Variation of some wood macroscopic properties along the stem of *Acacia melanoxylon* R. Br. adult trees in Portugal

A. Santos[1,2], R. Simoes[1]* and M. Tavares[2]

[1] *Universidade da Beira Interior. 6201-001 Covilhã, Portugal*
[2] *Instituto Nacional de Investigação Agrária e Veterinária, IP. 2780-159 Oeiras, Portugal*

Abstract

Aim of the study: The aim of the study is to assess the variation of pith eccentricity, heartwood proportion, latewood percentage and basic wood density along the stem of 45-year-old *A. melanoxylon* trees collected in four sites of Portugal, and investigate the eventual relationship between these variables.

Area of study: Sites covering littoral north, mid interior north and centre interior of Portugal.

Materials and methods: Four sites and five trees per site were selected in the *Acacia melanoxylon* Portuguese forest. One wood sample at each of six height levels per tree was collected in order to evaluate its basic density, pith eccentricity, heartwood and latewood proportions.

Main results: The high variability of the wood macroscopic properties among trees from the same site regarding to the variation of the corresponding average properties along the stem is a key characteristic of the experimental data. As a consequence, a multiple linear regression model tested was not able to properly explain the wood basic density variation of the 120 wood samples analysed. In spite of this, the following trends could be recognized: (i) excluding the base level, wood basic density moderately increased with tree level; (ii) latewood proportion followed similar behaviour; (iii) pith eccentricity was low; (iv) heartwood proportion decreased markedly with tree height, from 70% at the base to 7% at the top.

Research highlights: The high basic density, the relatively low variability along the stem and the low pith eccentricity enable us to anticipate good performance as raw material for the wood industry.

Key words: *Acacia melanoxylon;* basic density; earlywood; latewood; heartwood; sapwood; pith eccentricity.

Introduction

Acacia is a woody genus with more than 1000 species occurring naturally in arid areas of Australia, Asia, Africa, and tropical America (Playford *et al*., 1991). During the eighteen and nineteen centuries some native acacia from Australia were introduced in several countries, *e.g. Acacia mangium* Willd was planted in Brazil in order to profit by its fast growth rate and rectilinear stem. Nowadays, several acacia species are exploited worldwide for firewood, pulpwood, tannins and other colouring extractives, carpentry, forage, as well as ornamental trees and sloping banks (Playford *et al*., 1991).

Acacia melanoxylon R. Br. is distributed in Australia along the east coast, from southern Tasmania to Atherton in Queensland, and is a prized native tree for furniture.

This acacia, also named Blackwood, has been extensively utilized in South Africa for fuel, shelter belts, fence droppers, building structures and mine props, and high quality Blackwood stems are highly rated for quality sawn products (Playford *et al*., 1991).

In the beginning of the twentieth century various acacia species were introduced in Portugal in order to colonize dry and poor sandy soils along the coast. The country has revealed good ecological conditions for the development of some of them, particularly *A. melanoxylon* and *A. dealbata* and, nowadays, there are several spontaneous stands dispersed by natural dissemination in all the territory. So far, because the control of these alien invader species using chemical and mechanical methods has not been done with satisfactory results (Tavares *et al.,* 1999), nowadays *Acacia melanoxylon* is one of the most disseminated wattle species in north and west of Portugal. Here the national forest inventory count about 4,000 hectares of different acacia species and more 6,300 hectares in Azores and

Madeira (Anonymous, 2010). The timbers seem to be rather interesting for sawmilling and its high pulp and papermaking potential was recently reported (Santos *et al.,* 2006; Anjos *et al.,* 2011).

Despite its potential for wood production, little information can be found in literature on Blackwood properties and respective variability (Igartúa and Monteoliva, 2009; Igartúa *et al.*, 2009; Lourenço *et al.*, 2008; Knapic *et al.*, 2006; Searle and Owen, 2005). In particular, very few data have been found on tree quality of European stands, as well as on their wood density (Knapic *et al.*, 2006), which is an important property for its industrial utilization. Wood density is a complex physical property, related to the anatomical structure, including cell wall thickness, vessel number and characteristics, and the wood chemical composition, including extractives contents, that responds to genetic, environmental and physiological influences (Silva *et al.*, 2009). Tree age has also a marked effect on wood density (Trugilho *et al.,* 1996). The basic density of the wood influences many of the end-use properties of the solid wood as well as those of the corresponding fiber products, such as pulp yield and paper quality (Balodis, 1980; Wimmer *et al.*, 2002). Basic density is therefore a key parameter in any selecting and/or tree breeding program, requiring extensive screening.

The relative proportion of both latewood/earlywood and heartwood/sapwood, the type and proportion of the several anatomical elements and their corresponding cell-wall thickness, and the chemical composition determine the wood basic density. In addition, pith eccentricity, which is related to the occurrence of reaction wood, was assumed to be an explicative variable for the basic density variation (Panshin and DeZeeuw, 1980).

Regarding basic density of hardwood species, no standard of axial density variation was defined so far, contrasting with the softwoods, where a decreasing of the density values is performed with tree level (Downes *et al.*, 1997). Concerning hardwoods, the basic density stem profile depends on the species. In the case of *Eucalyptus* sp., the interaction between radial and axial variations allows density either to remain constant or to increase with tree height (Hillis and Brown, 1984; Downes *et al.*, 1997). The upper part of the stem will be under the influence of the crown, and the base will be under the influence of the root system. Then, the less impacted positions are in the medium part of the stem, *i.e.* between 25% and 50% of total tree height

(Goulart *et al.*, 2003). According to these authors, the basic density of *Eucalyptus grandis* decreases from base to breast height, then increases slightly up to 75%, and after that follows a decreasing tendency up to the apex. Similar trends were reported by other authors (Raymond and Muneri, 2001; Quilhó and Pereira, 2001). Working with several *Eucalyptus* species, Clark (2001) observed different longitudinal density profiles. Even so, the predominant trend was for a reduction in density from the base of the stem to 10% of the total tree height, followed by a progressive increase in density thereafter (Clark, 2001). For young 6-years-old trees of two *Acacia* species planted in Australia, the same author reported a reduction in density with tree height. Depending on *Acacia* species, Searle and Owen (2005) also reported small positive and negative linear regression coefficients.

The present paper aims to report on the variation of pith eccentricity, heartwood proportion, latewood percentage and basic wood density along the stem of 45-year-old *A. melanoxylon* trees collected in four sites of Portugal. An attempt was also made to correlate wood density with the other macroscopic properties and height level on the tree.

Materials and methods

Wood samples

In the scope of a research project involving several Portuguese institutions, wood samples of *Acacia melanoxylon* trees of unknown seed origin were collected from four different sites in Portugal – the *Camarido National Forest* (MNC), at the mouth of Minho River, in the very littoral north close to Caminha, the *Forest Perimeter of Ovar Dunes* (PFDOVM), in the littoral north close to Ovar, the *Forest Perimeter of Rebordões de Santa Maria* (PFRSM), in the north mid interior close to Ponte de Lima, and the *Forest Perimeter of Crasto Mountain* (PFC), in the centre interior close to Viseu. Additional information about sites location, forestry and ecology are presented in Table 1. These sites are state-owned or community acacia uneven aged stands mixed with *Pinus pinaster* Aiton and conducted in high forestry for wood production. Selective harvesting was done for a sawtimber diameter at breast height (*dbh*) above 40 cm over-bark, and a revolution age of about 50 years in the case of acacia and somewhat more for pine.

Table 1. Ecological and forestry features of four tree samples sites

	Camarido National Forest, MNC	Ovar Dunes Forest Perimenter, Drain of Maceda, PFDOVM	Rebordões/Santa Maria Forest Perimeter, PFRSM	Crasto Mountain Forest Perimeter PFC
Latitude (North)	41° 53' N	40° 57' N	41° 43' N	40° 41' N
Longitude (West)	8° 43' W	8° 34' W	8° 34' W	7° 56' W
Altitude (m)	8	7	154	548
Sun exposition	Flat	Flat	North	South
Soil origin	Sand	Sand	Granite	Granite
Rainfall (mm/year)*	1,427	1,152	1,720	1,229
Mean T (°C)*	14.3	13.9	14.0	13.0
Mean T maximum (°C)*	19.4	19.3	19.5	19.0
Mean T minimum (°C)*	9.2	8.5	8.5	7.0
Forest regime mean age (years)	High stand 44	High stand 46	High stand 45	High stand 46
Mean DBH (cm)	39.6	39.2	41.1	41.0
Mean total height (m)	30.4	33.0	28.7	28.6
Mean timber height (m)	24.0	29.7	23.1	24.1

* Climatic normal 1951/80.

Five randomized selected trees were collected per site. After felling, the total and timber (excluding bole with diameter lower than 7.5 cm) tree heights were recorded, as well as the basal cutting levels. For each tree, a pair of sample discs was taken from six different height levels along the stem, at base cutting level, 5, 15, 35 and 65% of total tree height and at the top (bole with diameter lower than 7.5 cm), following the procedure of Sardinha (1974). One disc of each pair was used to collect wood biometric data and the other was utilized for basic wood density evaluation. Samples at breast height were also collected for pith eccentricity evaluation.

Wood biometric data

After disc surface polishing, the following biometric data were evaluated in each disc: pith eccentricity, heartwood/sapwood content, and earlywood/latewood content.

Pith eccentricity N-S and E-W absolute values were determined as the difference between the mean radius and the real distance from pith to the disc edge. The mean radius is one half of the arithmetic mean of the cross-diameters north/south (N-S) and east-west (E-W). The relative pith eccentricity value was then calculated as the ratio between the absolute values and the mean diameter.

The visible heartwood (hw) area was estimated directly on each disc by manual measurements, considering the mean radius of its four expositions. The

sapwood (sw) area was calculated as the difference between each disc's area and the heartwood area. The relative values were also calculated as $hw/(hw + sw)$.

Total amounts and corresponding relative values of earlywood and latewood were assessed by image analysis, based on grey level differentiation, using *Wood Ring Analysis*® software (CISUC/LPC, 2001). Absolute partial values were reached by area estimations referred to as direct radius evaluations of successive early and latewood layers. Each total was calculated as the sum of those partials.

Wood basic density

Each 5 cm thick disc was processed into 3-5 mm thick chips, which were carefully homogenized, and 100-250 g aliquots were used to determine wood basic density (mass of the oven-dry wood per volume unit of green wood) employing a displacement method according to TAPPI T 258 om-94 standard (Tappi, 1995).

Data analysis

The normality of the wood basic density distribution was tested by *Kolmogorov-Smirnov* test. For each factor the homogeneity of variances was determined using the *Levene* test. Analysis of variance and mean difference tests according to *Duncan and Schefée* were employed to assess significant differences for different

variability sources. The data analysis was performed using the *Statistica*® software (Statsoft Inc., 2003).

Results and discussion

The mean values of relative pith eccentricity (Fig. 1) are very low (less than 1%), which reveals a regular growth of the trees and the structural homogeneity of the wood. Moreover, the values are mostly of the same range in both the geographic directions considered. The considerable variability among the five trees of each site makes hard to identify a clear tendency along the tree, but some reduction of eccentricity is generally found from the base of the tree to the 65% height level, with a slightly regain close to the top, particularly in the PFRSM site. As expected, the statistical analysis of the data (*Schefée*, $\alpha = 0.05$) showed no significant differences among sites or tree levels considering N-S or E-W relative eccentricities.

As far as we know, so far no pith eccentricity data have been available for acacia species. Akachuku and Abolarin (1989) reported values in the 7.1-21.2 %

range, based on disc's mean radius, for teak growing in south-western Nigeria. Saint-André and Leban (2001), studying the asymmetry of spruce stems from north-eastern part of France, reported mean values close to 5%, based on mean diameter.

The very low pith eccentricity of our samples is consistent with both the good tree form and straightness of the stem, in spite of the usual oceanic Atlantic winds. The fact that the selected trees were dominant and co-dominant in the stand and mixed with pine certainly has an important contribution to the observed behaviour. Moreover, as stem asymmetry is usually associated with reaction wood, the data for *A. melanoxylon* suggest that the stem should have low percentage of reaction wood.

Table 2 presents the values of heartwood proportions along the stem. On average, until the level of 35% of the total height, more than a half of the stem volume corresponds to heartwood. Values of 38-45% at 65% height level and of 2-15% at the tree top were reached. The statistical analysis of the experimental data enabled to identify three level groups: from base until 35% of height; 65% of height; and top. Regarding the sites,
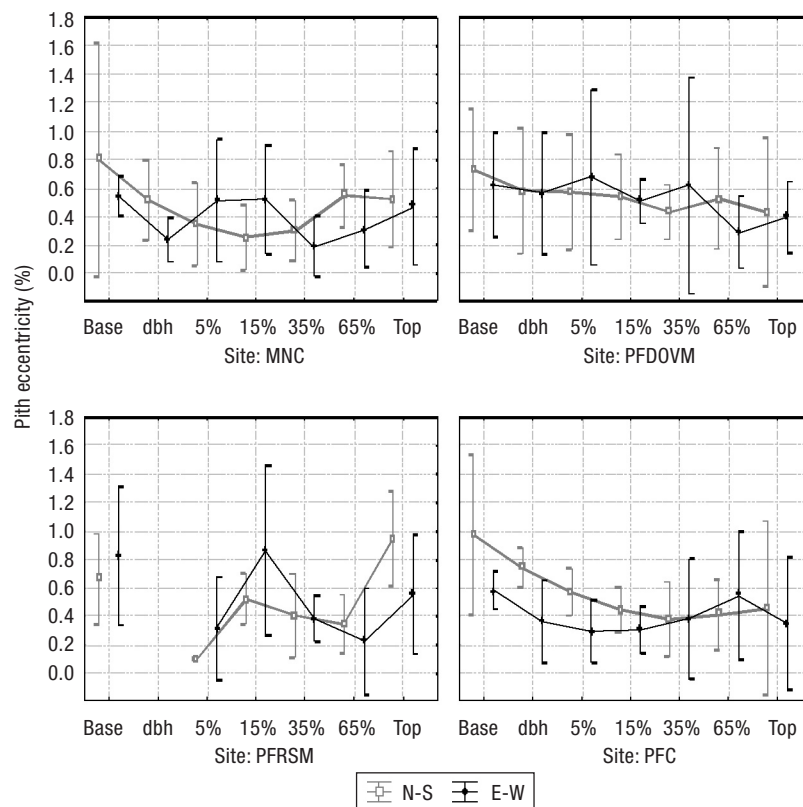

Figure 1. Pith relative eccentricity and respective standard deviation (five trees) by site and tree level.

Table 2. Heartwood (*hw*) mean relative proportions and coefficient of variation (five trees) by site and tree level (% of total height)

Site	MNC		PFDOVM		PFRSM		PFC	
Tree level	*hw/(hw + sw)*	C_v	*hw/(hw + sw)*	C_v	*hw/(hw + sw)*	C_v	*hw/(hw + sw)*	C_v
Top	0.12	0.93	—	—	0.15	0.78	0.02	1.45
65%	0.42	0.22	0.45	0.33	0.38	0.30	0.39	0.47
35%	0.61	0.08	0.63	0.13	0.61	0.10	0.63	0.19
15%	0.66	0.09	0.66	0.14	0.68	0.09	0.68	0.13
5%	0.71	0.06	0.70	0.10	0.71	0.12	0.70	0.16
Base	0.72	0.11	0.69	0.18	0.75	0.10	0.66	0.20

n = 115; sw = sapwood; C_v = coefficient of variation.

at a given tree level there are no significant differences among the four considered sites (*Schefée*, α = 0.05), which suggests that soil and climatic conditions have no significant influence on heartwood content for the tree age examined and that the genetic variability of the trees introduced in Portugal is probably low. Trees diameter growth rate, which has been considered as affecting the heartwood content, seem to be similar in the different sites, as the values of DBH suggest (Table 1).

As expected for old trees (around 45-year-old), the heartwood percentage is very high (38% to 75%) until the 65% height level in the tree, which includes the major stem merchantable part. The results reported in the present work were estimated from manual measurements, and they are in accordance with those obtained by image analysis for corresponding samples of the same trees (Knapic *et al.*, 2006). The heartwood percentages observed for these trees contrast, as expected, with the 2.4% reported for 8-year-old *A. melanoxylon* trees (Searle and Owen, 2005). Both the very low pith eccentricity and this high heartwood percentage are good indicators of the potential of these old trees for solid wood uses, as was confirmed by mechanical tests on the same wood samples (Santos *et al.*, 2007).

The diameter annual growth rhythm of *Acacia melanoxylon* reflects nearly all the changes of ecological conditions. So, in the annual rings, there is a lot of earlywood (*ew*) and latewood (*lw*) types all over the sample. The suspicion of a relationship between wood basic density and the relative latewood amount led to the assessment of their relative proportion for each level. Table 3 presents the experimental data obtained and shows that, excluding tree basal data, the generalized trend for all sites is a small increase of latewood proportion with tree height. In addition, and in absolute terms, there are significant differences between the group of PFDOVM and PFC sites, which is statistically indistinguishable (*Duncan*, α = 0.05), and the other two sites (PFRSM and MNC). Climatic conditions, may, hypothetically, be related with these experimental observations. In both groups, latewood content at the top is higher than the values of the lower levels.

In short, the latewood content is in the range of 36%-46% and, after a slight decrease from the base to the 5% level, increases moderately with tree level, in agreement with the corresponding profile of the wood basic density discussed below. The variation of late-

Table 3. Latewood (*lw*) mean relative proportions and coefficient of variation (five trees) by site and tree level (% of total height)

Site	MNC		PFDOVM		PFRSM		PFC	
Tree level	*lw/(lw + ew)*	C_v	*lw/(lw + ew)*	C_v	*lw/(lw + ew)*	C_v	*lw/(lw + ew)*	C_v
Top	0.46	0,10	0.41	0,08	0.42	0,11	0.42	0,08
65%	0.41	0,03	0.37	0,05	0.41	0,03	0.40	0,05
35%	0.41	0,07	0.38	0,10	0.41	0,02	0.39	0,08
15%	0.40	0,02	0.37	0,07	0.40	0,03	0.37	0,08
5%	0.39	0,06	0.37	0,07	0.39	0,04	0.36	0,07
Base	0.40	0,03	0.38	0,09	0.40	0,06	0.38	0,04

n = 120; ew = earlywood; C_v = coefficient of variation.
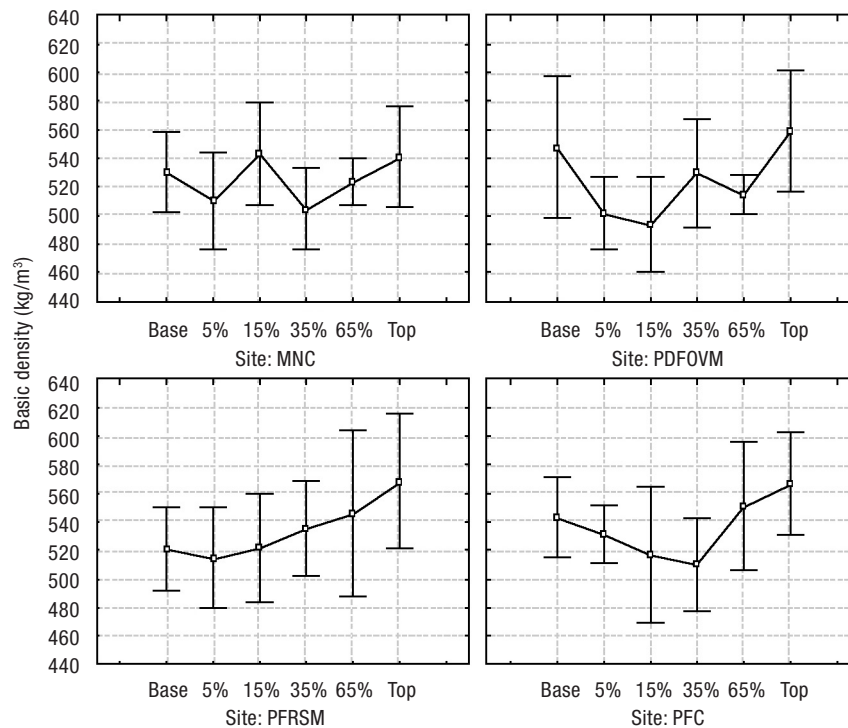
Figure 2. Basic density and respective standard deviation (five trees) by site and tree level for the four sites.

wood content along the stem is not clearly established in literature. For instance, Adamopoulos *et al.* (2009) have reported a decrease in latewood proportion and dry density with the stem height for softwood.

The results obtained for wood basic density are presented in Fig. 2. They vary between 432 and 658 kg/m³, and the tendency is to exhibit higher values near the top than near the base. The standard deviations (for the five trees at each level) are high but rather constant along the stem. Considering site and tree level as variation sources of basic density, variance analysis have shown that only the second one is significantly responsible for the expression of density values, at 5.1% of total variation. However, this value increased to 7%, when the basal data were excluded. There were no significant differences among the four sites. Therefore, Fig. 3 shows the mean values of density along the stem for all trees (20) and illustrates the decrease of wood basic density from base to 5% of height, as well as an increase until the top. In accordance with the data in Fig. 3, the *Duncan* test has confirmed that top and base (and also 65% of total height) belong to the same group, and sites are indistinguishable.

Wood basic density exhibits high variability range of 432 kg/m³ to 658 kg/m³. Searle and Owen (2005)

showed weighted mean basic density of whole-tree volume of 576 for 8-year-old *A. melanoxylon* grown near Canberra. However, markedly higher values were reported by the same authors for other acacia species grown in the same place.

In agreement with other works on hardwoods (Clark, 2001; Goulart *et al.*, 2003), we report a decrease of basic density from the base to around the breast height,
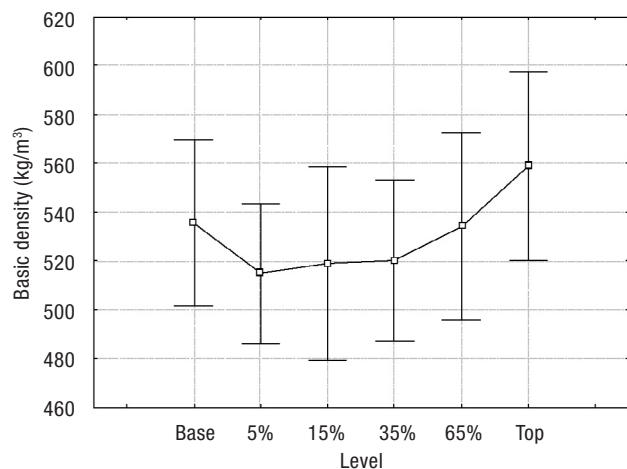

Figure 3. Mean basic density and respective standard deviation by level for all four sites.

Table 4. Mean and coefficient of variation of studied variables

	Base		5%		15%		35%		65%		Top	
	$\overline{X}$	C_v	$\overline{X}$	C_v	$\overline{X}$	C_v	$\overline{X}$	C_v	$\overline{X}$	C_v	$\overline{X}$	C_v
Basic density (kg/m³)	535	0.07	515	0.06	519	0.08	520	0.07	534	0.08	559	0.07
Latewood/Annual ring wood thickness	0.39	0.06	0.38	0.07	0.38	0.06	0.40	0.08	0.40	0.05	0.43	0.10
Eccentricity N-S (cm)	0.79	0.71	0.45	0.71	0.44	0.56	0.38	0.63	0.46	0.57	0.59	0.85
Eccentricity E-W (cm)	0.64	0.51	0.47	0.96	0.55	0.75	0.39	1.18	0.35	1.04	0.44	0.88
Heartwood/Cross section surface	0.70	0.15	0.71	0.10	0.67	0.11	0.62	0.12	0.41	0.32	0.07	1.39

n = 120; $\overline{X}$ = mean; C_v = coefficient of variation.

and then an increase up to the top. For *Acacia* species, including *A. melanoxylon*, but for much younger trees, Clark (2001) indicated a continuous reduction in basic density with height in the tree. Igartúa and Monteoliva (2009) have reported similar trends for 26-32 year-old Blackwood trees. Wimmer *et al*. (2008), working with 8-year-old *Eucalyptus globulus* Labill clones grown in Tasmania, also reported a general trend towards an increase of wood density with height.

Relationships between wood basic density and some wood macroscopic biometric data, such as latewood percentage, pith eccentricities N-S and E-W, and heartwood proportion were also explored for the 120 samples obtained from the 4 sites, the 5 trees per site and the six levels in the trees. The high variability of the wood properties between trees led that a multiple linear regression model explains at most close to 15% of the basic density variation, which prevents their use as predictive model.

As no significant differences between sites were observed, Table 4 resumes the average and coefficient of variation (standard deviation/average) of the wood variables studied for the 120 samples, organized as a function of height level in the tree. The variations of the average values of wood properties along the stem are relatively low and of the same order of magnitude of the corresponding standard deviation.

Conclusions

The general trend of the 45-year-old *Acacia melanoxylon* wood basic density of the trees grown in Portugal showed a decrease from base (mean value 535 kg/m³) to 5-15% tree level (mean values 515-519 kg/m³), and a subsequent moderate increase with the height level in the tree (mean value at top 559 kg/m³). Despite this

clearly identifiable trend, the high variability between trees of the same site and a no significant variability among sites are important features of the researched samples. Latewood proportion and wood density follow a similar trend. However, the correlation between these two macroscopic properties is poor, especially if the base level data are also included. Relative pith eccentricity values are generally very low. The higher values were identified at the top and, particularly, at the base level. Heartwood proportion is high and markedly decreases with tree height level. The very low pith eccentricity and the high heartwood percentage and basic density are good indicators of the potential of these old trees for solid wood uses. A multiple linear regression of wood basic density with tree level, latewood proportion, eccentricities (E-W and N-S) and heartwood proportion only explain a small part of the wood basic density variation, which prevents their use as a predictive model.

Acknowledgements

References

Anjos O, Santos A, Simões R, 2011. Effect of *Acacia melanoxylon*. fibre morphology on papermaking potential. Appita Journal 64(2): 185-191.

Anonymous, 2010. Inventário Florestal Nacional. Portugal Continental. IFN5 2005-2006. Autoridade Florestal Nacional, Lisboa.

Adamopoulos S, Milios E, Doganos D, Bistinas I, 2009. Ring width, latewood proportion and dry density in stems of

Pinus brutia Ten. European Journal Wood Products 67: 471-477.

Akachuku AE, Abolarin ADO, 1989. Variations in pith eccentricity and ring width in teak (*Tectona grandis* L. F.). Trees 3: 111-116.

Balodis V, 1980. Assessment of the pulpwood quality of forest resources. CSIRO Division Chemistry Technology Research Revue. pp: 13-32.

CISUC/LPC – Centro de Informática e Sistemas da Universidade de Coimbra. Laboratório de Percepção Computacional, 2001. Wood Ring Analysis® software.

Clark N, 2001. Longitudinal density variation in irrigated hardwoods. Appita Journal 54(1): 49-53.

Downes G, Hudson I, Raymond C, Dean G, Michell A, Schimleck L *et al.* 1997. Sampling plantation eucalypts for wood and fibre properties. Publishing CSIRO, Edited by Alexa Cloud-Guest. Australia.

Goulart M, Haselein C, Hoppe J, Farias J, Pauleski D, 2003. Massa específica básica e massa seca de madeira de Eucalyptus grandis sob o efeito do espaçamento de plantio e da posição axial no tronco. Ciência Florestal 13: 167-175.

Hillis E, Brown A, 1984. Eucalyptus for wood production. CSIRO Griffin Press, Adelaide, Australia. 434 pp.

Igartúa DV, Monteoliva S, 2009. Densidad básica de la madera de *Acacia melanoxylon* R. Br en relación con la altura de muestreo, el árbol y el sitio. Invest Agrar: Sist Recur For 18(1): 101-110.

Igartúa DV, Monteoliva S, Piter JC, 2009. Estúdio de algunas propriedades físicas de la madera de *Acacia melanoxylon* en Argentina. Maderas, Ciência e Tecnologia 11(1): 3-18.

Knapic S, Tavares F, Pereira H, 2006. Heartwood and sapwood variation in *Acacia melanoxylon* R. Br. trees in Portugal. Forestry 79(4): 371-380.

Lourenço A, Baptista I, Gominho J, Pereira H, 2008. The influence of heartwood on the pulping properties of *Acacia melanoxylon* wood. J Wood Sci 54: 464-469.

Panshin J, De Zeeuw C, 1980. Textbook of wood technology, 4th ed. New York, McGraw Hill. 643 pp.

Playford J, Bell C, Moran GF. 1991. Genetic variation of *Acacia melanoxylon*. In: Advances in tropical acacia research (Turnbull JW, ed). ACIAR proceedings No. 35. Bangkok, Thailand, 11-15 February. pp: 92-93.

Quilhó T, Pereira H, 2001. Within and between tree variation of bark content and wood density of *Eucalyptus globulus*

in commercial plantations. IAWA Journal 22 (3): 255-265.

Raymond CA, Muneri A, 2001. Nondestructive sampling of *Eucalyptus globulus* and *E. nitens* for wood properties. I. Basic density. Wood Sci Tech 35: 27-39.

Saint-André L, Leban J-M, 2001. A model for the position and ring eccentricity in transverse sections of Norway spruce logs. Holz als Roh- und Werkstoff 59: 137-144.

Santos A, Anjos O, Simões R, 2006. Papermaking potential of *Acacia dealbata* and *Acacia melanoxylon*. Appita Journal 59(1): 58-64.

Santos A, Teixeira A, Anjos O, Simões R, Nunes L, Machado J, Tavares M, 2007. Utilização potencial do lenho de *Acacia melanoxylon* a crescer em povoamentos puros ou mistos com *Pinus pinaster* pela indústria florestal portuguesa. Silva Lusitana 15(1): 57-77.

Sardinha R, 1974. Variation in density and some structural features of wood of *Eucalyptus saligna*. Ph D thesis. University of Oxford, Sm Frame, Angola.

Searle SD, Owen JV, 2005 Variation in basic wood density and percentage heartwood in temperate Australian *Acacia* species. Australian Forestry 68(2): 126-136.

Silva JC, Borralho NMG, Araújo JA, Vaillancourt RE, Potts BM, 2009. Genetic parameters for growth, wood density and pulp yield in *Eucalyptus globulus*. Tree Genet Genomes 5: 291-305.

StatSoft, Inc, 2003. STATISTIC®. Data analysis software system. Version 6.1.

TAPPI, 1995. Basic density and moisture content of pulpwood. Test methods: T 258 om-94, Atlanta, USA.

Tavares M, Campos J, Silva C, Caetano F, 1999. Estratégias de invasão das dunas do litoral pelas *Acacia dealbata, A. melanoxylon* e *A. longifolia*. Proc 1º Encontro sobre Invasoras lenhosas, Gerês, Portugal, vol 1, pp: 42-49.

Trugilho P, Lima J, Mendes L, 1996. Influência da idade nas características físico-químicas e anatómicas da madeira de *Eucalyptus saligna*. CERNE 2(1): 94-111.

Wimmer R, Downes GM, Evans R, Rasmussen G, French J, 2002. Direct effects of wood characteristics on pulp and handsheet properties of *Eucalyptus globulus*. Holzforschung 56: 244-252.

Wimmer R, Downes GM, Evans R, French J, 2008. Effects of site on fibre, kraft pulp and handsheet properties of *Eucalyptus globulus*. Annals Forest Science 65: 602.