68285847
 partroots B:p.code08BUSO    parttrunk:p.code08BUSO
             0.95946003                0.51421614
  partroots B:p.code09GRE     parttrunk:p.code09GRE
            -0.54945877               -0.65103160
 partroots B:p.code10LEIR    parttrunk:p.code10LEIR
             0.17615995                0.25625252
Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:   0.4096874
```

```
 Formula: ~1 | tree %in% block
        (Intercept)  Residual
StdDev:   0.7464751 0.9132556

Number of Observations: 238
Number of Groups: 
          block tree %in% block 
             10              98 
```

- Repeated measured ANOVA for Minor radius(r)

```
Linear mixed-effects model fit by REML
  Data: datos.r 
  Log-restricted-likelihood: -276.4056
  Fixed: r ~ part * p.code 
              (Intercept)               partroots B 
               3.69903596               -1.15913596 
                parttrunk              p.code02NIEV 
               1.10473758                0.11844244 
             p.code03ESPA              p.code04ALMI 
               0.01816404                0.56142616 
             p.code05SEGU              p.code06ALMO 
               0.24395765               -0.17723596 
            p.code07NOINT              p.code08BUSO 
               0.67996404               -0.03453596 
              p.code09GRE              p.code10LEIR 
               0.80525923                0.46760081 
 partroots B:p.code02NIEV    parttrunk:p.code02NIEV 
              -0.78960104               -0.37605251 
 partroots B:p.code03ESPA    parttrunk:p.code03ESPA 
              -0.30464094                0.70839688 
 partroots B:p.code04ALMI    parttrunk:p.code04ALMI 
              -0.34815379                0.30718580 
 partroots B:p.code05SEGU    parttrunk:p.code05SEGU 
              -0.29615765                0.79153523 
 partroots B:p.code06ALMO    parttrunk:p.code06ALMO 
              -0.03256404                0.35404234 
partroots B:p.code07NOINT   parttrunk:p.code07NOINT 
```

```
             -0.78588357                 0.46459068
 partroots B:p.code08BUSO    parttrunk:p.code08BUSO
             -0.51104157                -0.16477606
  partroots B:p.code09GRE     parttrunk:p.code09GRE
             -1.02845500                 0.11355949
 partroots B:p.code10LEIR    parttrunk:p.code10LEIR
             -0.64050208                -0.05233215

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:   0.3644958

 Formula: ~1 | tree %in% block
        (Intercept)  Residual
StdDev:   0.5635659 0.6099313

Number of Observations: 238
Number of Groups:
          block tree %in% block
             10              98
```

- Repeated measured ANOVA for Eccentricity (Ecct)

```
Linear mixed-effects model fit by REML
  Data: datos.ecct
  Log-restricted-likelihood: 55.73268
  Fixed: LNecct ~ part * p.code

             (Intercept)               partroots B
             0.391179454              -0.078361597
               parttrunk              p.code02NIEV
            -0.207010608              -0.060420980
            p.code03ESPA              p.code04ALMI
             0.028226575              -0.098408101
            p.code05SEGU              p.code06ALMO
             0.021150914              -0.027314908
           p.code07NOINT              p.code08BUSO
             0.133674153              -0.086014212
```

```
              p.code09GRE              p.code10LEIR
              0.031987985               0.059070269
 partroots B:p.code02NIEV   parttrunk:p.code02NIEV
              0.195456983               0.114910988
 partroots B:p.code03ESPA   parttrunk:p.code03ESPA
              0.060200175              -0.055324304
 partroots B:p.code04ALMI   parttrunk:p.code04ALMI
              0.084802992              -0.004054036
 partroots B:p.code05SEGU   parttrunk:p.code05SEGU
              0.093441032              -0.106437144
 partroots B:p.code06ALMO   parttrunk:p.code06ALMO
              0.104756792              -0.052450905
partroots B:p.code07NOINT  parttrunk:p.code07NOINT
             -0.040291388              -0.080000865
 partroots B:p.code08BUSO   parttrunk:p.code08BUSO
              0.096568308               0.025192763
  partroots B:p.code09GRE    parttrunk:p.code09GRE
              0.116650846              -0.133033205
 partroots B:p.code10LEIR   parttrunk:p.code10LEIR
              0.104216857              -0.018819535

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:  0.02089358

 Formula: ~1 | tree %in% block
        (Intercept)  Residual
StdDev:  0.04405919 0.1496842

Number of Observations: 227
Number of Groups:
          block tree %in% block
             10              97
```

- Repeated measures ANOVA for porosity in zone 1 (P1)

```
Linear mixed-effects model fit by REML
  Data: datos.P1b
  Log-restricted-likelihood: -703.6935
  Fixed: P1 ~ part * p.code
            (Intercept)             partroots B
            52.07200000              0.43526525
              parttrunk            p.code02NIEV
           -35.38210353              3.67747192
           p.code03ESPA            p.code04ALMI
             2.54600000              0.24089593
           p.code05SEGU            p.code06ALMO
             3.45025979              0.05000000
          p.code07NOINT            p.code08BUSO
             1.98400000              0.57400000
            p.code09GRE            p.code10LEIR
             2.96908688              1.04328159
 partroots B:p.code02NIEV  parttrunk:p.code02NIEV
            -1.58102154             -7.87385717
 partroots B:p.code03ESPA  parttrunk:p.code03ESPA
             1.21992547             -9.27205236
 partroots B:p.code04ALMI  parttrunk:p.code04ALMI
             0.09824592             -4.08898327
 partroots B:p.code05SEGU  parttrunk:p.code05SEGU
            -2.95052504             -3.57818464
 partroots B:p.code06ALMO  parttrunk:p.code06ALMO
            -3.74397401             -2.55790462
partroots B:p.code07NOINT parttrunk:p.code07NOINT
             1.07273475              7.61045130
 partroots B:p.code08BUSO  parttrunk:p.code08BUSO
             3.01692961             -7.63272769
  partroots B:p.code09GRE   parttrunk:p.code09GRE
             0.21964786             -2.10704283
 partroots B:p.code10LEIR  parttrunk:p.code10LEIR
             6.60188096             -7.01563247

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:    3.632478
```

```
 Formula: ~1 | tree %in% block
        (Intercept) Residual
StdDev:    2.290159 5.277136

Number of Observations: 240
Number of Groups: 
          block tree %in% block 
             10              98 
```

- Repeated measures ANOVA for porosity in zone 2 (P2)

```
Linear mixed-effects model fit by REML
  Data: datos 
  Log-restricted-likelihood: -728.2868
  Fixed: P2 ~ part * p.code 
            (Intercept)              partroots B 
            53.37500000              -0.49300000 
              parttrunk             p.code02NIEV 
           -24.66883487               2.41708612 
           p.code03ESPA             p.code04ALMI 
             1.59300000              -2.36905678 
           p.code05SEGU             p.code06ALMO 
             1.96471312               1.19500000 
          p.code07NOINT             p.code08BUSO 
             3.58500000              -2.98200000 
            p.code09GRE             p.code10LEIR 
             1.33360669               3.21423620 
 partroots B:p.code02NIEV   parttrunk:p.code02NIEV 
            -1.12554932              -1.41989798 
 partroots B:p.code03ESPA   parttrunk:p.code03ESPA 
             2.95292583              -1.66388279 
 partroots B:p.code04ALMI   parttrunk:p.code04ALMI 
             0.41782909               3.29959632 
 partroots B:p.code05SEGU   parttrunk:p.code05SEGU 
             0.02738799               6.01337936 
 partroots B:p.code06ALMO   parttrunk:p.code06ALMO 
```

```
               0.66100000                -1.04071487
partroots B:p.code07NOINT   parttrunk:p.code07NOINT
              -2.01400000                 3.26134090
 partroots B:p.code08BUSO    parttrunk:p.code08BUSO
               4.71580835                 3.49074675
  partroots B:p.code09GRE     parttrunk:p.code09GRE
               2.80165006                 4.50306807
 partroots B:p.code10LEIR    parttrunk:p.code10LEIR
               4.09107361                -3.52534891

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:    2.866378

 Formula: ~1 | tree %in% block
        (Intercept) Residual
StdDev:    2.966547 5.779904

Number of Observations: 241
Number of Groups:
          block tree %in% block
             10              98
```

- Repeated measures ANOVA for porosity in zone 3 (P3)

```
Linear mixed-effects model fit by REML
  Data: datos.P3
  Log-restricted-likelihood: -691.5669
  Fixed: P3 ~ part * p.code
             (Intercept)              partroots B
             52.33800000               1.93800000
               parttrunk             p.code02NIEV
            -26.52947648               4.44542095
            p.code03ESPA             p.code04ALMI
             -0.80000000              -1.82710006
            p.code05SEGU             p.code06ALMO
             -0.07464636              -0.45400000
           p.code07NOINT             p.code08BUSO
              1.88100000              -0.22500000
             p.code09GRE             p.code10LEIR
             -0.21246466               2.36094650
 partroots B:p.code02NIEV    parttrunk:p.code02NIEV
             -4.11769774              -2.89488947
 partroots B:p.code03ESPA    parttrunk:p.code03ESPA
              2.25438707              -2.61167303
 partroots B:p.code04ALMI    parttrunk:p.code04ALMI
              2.44957141               4.98122506
 partroots B:p.code05SEGU    parttrunk:p.code05SEGU
             -0.60135364               6.36962988
 partroots B:p.code06ALMO    parttrunk:p.code06ALMO
             -0.96713609               2.70232455
partroots B:p.code07NOINT   parttrunk:p.code07NOINT
             -1.61093888               7.54242678
 partroots B:p.code08BUSO    parttrunk:p.code08BUSO
              2.61856862              -3.27335897
  partroots B:p.code09GRE     parttrunk:p.code09GRE
             -2.72953534               3.46677245
 partroots B:p.code10LEIR    parttrunk:p.code10LEIR
              3.07763425              -1.70068147

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:    1.984694
```

```
 Formula: ~1 | tree %in% block
        (Intercept) Residual
StdDev:    1.896265 5.356247

Number of Observations: 238
Number of Groups: 
          block tree %in% block 
             10              98 
```

- Repeated measures ANOVA for porosity in zone 4 (P4)

```
Linear mixed-effects model fit by REML
  Data: datos.P4b2b 
  Log-restricted-likelihood: -703.1572
  Fixed: P4 ~ part * p.code 
              (Intercept)              partroots B 
              51.53380996               2.72119004 
                parttrunk             p.code02NIEV 
             -23.27148310               2.43982222 
             p.code03ESPA             p.code04ALMI 
               0.55919004              -2.68845723 
             p.code05SEGU             p.code06ALMO 
               0.16340456               0.34019004 
            p.code07NOINT             p.code08BUSO 
               2.35619004               0.75719004 
              p.code09GRE             p.code10LEIR 
               2.01926977               2.15058862 
 partroots B:p.code02NIEV    parttrunk:p.code02NIEV 
              -2.90275142              -0.64322037 
 partroots B:p.code03ESPA    parttrunk:p.code03ESPA 
              -0.09040529              -1.31248980 
 partroots B:p.code04ALMI    parttrunk:p.code04ALMI 
              -0.18300775               3.17175994 
 partroots B:p.code05SEGU    parttrunk:p.code05SEGU 
              -2.18640456               1.84343028 
 partroots B:p.code06ALMO    parttrunk:p.code06ALMO 
              -0.67722447              -0.34901884 
partroots B:p.code07NOINT   parttrunk:p.code07NOINT 
              -1.60266478               8.16343096 
 partroots B:p.code08BUSO    parttrunk:p.code08BUSO 
```

```
             -2.83659266                2.42999397
   partroots B:p.code09GRE     parttrunk:p.code09GRE
             -1.43308086                6.68581523

  partroots B:p.code10LEIR    parttrunk:p.code10LEIR
       3.48102397        -8.22881072

Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:    2.161062

 Formula: ~1 | tree %in% block
        (Intercept) Residual
StdDev:    3.503126 5.700983

Number of Observations: 233
Number of Groups:
          block tree %in% block
             10              98
```

- ANOVA for compression wood area

```
Linear mixed-effects model fit by REML

  Data: datos_CW_tronco
  Log-restricted-likelihood: -116.777
  Fixed: XCW ~ p.code

  (Intercept)  p.code02NIEV  p.code03ESPA
p.code04ALMI
   4.39666840    2.09334524    0.91500023   -
0.03668937
 p.code05SEGU  p.code06ALMO p.code07NOINT
p.code08BUSO
  -0.10500000   -0.51095316    3.13335111
3.73761827
  p.code09GRE  p.code10LEIR
   3.38664221    5.14334616
```

```
Random effects:
 Formula: ~1 | block
        (Intercept)
StdDev:   0.0098142

 Formula: ~1 | tree %in% block
        (Intercept)  Residual
StdDev:    3.216784 0.1918322

Number of Observations: 52
Number of Groups:
          block tree %in% block
              8              52
```

Differences in provenances, part and the interaction between them.

An ANOVA was performed to each model to evaluate the differences between provenances and part, as well as the interaction between them.

Table 5. Analysis of Variance of the variables. Comparison between part, provenances and their interaction.

Total A	numDF	denDF	F-value	p-value
(Intercept)	1	116	267.732	<.0001***
Part	2	116	302.451	<.0001***
Provenance	9	78	3.641	0.0035**
Provenance * Part	18	116	2.33	0.0386*

R	numDF	denDF	F-value	p-value
(Intercept)	1	120	992.5754	<.0001***
Part	2	120	194.5732	<.0001***
Provenance	9	79	3.415	0.0088**
Provenance * Part	18	120	1.4906	0.1918

r	numDF	denDF	F-value	p-value
(Intercept)	1	120	721.27	<.0001***
Part	2	120	372.905	<.0001***
Provenance	9	79	1.738	0.1628
Provenance * Part	18	120	1.3919	0.3852

Table 5 (cont). Analysis of Variance of the variables. . Comparison between part, provenances and their iraction.

Ecct	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	122	651.918	<.0001***
Part	2	122	47.9506	<.0001***
Provenance	9	79	1.7602	0.0893
Provenance * Part	18	122	0.6258	0.8735

P1	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	175	193.37415	<.0001***
Part	2	175	77.341	<.0001***
Provenance	9	81	1.357	0.1958
Provenance * Part	18	175	0.854	0.0006**

P2	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	127	1513.9482	<.0001
Part	2	127	898.2643	<.0001
Provenance	9	79	1.0395	0.3537
Provenance * Part	18	127	1.6932	0.1975

P3	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	119	1947.987	<.0001
Part	2	119	400.147	<.0001
Provenance	9	79	1.706	0.2132
Provenance * Part	18	119	1.41	0.0231

P3	**numDF**	**denDF**	**F-value**	**p-value**
(Intercept)	1	118	4462.542	<.0001
Part	2	118	421.858	<.0001
Provenance	9	79	0.904	0.4113
Provenance * Part	18	118	1.322	0.0413

9.3.3. Kolmogorov–Smirnov test

Kolmogorov–Smirnov test (K–S test or KS test) is a nonparametric test of the equality of continuous, one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution (one-sample K–S test), or to compare two samples (two-sample K–S test). The Kolmogorov–Smirnov statistic quantifies a distance between the empirical distribution function of the sample and the cumulative distribution function of the reference distribution, or between the empirical distribution functions of two samples. The null distribution of this statistic is calculated under the null hypothesis that the samples are drawn from the same distribution (in the two-sample case) or that the sample is drawn from the reference distribution (in the one-sample case). In each case, the distributions considered under the null hypothesis are continuous distributions but are otherwise unrestricted.

The two-sample K–S test is one of the most useful and general nonparametric methods for comparing two samples, as it is sensitive to differences in both location and shape of the empirical cumulative distribution functions of the two samples.

The Kolmogorov–Smirnov test can be modified to serve as a goodness of fit test. In the special case of testing for normality of the distribution, samples are standardized and compared with a standard normal distribution. This is equivalent to setting the mean and variance of the reference distribution equal to the sample estimates, and it is known that using these to define the specific reference distribution changes the null distribution of the test statistic: see below. Various studies have found that, even in this corrected form, the test is less powerful for testing normality than the Shapiro–Wilk test or Anderson–Darling test (Stephens, 1974). However, other tests have their own disadvantages. For instance the Shapiro–Wilk test is known not to work well with many ties (many identical values).

9.3.4. LSD test

When an analysis of variance (anova) gives a significant result, this indicates that at least one group differs from the other groups. Yet, the omnibus test does not indicate which group differs. In order to analyze the pattern of difference between means, the anova is often followed by specific comparisons, and the most commonly used involves comparing two means (the so called “pairwise comparisons”).

The first pairwise comparison technique was developed by Fisher in 1935 and is called the least significant difference (lsd) test. This technique can be used only if the anova F omnibus is significant. The main idea of the lsd is to compute the smallest significant difference (i.e., the lsd) between two means as if these means had been the only means to be compared (i.e., with a t test) and to declare significant any difference larger than the lsd (Williams and Abdi, 2010).

The formula for the least significant difference is:

$$\boldsymbol{LSD_{A,B} = t_{0.05/2,DFW}\sqrt{MSW\,(1/n_A + 1/n_B)}} \qquad \text{(EQUATION 4)}$$

Where:

t = critical value from the t-distribution table

MSw = mean square within, obtained from the results of your ANOVA test

n = number of scores used to calculate the means

In this section, LSD test results applied for the different variables are showed. We had to make a selection about these results due to the large extension of them. We considered that the most important results are those that we show below.

- LSD test results for total cross section area (Variable = Provenance)

Pairwise LSD

	01ONA	02NIEV	03ESPA	04ALMI	05SEGU	06ALMO	07NOINT	08BUSO	09GRE	10LEIR
01ONA	0.00	7.58	-5.17	-8.96	-11.63	9.04	-26.73	14.17	-18.61	-6.23
02NIEV	30.28	0.00	12.76	-16.54	-19.21	1.46	-34.31	6.59	-26.19	-13.81
03ESPA	30.31	30.83	0.00	-3.78	-6.45	14.21	-21.56	19.34	-13.43	-1.05
04ALMI	31.10	31.61	31.60	0.00	-2.67	17.99	-17.77	23.12	-9.65	2.73
05SEGU	30.07	30.60	30.61	31.41	0.00	20.66	-15.10	25.79	-6.98	5.40
06ALMO	29.67	30.20	30.23	31.02	29.99	0.00	-35.77	5.13	-27.64	-15.26
07NOINT	30.81	31.33	31.35	32.13	31.12	30.74	0.00	40.90	8.12	20.50
08BUSO	29.60	30.13	30.16	30.96	29.92	29.52	30.67	0.00	-32.77	-20.39
09GRE	31.67	32.18	32.18	32.94	31.95	31.60	32.67	31.52	0.00	12.38
10LEIR	31.61	32.08	32.09	32.86	31.90	31.50	32.59	31.46	33.43	0.00

Table 7. Pairwise LSD for total cross section area

Pairwise p-value

	01ONA	02NIEV	03ESPA	04ALMI	05SEGU	06ALMO	07NOINT	08BUSO	09GRE	10LEIR
01ONA	0.00	0.85	-0.58	-0.97	-1.31	1.03	-2.94	1.62	-1.99	-0.66
02NIEV	1.00	0.00	-1.40	-1.77	-2.12	0.16	-3.71	0.74	-2.75	-1.45
03ESPA	1.00	1.00	0.00	-0.41	-0.71	1.59	-2.33	2.17	-1.41	-0.11
04ALMI	1.00	1.00	1.00	0.00	-0.29	1.96	-1.87	2.53	-0.99	0.28
05SEGU	1.00	1.00	1.00	1.00	0.00	2.33	-1.64	2.92	-0.74	0.57
06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-3.94	0.59	-2.96	-1.64
07NOINT	0.20	0.02	1.00	1.00	1.00	0.01	0.00	4.51	0.84	2.12
08BUSO	1.00	1.00	1.00	0.61	0.21	1.00	0.00	0.00	-3.52	-2.19
09GRE	1.00	0.33	1.00	1.00	1.00	0.18	1.00	0.03	0.00	1.25
10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00

Table 8. Pairwise p-value for total cross section area

- LSD test results for major radius (Variable = Provenance)

Pairwise LSD

	01ONA	02NIEV	03ESPA	04ALMI	05SEGU	06ALMO	07NOINT	08BUSO	09GRE	10LEIR
01ONA	0.00	-0.20	0.33	-0.13	-0.43	0.32	-1.30	0.57	-0.61	-0.70
02NIEV	1.49	0.00	0.53	-0.33	-0.63	0.12	-1.51	0.37	-0.82	-0.90
03ESPA	1.49	1.52	0.00	0.20	-0.10	0.65	-0.98	0.90	-0.29	-0.37
04ALMI	1.53	1.55	1.55	0.00	-0.30	0.45	-1.17	0.71	-0.48	-0.57
05SEGU	1.48	1.50	1.50	1.54	0.00	0.75	-0.87	1.01	-0.18	-0.27
06ALMO	1.45	1.48	1.48	1.52	1.47	0.00	-1.62	0.26	-0.93	-1.02
07NOINT	1.51	1.53	1.53	1.57	1.52	1.50	0.00	1.88	0.69	0.60
08BUSO	1.44	1.47	1.47	1.51	1.46	1.44	1.49	0.00	-1.19	-1.28
09GRE	1.56	1.59	1.59	1.62	1.58	1.56	1.61	1.55	0.00	-0.09
10LEIR	1.50	1.52	1.52	1.56	1.51	1.49	1.54	1.48	1.59	0.00

Table 9. Pairwise LSD results for major radius.

Pairwise p-value

	01ONA 02	NIEV 0	3ESPA 0	4ALMI	05SEGU	06ALMO 0	7NOINT	08BUSO	09GRE	10LEIR
01ONA	0.00	-0.46	0.74	-0.29	-0.99	0.74	-2.93	1.35	-1.33	-1.59
02NIEV	1.00	0.00	1.18	-0.73	-1.43	0.26	-3.32	0.85	-1.74	-2.01
03ESPA	1.00	1.00	0.00	0.43	-0.23	1.47	-2.15	2.07	-0.61	-0.83
04ALMI	1.00	1.00	1.00	0.00	-0.66	1.00	-2.52	1.58	-1.00	-1.24
05SEGU	1.00	1.00	1.00	1.00	0.00	1.72	-1.94	2.33	-0.39	-0.61
06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-3.66	0.60	-2.03	-2.32
07NOINT	0.20	0.06	1.00	0.61	1.00	0.02	0.00	4.26	1.45	1.32
08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	-2.60	-2.92
09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	-0.19
10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.21	1.00	0.00

Table 10. Pairwise p-value for major radius.

- LSD test results for compression wood area (Variable = Provenance)

Pairwise LSD

	01ONA	02NIEV	03ESPA	04ALMI	05SEGU	06ALMO	07NOINT	08BUSO	09GRE	10LEIR
01ONA	0.00	-2.37	-1.56	-2.94	-1.27	0.38	-6.66	-2.47	-4.74	-6.95
02NIEV	7.55	0.00	0.81	-0.57	1.11	2.76	-4.29	-0.10	-2.37	-4.57
03ESPA	7.20	7.55	0.00	-1.38	0.30	1.95	-5.10	-0.90	-3.18	-5.38
04ALMI	8.04	8.36	8.04	0.00	1.68	3.33	-3.72	0.47	-1.80	-4.00
05SEGU	7.20	7.55	7.20	8.04	0.00	1.65	-5.40	-1.20	-3.47	-5.68
06ALMO	6.93	7.30	6.93	7.81	6.93	0.00	-7.05	-2.85	-5.12	-7.33
07NOINT	8.04	8.36	8.04	8.81	8.04	7.81	0.00	4.19	1.92	-0.28
08BUSO	6.93	7.30	6.93	7.81	6.93	6.66	7.81	0.00	-2.27	-4.48
09GRE	8.81	9.10	8.81	9.52	8.81	8.60	9.52	8.60	0.00	-2.21
10LEIR	7.20	7.55	7.20	8.04	7.20	6.93	8.04	6.93	8.81	0.00

Table 11. Pairwise LSD results for compression wood area.

Pairwise p-value

	01ONA	02NIEV	03ESPA	04ALMI	05SEGU	06ALMO	07NOINT	08BUSO	09GRE	10LEIR
01ONA	0.00	-1.11	-0.77	-1.29	-0.62	0.20	-2.93	-1.26	-1.90	-3.41
02NIEV	1.00	0.00	0.38	-0.24	0.52	1.34	-1.81	-0.05	-0.92	-2.14
03ESPA	1.00	1.00	0.00	-0.61	0.15	0.99	-2.24	-0.46	-1.27	-2.65
04ALMI	1.00	1.00	1.00	0.00	0.74	1.51	-1.49	0.21	-0.67	-1.76
05SEGU	1.00	1.00	1.00	1.00	0.00	0.84	-2.37	-0.61	-1.39	-2.79
06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-3.19	-1.51	-2.11	-3.74
07NOINT	0.26	1.00	1.00	1.00	1.00	0.13	0.00	1.90	0.71	-0.12
08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.93	-2.28
09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.89
10LEIR	0.07	1.00	0.54	1.00	0.37	0.03	1.00	1.00	1.00	0.00

Table 12. Pairwise p-value for compression wood area.

- LSD test results for total cross section area (Variable = Interaction provenance and part)

Pairwise p-value

Table 13. Pairwise p-value for total cross section area.

	roots.A 01ONA	**roots.A 02NIEV**	**roots.A 03ESPA**	**roots.A 04ALMI**	**roots.A 05SEGU**	**roots.A 06ALMO**	**roots.A 07NOINT**	**roots.A 08BUSO**	**roots.A 09GRE**	**roots.A 10LEIR**
roots A:01ONA	0.00	1.33	0.54	-0.63	-0.20	1.86	-2.62	1.40	-2.37	0.17
roots A:01ONA	1.00	0.00	-0.82	-1.88	-1.52	0.49	-3.93	0.03	-3.68	-1.09
roots A:02NIEV	1.00	1.00	0.00	-1.15	-0.74	1.35	-3.21	0.88	-2.96	-0.34
roots A:03ESPA	1.00	1.00	1.00	0.00	0.44	2.39	-1.84	1.96	-1.61	0.75
roots A:04ALMI	1.00	1.00	1.00	1.00	0.00	2.06	-2.42	1.60	-2.17	0.35
roots A:05SEGU	1.00	1.00	1.00	1.00	1.00	0.00	-4.53	-0.47	-4.28	-1.57
roots A:06ALMO	1.00	0.06	0.75	1.00	1.00	0.01	0.00	4.07	0.24	2.62
roots A:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.04	0.00	-3.82	-1.14
roots A:08BUSO	1.00	0.15	1.00	1.00	1.00	0.02	1.00	0.09	0.00	2.39
roots A:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
roots A:10LEIR	0.00	1.00	0.21	0.01	0.02	1.00	0.00	1.00	0.00	0.19
roots B:01ONA	0.00	0.00	0.01	0.00	0.00	0.80	0.00	0.19	0.00	0.01
roots B:02NIEV	0.04	1.00	0.00	0.01	0.02	1.00	0.00	1.00	0.00	0.18
roots B:03ESPA	0.10	1.00	0.46	0.00	0.05	1.00	0.00	1.00	0.00	0.37
roots B:04ALMI	0.05	1.00	0.29	0.01	0.00	1.00	0.00	1.00	0.00	0.25

Table 13 (cont). Pairwise p-value for total cross section area.

	roots.A 01ONA	roots.A 02NIEV	roots.A 03ESPA	roots.A 04ALMI	roots.A 05SEGU	roots.A 06ALMO	roots.A 07NOINT	roots.A 08BUSO	roots.A 09GRE	roots.A 10LEIR
roots B:05SEGU	0.01	1.00	0.05	0.00	0.00	0.24	0.00	1.00	0.00	0.05
roots B:06ALMO	0.13	1.00	0.61	0.03	0.06	1.00	0.00	1.00	0.00	0.49
roots B:07NOINT	0.00	0.28	0.01	0.00	0.00	1.00	0.00	0.00	0.00	0.01
roots B:08BUSO	0.06	1.00	0.29	0.01	0.03	1.00	0.00	1.00	0.00	0.24
roots B:09GRE	0.07	1.00	0.32	0.01	0.03	1.00	0.00	1.00	0.00	0.01
roots B:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
trunk:01ONA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
trunk:02NIEV	0.86	0.01	0.00	1.00	1.00	0.00	1.00	0.01	1.00	0.88
trunk:03ESPA	1.00	0.09	0.80	1.00	1.00	0.01	1.00	0.06	1.00	1.00
trunk:04ALMI	0.07	0.00	0.01	1.00	0.00	0.00	1.00	0.00	1.00	0.09
trunk:05SEGU	1.00	1.00	1.00	1.00	1.00	0.17	1.00	1.00	1.00	1.00
trunk:06ALMO	0.00	0.00	0.00	0.03	0.00	0.00	0.66	0.00	1.00	0.00
trunk:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
trunk:08BUSO	1.00	0.04	0.30	1.00	1.00	0.01	1.00	0.03	1.00	1.00
trunk:09GRE	1.00	0.43	1.00	1.00	0.01	1.00	0.03	1.00	0.19	0.00
trunk:10LEIR	1.00	0.50	0.43	1.00	1.00	0.01	1.00	0.03	1.00	0.19

	roots.B 01ONA	roots.B 02NIEV	roots.B 03ESPA	roots.B 04ALMI	roots.B 05SEGU	roots.B 06ALMO	roots.B 07NOINT	roots.B 08BUSO	roots.B 09GRE	roots.B 10LEIR
roots A:01ONA	5.37	4.86	4.03	3.81	3.97	4.45	3.74	4.89	3.96	3.92
roots A:01ONA	2.67	4.62	2.70	2.49	2.58	3.05	2.38	3.51	2.60	2.60
roots A:02NIEV	3.59	4.43	4.64	3.36	3.50	3.99	3.27	4.44	3.50	3.47
roots A:03ESPA	4.45	5.19	4.43	5.38	4.37	4.82	4.15	5.24	4.36	4.33
roots A:04ALMI	4.25	5.03	4.22	3.99	5.49	4.64	3.93	5.07	4.15	4.10
roots A:05SEGU	2.24	3.19	2.30	2.08	2.15	3.55	1.95	3.12	2.18	2.19
roots A:06ALMO	6.72	7.31	6.57	6.34	6.63	7.11	8.24	7.49	6.56	6.44
roots A:07NOINT	2.71	3.62	2.74	2.52	2.62	3.11	2.41	4.73	2.64	2.63
roots A:08BUSO	6.47	7.08	6.33	6.10	6.38	6.86	6.10	7.25	8.19	6.20
roots A:09GRE	3.63	4.42	3.63	3.42	3.54	3.99	3.34	4.41	3.55	4.45
roots A:10LEIR	0.00	1.12	0.16	-0.05	-0.09	0.40	-0.25	0.92	-0.01	0.07
roots B:01ONA	1.00	0.00	-0.93	-1.11	-1.21	-0.75	-1.33	-0.25	-1.11	-1.00
roots B:02NIEV	1.00	1.00	0.00	-0.20	-0.25	0.22	-0.39	0.72	-0.17	-0.09
roots B:03ESPA	1.00	1.00	1.00	0.00	-0.04	0.42	-0.19	0.92	0.03	0.11
roots B:04ALMI	1.00	1.00	1.00	1.00	0.00	0.49	-0.16	1.01	0.08	0.16
roots B:05SEGU	1.00	1.00	1.00	1.00	1.00	0.00	-0.64	0.53	-0.40	-0.31
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.15	0.23	0.30
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.91	-0.81
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.08

Table 13 (cont). Pairwise p-value for total cross section area.

	roots.B 01ONA	roots.B 02NIEV	roots.B 03ESPA	roots.B 04ALMI	roots.B 05SEGU	roots.B 06ALMO	roots.B 07NOINT	roots.B 08BUSO	roots.B 09GRE	roots.B 10LEIR
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
roots B:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:01ONA	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.11	0.01	0.11	0.24	0.15	0.03	0.31	0.00	0.15	0.17
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	trunk 01ONA	trunk 02NIEV	trunk 03ESPA	trunk 04ALMI	trunk 05SEGU	trunk 06ALMO	trunk 07NOINT	trunk 08BUSO	trunk 09GRE	trunk 10LEIR
roots A:01ONA	-1.63	-1.09	-3.17	-2.68	-3.89	-1.08	-4.88	0.18	-3.04	-2.87
roots A:01ONA	-2.56	-2.77	-4.36	-3.82	-5.08	-2.34	-5.96	-1.13	-4.04	-4.01
roots A:02NIEV	-1.83	-1.57	-4.63	-3.19	-4.44	-1.61	-5.39	-0.35	-3.48	-3.38
roots A:03ESPA	-0.63	-0.48	-2.44	-2.37	-3.12	-0.42	-4.17	0.78	-2.46	-2.20
roots A:04ALMI	-1.11	-0.91	-2.99	-2.51	-4.65	-0.89	-4.72	0.37	-2.90	-2.70
roots A:05SEGU	-3.09	-2.71	-4.92	-4.33	-5.65	-3.65	-6.46	-1.64	-4.47	-4.52
roots A:06ALMO	1.19	1.19	-0.77	-0.40	-1.48	1.41	-3.25	2.74	-1.07	-0.60
roots A:07NOINT	-2.65	-2.32	-4.50	-3.93	-5.23	-2.43	-6.09	-1.55	-4.13	-4.13
roots A:08BUSO	0.96	0.98	-0.99	-0.62	-1.71	1.18	-2.93	2.50	-1.45	-0.81
roots A:09GRE	-1.38	-1.18	-3.16	-2.70	-3.83	-1.18	-4.81	0.01	-3.06	-3.62
roots A:10LEIR	-6.60	-4.61	-6.92	-6.23	-7.66	-4.95	-8.26	-3.78	-6.11	-6.41
roots B:01ONA	-5.87	-6.26	-7.48	-6.83	-8.18	-5.65	-8.75	-4.58	-6.69	-7.01
roots B:02NIEV	-5.11	-4.59	-8.61	-6.16	-7.52	-4.90	-8.14	-3.77	-6.08	-6.34
roots B:03ESPA	-4.90	-4.40	-6.60	-7.21	-7.30	-4.69	-7.94	-3.56	-5.91	-6.14
roots B:04ALMI	-5.08	-4.53	-6.83	-6.15	-9.45	-4.86	-8.18	-3.69	-6.05	-6.34
roots B:05SEGU	-5.54	-4.95	-7.27	-6.56	-8.01	-6.79	-8.58	-4.16	-6.41	-6.75
roots B:06ALMO	-4.85	-4.33	-6.58	-5.92	-7.31	-4.63	-9.19	-3.48	-5.87	-6.11
roots B:07NOINT	-5.94	-5.33	-7.64	-6.93	-8.36	-5.72	-8.90	-5.88	-6.73	-7.11
roots B:08BUSO	-5.06	-4.53	-6.79	-6.12	-7.51	-4.84	-8.13	-3.69	-6.96	-6.31
roots B:09GRE	-5.00	-4.50	-6.69	-6.04	-7.39	-4.79	-8.03	-3.66	-5.98	-7.73
roots B:10LEIR	0.00	0.10	-1.84	-1.44	-2.53	0.21	-3.63	1.44	-1.96	-1.63
trunk:01ONA	1.00	0.00	-1.80	-1.43	-2.43	0.10	-3.50	1.22	-1.93	-1.61
trunk:02NIEV	1.00	1.00	0.00	0.31	-0.66	2.04	-1.92	3.27	-0.41	0.12

Table 13 (cont). Pairwise p-value for total cross section area.

	trunk 01ONA	trunk 02NIEV	trunk 03ESPA	trunk 04ALMI	trunk 05SEGU	trunk 06ALMO	trunk 07NOINT	trunk 08BUSO	trunk 09GRE	trunk 10LEIR
trunk:03ESPA	1.00	1.00	1.00	0.00	-0.94	1.63	-2.12	2.79	-0.66	-0.18
trunk:04ALMI	1.00	1.00	1.00	1.00	0.00	2.73	-1.32	3.98	0.15	0.75
trunk:05SEGU	1.00	1.00	1.00	1.00	1.00	0.00	-3.82	1.23	-2.13	-1.82
trunk:06ALMO	0.18	0.29	1.00	1.00	1.00	0.09	0.00	4.95	1.27	1.95
trunk:07NOINT	1.00	1.00	0.61	1.00	0.05	1.00	0.00	0.00	-3.14	-2.98
trunk:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.00	0.50
trunk:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00
trunk:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00

- LSD test results for P1 (Variable = Interaction provenance and part)

Pairwise LSD

Table 14. Pairwise p-value for P1.

	roots.A 01ONA	roots.A 02NIEV	roots.A 03ESPA	roots.A 04ALMI	roots.A 05SEGU	roots.A 06ALMO	roots.A 07NOINT	roots.A 08BUSO	roots.A 09GRE	roots.A 10LEIR
roots A:01ONA	0.00	-1.39	-0.99	-0.09	-1.30	-0.02	-0.77	-0.22	-1.12	0.94
roots A:01ONA	1.00	0.00	0.43	1.23	0.08	1.37	0.64	1.17	0.26	0.55
roots A:02NIEV	1.00	1.00	0.00	0.84	-0.34	0.97	0.22	0.77	-0.16	-0.28
roots A:03ESPA	1.00	1.00	1.00	0.00	-1.15	0.07	-0.64	-0.12	-0.97	0.86
roots A:04ALMI	1.00	1.00	1.00	1.00	0.00	1.29	0.55	1.09	0.18	-0.36
roots A:05SEGU	1.00	1.00	1.00	1.00	1.00	0.00	-0.75	-0.20	-1.10	0.34
roots A:06ALMO	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.55	-0.37	-0.17
roots A:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.91	0.69
roots A:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00
roots A:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots A:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:01ONA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:02NIEV	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:03ESPA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:04ALMI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:05SEGU	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
roots B:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:01ONA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 14 (cont). Pairwise p-value for P1.

	roots.B 01ONA	roots.B 02NIEV	roots.B 03ESPA	roots.B 04ALMI	roots.B 05SEGU	roots.B 06ALMO	roots.B 07NOINT	roots.B 08BUSO	roots.B 09GRE	roots.B 10LEIR
roots A:01ONA	-0.18	-0.93	-1.59	-0.28	-0.36	1.23	-1.36	-1.48	-1.41	-3.06
roots A:01ONA	1.19	0.44	-0.19	1.04	1.04	2.56	0.07	-0.12	0.02	-1.62
roots A:02NIEV	0.80	0.01	-0.68	0.65	0.63	2.20	-0.37	-0.54	-0.42	-2.09
roots A:03ESPA	-0.07	-0.79	-1.42	-0.20	-0.25	1.25	-1.19	-1.32	-1.24	-2.81
roots A:04ALMI	1.11	0.33	-0.28	0.96	1.03	2.47	-0.02	-0.21	-0.07	-1.71
roots A:05SEGU	-0.15	-0.91	-1.57	-0.27	-0.34	1.36	-1.34	-1.46	-1.39	-3.04
roots A:06ALMO	0.59	-0.20	-0.84	0.44	0.41	1.98	-0.64	-0.75	-0.64	-2.31
roots A:07NOINT	0.05	-0.72	-1.37	-0.07	-0.14	1.45	-1.13	-1.37	-1.19	-2.84
roots A:08BUSO	0.93	0.16	-0.45	0.78	0.77	2.30	-0.20	-0.38	-0.27	-1.88
roots A:09GRE	0.22	-0.52	-1.13	0.09	0.04	1.54	-0.90	-1.04	-0.95	-2.70
roots A:10LEIR	0.00	-0.75	-1.39	-0.12	-0.19	1.36	-1.16	-1.29	-1.21	-2.82
roots B:01ONA	1.00	0.00	-0.60	0.61	0.58	2.07	-0.35	-0.52	-0.40	-1.98
roots B:02NIEV	1.00	1.00	0.00	1.23	1.24	2.75	0.27	0.06	0.22	-1.43
roots B:03ESPA	1.00	1.00	1.00	0.00	-0.06	1.44	-0.99	-1.13	-1.04	-2.62
roots B:04ALMI	1.00	1.00	1.00	1.00	0.00	1.59	-0.99	-1.13	-1.05	-2.70
roots B:05SEGU	1.00	1.00	1.00	1.00	1.00	0.00	-2.56	-2.61	-2.61	-4.18
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.20	-0.05	-1.74
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.15	-1.45
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-1.69
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	0.02	1.00	1.00	1.00	0.00
roots B:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:01ONA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	trunk 01ONA	trunk 02NIEV	trunk 03ESPA	trunk 04ALMI	trunk 05SEGU	trunk 06ALMO	trunk 07NOINT	trunk 08BUSO	trunk 09GRE	trunk 10LEIR
roots A:01ONA	13.40	12.58	14.20	12.46	11.97	13.38	7.61	15.57	9.16	13.93
roots A:01ONA	13.46	14.35	15.09	13.35	12.92	14.33	8.56	16.52	9.98	14.83
roots A:02NIEV	13.39	13.39	16.04	13.27	12.83	14.28	8.36	16.50	9.83	14.79
roots A:03ESPA	12.00	12.16	13.66	12.70	11.55	12.83	7.43	14.82	8.98	13.40

Table 14 (cont). Pairwise p-value for P1**.**

	trunk 01ONA	**trunk 02NIEV**	**trunk 03ESPA**	**trunk 04ALMI**	**trunk 05SEGU**	**trunk 06ALMO**	**trunk 07NOINT**	**trunk 08BUSO**	**trunk 09GRE**	**trunk 10LEIR**
roots A:04ALMI	13.39	13.44	15.06	13.32	13.78	14.29	8.50	16.45	9.95	14.81
roots A:05SEGU	12.51	12.59	14.21	12.48	11.99	14.37	7.62	15.59	9.17	13.95
roots A:06ALMO	13.19	13.21	14.86	13.09	12.64	14.08	8.60	16.29	9.68	14.60
roots A:07NOINT	12.69	12.76	14.39	12.64	12.17	13.58	7.78	17.02	9.31	14.12
roots A:08BUSO	13.25	13.26	14.90	13.17	12.72	14.10	8.36	16.25	10.24	14.64
roots A:09GRE	12.23	12.43	13.91	12.29	11.79	13.10	7.64	15.15	9.17	14.50
roots A:10LEIR	13.33	12.50	14.07	12.39	11.89	13.25	7.62	15.34	9.16	13.81
roots B:01ONA	12.74	13.55	14.38	12.73	12.25	13.56	8.08	15.66	9.54	14.12
roots B:02NIEV	13.68	13.68	16.38	13.57	13.13	14.55	8.72	16.68	10.15	15.06
roots B:03ESPA	12.16	12.34	13.83	12.87	11.70	13.01	7.57	15.01	9.09	13.58
roots B:04ALMI	12.82	12.88	14.51	12.76	13.09	13.71	7.88	15.91	9.41	14.25
roots B:05SEGU	11.10	11.33	12.83	11.21	10.67	12.75	6.55	14.03	8.19	12.57
roots B:06ALMO	13.72	13.69	15.37	13.57	13.15	14.62	9.06	16.85	10.08	15.11
roots B:07NOINT	13.27	13.35	14.92	13.22	12.76	14.14	8.51	17.23	9.94	14.66
roots B:08BUSO	13.77	13.73	15.42	13.61	13.19	14.66	8.68	16.90	10.52	15.15
roots B:09GRE	15.03	14.89	16.60	14.78	14.41	15.90	9.84	18.07	11.17	17.47
roots B:10LEIR	0.00	1.25	2.11	1.15	0.04	0.82	-2.68	2.37	-0.22	1.87
trunk:01ONA	1.00	0.00	0.73	-0.10	-1.17	-0.50	-3.60	0.88	-1.20	0.51
trunk:02NIEV	1.00	1.00	0.00	-0.83	-2.00	-1.33	-4.43	0.11	-1.88	-0.23
trunk:03ESPA	1.00	1.00	1.00	0.00	-1.07	-0.40	-3.50	0.98	-1.13	0.61
trunk:04ALMI	1.00	1.00	1.00	1.00	0.00	0.75	-2.64	2.24	-0.25	1.77
trunk:05SEGU	1.00	1.00	1.00	1.00	1.00	0.00	-3.38	1.53	-0.85	1.09
trunk:06ALMO	1.00	0.20	0.01	0.28	1.00	0.42	0.00	4.75	2.00	4.23
trunk:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	-2.04	-0.35
trunk:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.69
trunk:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	0.02	1.00	1.00	0.00
trunk:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	0.02	1.00	1.00	0.00

- LSD test results for P3 (Variable = Interaction provenance and part)

Pairwise LSD

Table 15. Pairwise p-value for P3.

	roots.A 01ONA	roots.A 02NIEV	roots.A 03ESPA	roots.A 04ALMI	roots.A 05SEGU	roots.A 06ALMO	roots.A 07NOINT	roots.A 08BUSO	roots.A 09GRE	roots.A 10LEIR
roots A:01ONA	0.00	-1.70	0.31	0.68	0.03	0.18	-0.74	0.09	0.08	-0.88
roots A:02NIEV	1.00	0.00	2.01	2.27	1.68	1.87	0.98	1.79	1.74	0.75
roots A:03ESPA	1.00	1.00	0.00	0.38	-0.28	-0.14	-1.06	-0.23	-0.22	-1.17
roots A:04ALMI	1.00	1.00	1.00	0.00	-0.63	-0.51	-1.37	-0.59	-0.58	-1.47
roots A:05SEGU	1.00	1.00	1.00	1.00	0.00	0.15	-0.75	0.06	0.05	-0.88
roots A:06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-0.92	-0.09	-0.09	-1.04
roots A:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.83	0.80	-0.18
roots A:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	-0.96
roots A:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.93
roots A:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
roots B:01ONA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:02NIEV	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:03ESPA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:04ALMI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:05SEGU	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:10LEIR	1.00	1.00	0.95	0.50	1.00	1.00	1.00	1.00	1.00	1.00
trunk:01ONA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 15 (cont). Pairwise p-value for P3.

	roots.B 01ONA	roots.B 02NIEV	roots.B 03ESPA	roots.B 04ALMI	roots.B 05SEGU	roots.B 06ALMO	roots.B 07NOINT	roots.B 08BUSO	roots.B 09GRE	roots.B 10LEIR
roots A:01ONA	-0.81	-0.84	-1.30	-0.95	-0.50	-0.20	-0.82	-1.55	0.40	-2.82
roots A:02NIEV	0.96	0.83	0.39	0.68	1.22	1.47	0.81	0.04	2.09	-1.09
roots A:03ESPA	-1.08	-1.14	-1.70	-1.25	-0.81	-0.50	-1.12	-1.83	0.08	-3.13
roots A:04ALMI	-1.40	-1.44	-1.89	-1.63	-1.14	-0.85	-1.42	-2.09	-0.31	-3.33
roots A:05SEGU	-0.77	-0.85	-1.29	-0.95	-0.54	-0.22	-0.83	-1.54	0.36	-2.78
roots A:06ALMO	-0.94	-1.01	-1.47	-1.12	-0.68	-0.39	-0.99	-1.71	0.22	-3.00
roots A:07NOINT	-0.02	-0.14	-0.58	-0.25	0.24	0.52	-0.13	-0.87	1.14	-2.10
roots A:08BUSO	-0.85	-0.92	-1.38	-1.03	-0.59	-0.28	-0.90	-1.71	0.31	-2.91
roots A:09GRE	-0.82	-0.90	-1.34	-1.00	-0.56	-0.27	-0.88	-1.59	0.32	-2.83
roots A:10LEIR	0.16	0.03	-0.37	-0.07	0.41	0.67	0.05	-0.67	1.25	-1.90
roots B:01ONA	0.00	-0.12	-0.56	-0.23	0.27	0.54	-0.10	-0.85	1.16	-2.08
roots B:02NIEV	1.00	0.00	-0.41	-0.10	0.37	0.63	0.02	-0.70	1.21	-1.85
roots B:03ESPA	1.00	1.00	0.00	0.30	0.82	1.07	0.43	-0.33	1.68	-1.49
roots B:04ALMI	1.00	1.00	1.00	0.00	0.48	0.74	0.12	-0.60	1.32	-1.74
roots B:05SEGU	1.00	1.00	1.00	1.00	0.00	0.29	-0.35	-1.10	0.89	-2.34
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-0.61	-1.33	0.58	-2.56
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.72	1.19	-1.87
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.90	-1.06
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-3.21
roots B:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	0.00
trunk:01ONA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	trunk 01ONA	**trunk 02NIEV**	**trunk 03ESPA**	**trunk 04ALMI**	**trunk 05SEGU**	**trunk 06ALMO**	**trunk 07NOINT**	**trunk 08BUSO**	**trunk 09GRE**	**trunk 10LEIR**
roots A:01ONA	9.94	8.02	10.20	7.50	6.89	8.67	5.08	11.14	6.22	8.81
roots A:02NIEV	10.80	9.67	11.46	8.75	8.22	10.02	6.31	12.49	7.30	10.10
roots A:03ESPA	9.19	7.76	10.37	7.24	6.62	8.38	4.84	10.84	6.01	8.54
roots A:04ALMI	8.41	7.14	9.16	6.89	6.00	7.63	4.39	9.91	5.58	7.83

Table 15 (cont). Pairwise p-value for P3**.**

	trunk 01ONA	**trunk 02NIEV**	**trunk 03ESPA**	**trunk 04ALMI**	**trunk 05SEGU**	**trunk 06ALMO**	**trunk 07NOINT**	**trunk 08BUSO**	**trunk 09GRE**	**trunk 10LEIR**
roots A:06ALMO	9.31	7.87	10.04	7.36	6.74	8.93	4.95	10.97	6.10	8.65
roots A:07NOINT	10.14	8.62	10.84	8.10	7.53	9.34	5.83	11.84	6.72	9.45
roots A:08BUSO	9.39	7.95	10.12	7.43	6.82	8.59	5.02	11.65	6.16	8.73
roots A:09GRE	9.20	7.80	9.93	7.30	6.69	8.40	4.94	10.79	6.26	8.56
roots A:10LEIR	9.81	8.44	10.52	7.93	7.36	9.06	5.58	11.41	6.66	9.58
roots B:01ONA	10.67	8.64	10.86	8.12	7.55	9.36	5.66	11.86	6.74	9.47
roots B:02NIEV	9.79	8.70	10.48	7.90	7.32	9.01	5.57	11.37	6.63	9.15
roots B:03ESPA	10.46	8.95	11.66	8.44	7.89	9.67	6.00	12.09	7.04	9.77
roots B:04ALMI	9.89	8.50	10.59	8.29	7.42	9.13	5.64	11.45	6.71	9.26
roots B:05SEGU	9.92	8.42	10.63	7.91	7.65	9.12	5.46	11.61	6.56	9.24
roots B:06ALMO	9.45	8.03	10.16	7.52	6.93	9.04	5.16	11.06	6.28	8.80
roots B:07NOINT	9.76	8.37	10.45	7.89	7.30	8.99	5.64	11.33	6.63	9.12
roots B:08BUSO	10.16	8.81	10.85	8.33	7.76	9.43	6.01	12.13	7.04	9.56
roots B:09GRE	9.11	7.70	9.86	7.18	6.55	8.31	4.78	10.77	6.11	8.47
roots B:10LEIR	11.85	10.21	12.47	9.70	9.22	11.06	7.17	13.53	8.09	11.62
trunk:01ONA	0.00	-0.47	1.08	-0.95	-2.00	-0.74	-2.65	1.19	-0.83	-0.21
trunk:02NIEV	1.00	0.00	1.44	-0.45	-1.38	-0.21	-2.07	1.56	-0.41	0.26
trunk:03ESPA	1.00	1.00	0.00	-1.91	-2.97	-1.80	-3.51	0.03	-1.66	-1.25
trunk:04ALMI	1.00	1.00	1.00	0.00	-0.91	0.27	-1.64	2.05	-0.02	0.73
trunk:05SEGU	1.00	1.00	1.00	1.00	0.00	1.28	-0.86	3.19	0.76	1.72
trunk:06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-2.02	1.95	-0.26	0.50
trunk:07NOINT	1.00	1.00	0.28	1.00	1.00	1.00	0.00	3.71	1.42	2.40
trunk:08BUSO	1.00	1.00	1.00	1.00	0.79	1.00	0.14	0.00	-1.75	-1.35
trunk:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.65
trunk:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00

- LSD test results for P4 (Variable = Interaction provenance and part)

Pairwise LSD

Table 16. Pairwise p-value for P4**.**

	roots.A 01ONA	roots.A 02NIEV	roots.A 03ESPA	roots.A 04ALMI	roots.A 05SEGU	roots.A 06ALMO	roots.A 07NOINT	roots.A 08BUSO	roots.A 09GRE	roots.A 10LEIR
roots A:01ONA	0.00	-0.75	-0.18	0.83	-0.05	-0.11	-0.77	-0.25	-0.64	-0.66
roots A:02NIEV	1.00	0.00	0.59	1.54	0.68	0.66	0.03	0.53	0.13	0.09
roots A:03ESPA	1.00	1.00	0.00	1.03	0.13	0.07	-0.60	-0.07	-0.48	-0.50
roots A:04ALMI	1.00	1.00	1.00	0.00	-0.86	-0.96	-1.59	-1.09	-1.45	-1.45
roots A:05SEGU	1.00	1.00	1.00	1.00	0.00	-0.06	-0.69	-0.19	-0.57	-0.60
roots A:06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-0.67	-0.14	-0.55	-0.57
roots A:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.53	0.11	0.07
roots A:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.41	-0.44
roots A:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.04
roots A:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
roots B:01ONA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:02NIEV	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:03ESPA	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:04ALMI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:05SEGU	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
roots B:10LEIR	1.00	1.00	1.00	0.39	1.00	1.00	1.00	1.00	1.00	1.00
trunk:01ONA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.68	0.11	0.36	1.00	0.71	0.43	0.02	0.30	0.12	0.14
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.48	0.09	0.27	1.00	0.50	0.32	0.06	0.23	0.03	0.11
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 16 (cont). Pairwise p-value for P4**.**

	roots.B 01ONA	roots.B 02NIEV	roots.B 03ESPA	roots.B 04ALMI	roots.B 05SEGU	roots.B 06ALMO	roots.B 07NOINT	roots.B 08BUSO	roots.B 09GRE	roots.B 10LEIR
roots A:01ONA	-1.03	-0.70	-1.01	0.05	-0.23	-0.76	-1.11	-0.20	-1.05	-2.65
roots A:02NIEV	-0.09	0.06	-0.23	0.78	0.55	0.02	-0.32	0.54	-0.27	-1.82
roots A:03ESPA	-0.72	-0.54	-1.00	0.22	-0.05	-0.60	-0.95	-0.03	-0.90	-2.54
roots A:04ALMI	-1.71	-1.48	-1.82	-0.88	-1.07	-1.57	-1.90	-1.00	-1.85	-3.41
roots A:05SEGU	-0.81	-0.63	-0.94	0.09	-0.19	-0.69	-1.03	-0.14	-0.97	-2.53
roots A:06ALMO	-0.80	-0.61	-0.93	0.15	-0.12	-0.78	-1.02	-0.10	-0.97	-2.61
roots A:07NOINT	-0.12	0.03	-0.27	0.79	0.55	-0.01	-0.42	0.54	-0.31	-1.95
roots A:08BUSO	-0.66	-0.47	-0.79	0.29	0.02	-0.53	-0.89	0.04	-0.83	-2.47
roots A:09GRE	-0.23	-0.07	-0.37	0.67	0.43	-0.12	-0.46	0.43	-0.47	-2.01
roots A:10LEIR	-0.18	-0.03	-0.32	0.69	0.46	-0.07	-0.41	0.45	-0.36	-2.18
roots B:01ONA	0.00	0.15	-0.15	0.91	0.68	0.11	-0.25	0.66	-0.19	-1.83
roots B:02NIEV	1.00	0.00	-0.29	0.72	0.49	-0.04	-0.38	0.49	-0.32	-1.88
roots B:03ESPA	1.00	1.00	0.00	1.03	0.81	0.26	-0.09	0.79	-0.04	-1.64
roots B:04ALMI	1.00	1.00	1.00	0.00	-0.27	-0.78	-1.12	-0.24	-1.07	-2.63
roots B:05SEGU	1.00	1.00	1.00	1.00	0.00	-0.55	-0.91	0.02	-0.85	-2.49
roots B:06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-0.35	0.54	-0.29	-1.90
roots B:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.88	0.05	-1.55
roots B:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-0.82	-2.39
roots B:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-1.61
roots B:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
trunk:01ONA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:02NIEV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:03ESPA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:04ALMI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:05SEGU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:06ALMO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:07NOINT	0.05	0.12	0.04	0.93	0.32	0.08	0.01	0.49	0.04	0.00
trunk:08BUSO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
trunk:09GRE	0.04	0.10	0.04	0.64	0.24	0.07	0.03	0.34	0.01	0.00
trunk:10LEIR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

	trunk 01ONA	trunk 02NIEV	trunk 03ESPA	trunk 04ALMI	trunk 05SEGU	trunk 06ALMO	trunk 07NOINT	trunk 08BUSO	trunk 09GRE	trunk 10LEIR
roots A:01ONA	7.98	5.44	6.90	6.19	6.11	6.97	3.24	5.76	3.35	8.41
roots A:02NIEV	7.48	6.59	7.41	6.69	6.63	7.50	3.79	6.30	3.83	8.89
roots A:03ESPA	7.29	5.67	8.11	6.46	6.39	7.30	3.44	6.05	3.52	8.75
roots A:04ALMI	6.01	4.67	5.99	5.91	5.21	6.01	2.51	4.88	2.69	7.47
roots A:05SEGU	6.84	5.39	6.80	6.11	6.73	6.86	3.23	5.69	3.33	8.29

Table 16 (cont). Pairwise p-value for P4**.**

	trunk 01ONA	**trunk 02NIEV**	**trunk 03ESPA**	**trunk 04ALMI**	**trunk 05SEGU**	**trunk 06ALMO**	**trunk 07NOINT**	**trunk 08BUSO**	**trunk 09GRE**	**trunk 10LEIR**
roots A:06ALMO	7.22	5.61	7.14	6.40	6.33	8.24	3.38	5.98	3.47	8.69
roots A:07NOINT	7.84	6.13	7.73	6.95	6.92	7.85	4.26	6.57	3.94	9.28
roots A:08BUSO	7.35	5.72	7.26	6.51	6.45	7.36	3.49	6.87	3.57	8.81
roots A:09GRE	7.57	5.94	7.48	6.74	6.69	7.57	3.76	6.34	4.12	9.00
roots A:10LEIR	7.42	5.88	7.35	6.64	6.58	7.44	3.72	6.25	3.78	9.87
roots B:01ONA	9.05	6.22	7.84	7.06	7.02	7.96	3.99	6.68	4.02	9.38
roots B:02NIEV	7.44	6.40	7.36	6.66	6.59	7.44	3.75	6.25	3.80	8.85
roots B:03ESPA	7.92	6.25	8.85	7.07	7.03	7.93	4.05	6.69	4.08	9.34
roots B:04ALMI	6.74	5.31	6.70	6.65	5.92	6.75	3.14	5.60	3.26	8.18
roots B:05SEGU	7.33	5.70	7.24	6.50	7.24	7.34	3.47	6.09	3.55	8.79
roots B:06ALMO	7.69	6.04	7.60	6.85	6.80	8.67	3.85	6.46	3.90	9.12
roots B:07NOINT	8.01	6.32	7.90	7.14	7.11	8.02	4.45	6.77	4.15	9.42
roots B:08BUSO	6.99	5.51	6.93	6.25	6.15	7.00	3.34	6.51	3.45	8.42
roots B:09GRE	7.96	6.29	7.86	7.09	7.06	7.97	4.08	6.72	4.34	9.38
roots B:10LEIR	9.47	7.56	9.31	8.47	8.51	9.48	5.37	8.17	5.27	12.24
trunk:01ONA	0.00	-0.44	0.21	-0.13	-0.55	0.00	-2.57	-0.87	-1.94	1.66
trunk:02NIEV	1.00	0.00	0.60	0.30	-0.05	0.44	-1.90	-0.33	-1.39	1.87
trunk:03ESPA	1.00	1.00	0.00	-0.31	-0.73	-0.20	-2.68	-1.04	-2.06	1.41
trunk:04ALMI	1.00	1.00	1.00	0.00	-0.38	0.13	-2.30	-0.68	-1.74	1.65
trunk:05SEGU	1.00	1.00	1.00	1.00	0.00	0.55	-2.03	-0.31	-1.46	2.14
trunk:06ALMO	1.00	1.00	1.00	1.00	1.00	0.00	-2.58	-0.87	-1.94	1.66
trunk:07NOINT	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.74	0.37	3.95
trunk:08BUSO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	-1.20	2.44
trunk:09GRE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	3.21
trunk:10LEIR	1.00	1.00	1.00	1.00	1.00	1.00	0.06	1.00	0.74	0.00

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Fig 23. Pairwise p-value for total cross section area

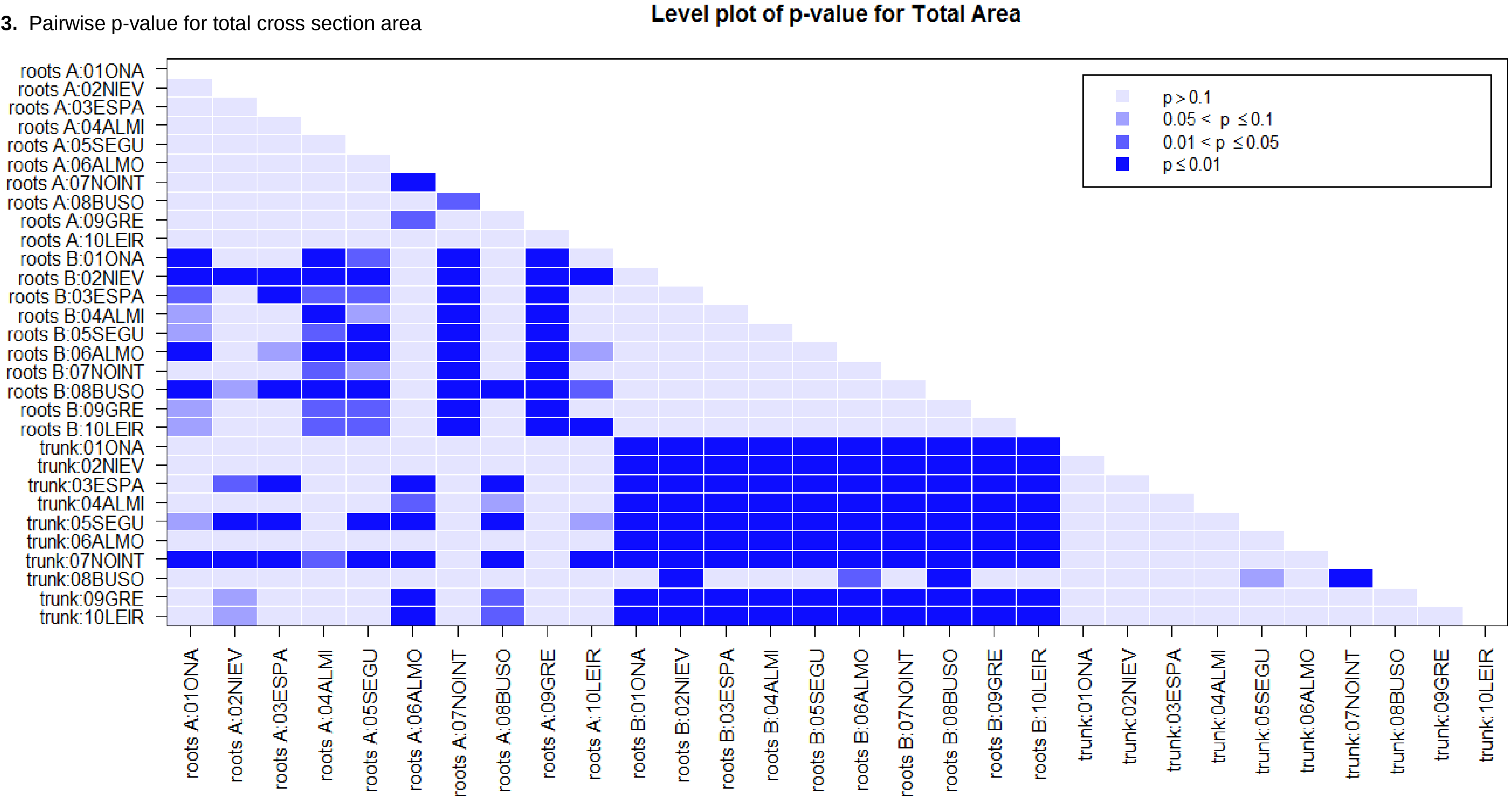

Fig 24. Pairwise p-value for P1

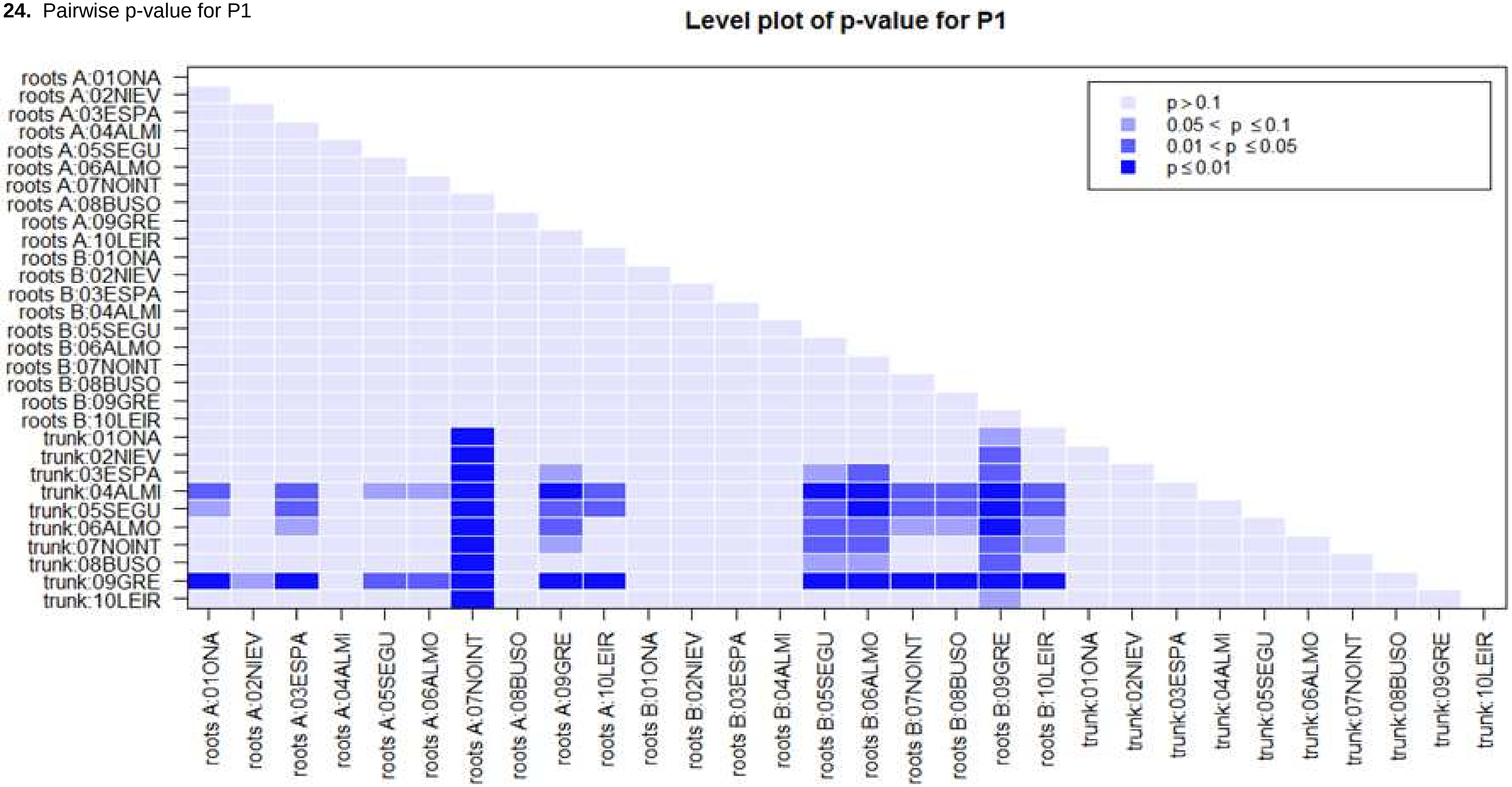

Fig 25. Pairwise p-value for P3

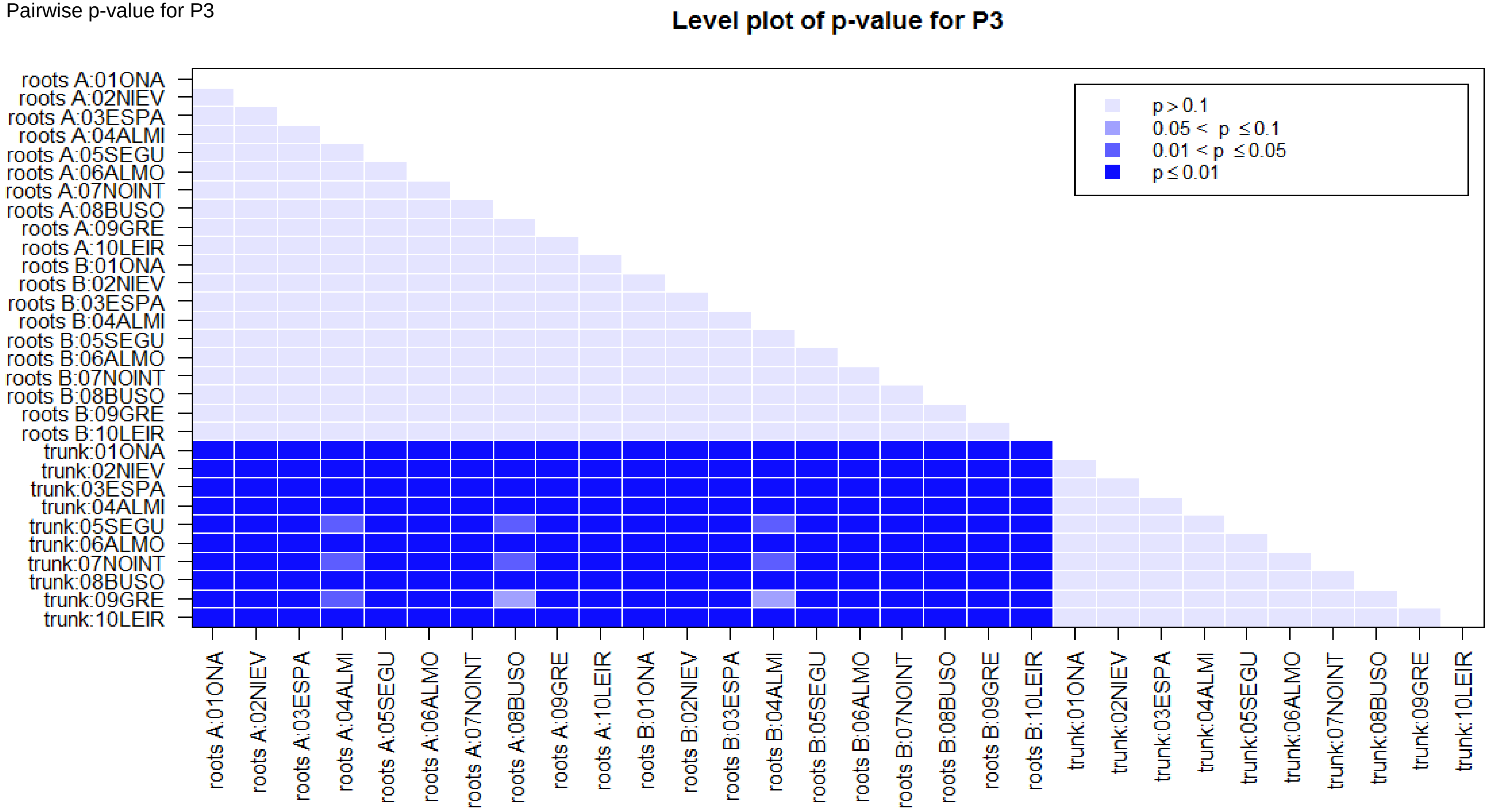

Fig 26. Pairwise p-value for P4