

1 José Ángel Pulgar Lorenzo

2 Guillermo Riesco Muñoz*

3

4 **INTER-TREE AND INTRA-TREE VARIATION IN THE PHYSICAL PROPERTIES OF WOOD OF**
5 **LAUREL (*Laurus nobilis*)**

6

7 Departamento de Enxeñaría Agroforestal, University of Santiago de Compostela.

8 Escola Politécnica Superior de Enxeñaría. Campus Universitario s/n. 27002 Lugo (Spain).

9

10 guillermo.riesco@usc.es; telephone number: 0034982823233

11 ORCID iD: 0000-0002-9830-7398

12

13 **Abstract**

14 The laurel (*Laurus nobilis* L.) is a common species in southern Europe but the properties of its wood are not well
15 described in the literature and from that perspective any novel information is valuable. Because of that, a group
16 of laurels was felled for analysis of wood properties on small defect-free specimens (17 trees and 1,250 valid
17 specimens). The sampled wood was moderately heavy and unstable. The following mean values were obtained
18 (density at 12% moisture content: 699 kg m⁻³; basic density: 566 kg m⁻³; total volumetric shrinkage: 18.0%;
19 volumetric shrinkage coefficient: 0.59%). Highly significant inter-tree and intra-tree variation was observed for
20 most of the properties considered. The inter-tree variation was attributed to tree dimensions, being remarkable
21 that volumetric, radial and tangential shrinkage coefficients were significantly related to breast height diameter
22 and slenderness. The trends of these variables suggest that in trees older than those used in the study (24-41
23 years old) the dimensional stability would increase. As regards the in-tree variation, a low but highly significant
24 decreasing was found for density at highest positions in the tree. Volumetric and linear shrinkage diminish very
25 significantly along the stem. Due to the uniformity of density and the increment of wood dimensional stability
26 along the trunk, it is advisable the harvesting of the full stem.

27

28 **Keywords**

29 Density, Dimensional stability, Gravimetric property, Laurel, Shrinkage.

30

31 **Acknowledgements**

32 Funding for this research was received from the Regional Government of Galicia through the GRC2014/015,
33 competitive reference research groups, cofounded by ERDF.

34

35 **Compliance with Ethical Standards. Disclosure of potential conflicts of interest**

36 Conflict of Interest: The authors declare that they have no conflict of interest.

37

38

39

40

41

42

43

44

45

46

47

48

49

50

51

52

53

54

55

56

57 **Introduction**

58 The laurel (*Laurus nobilis* L.) is a lauraceous tree species, considered original from the Anatolian peninsula
59 (Turkey). It grows in all the Mediterranean countries and it is common in Spain, whether naturally regenerated or
60 cultivated. It is frequently distributed in Galicia (NW Spain) along wet areas with warm temperature, such as
61 riverbanks, coastal lands and low altitude forests.

62

63 The laurel is an evergreen broadleaf tree, shrubby or arboreal-shaped, that reaches its optimum development in
64 loose and humid soils (Ruiz de la Torre 1979). The laurel woodlands can be considered as arboreal scrublands
65 with forest structure. It grows 8-12 m high (Fig. 1), although it can reach up to 20 m (García Esteban and
66 Guindeo Casasús 1989). The stem is straight, with a very thin bark (around 1 cm thick in the biggest trees). The
67 wood has white sapwood and darker heartwood. It is a homogeneous wood, heavy, strong and quite hard, with
68 checks that tend to appear during drying: some big checks from the pith, occasional micro-splits no longer than
69 the ring width, and mostly small and numerous fissures covering several growth rings (Fig. 2). Because of that, it
70 is convenient to saw the logs by radial cutting before drying checks appear. The wood rays are not perceptible to
71 the naked eye. The vessels are also not perceptible, although the growth rings can be noticed since the wood is
72 ring-porous (García Esteban and Guindeo Casasús 1989; Ruiz de la Torre 1979), with tendency to form semi
73 porous rings. The spring band of the growth ring has a very variable width. Supernumerary or fake rings are
74 frequent.

75

76 The wood is somewhat aromatic, machinable, and admits decorative polish. It is used to craft small marquetry
77 objects, and for carving and turnery (García Esteban and Guindeo Casasús 1989). Nevertheless, it is highly
78 abrasive on the cutting tools and toxic by inhalation, since it irritates the mucous membrane and produces
79 breathing problems.

80

81 The laurel contains essential oils that are more abundant in the palisade parenchyma and central nerve of the leaf.
82 The laurel leaves are collected for the production of bio-oil, which has been largely used for flavoring food and
83 for therapeutic uses and it is been tested nowadays as wood preservative front of fungal decay (e.g. Akbas et al.
84 2016; Ertaş and Alma 2016).

85

86 Despite the environmental value of the laurel tree, its woodlands have been frequently replaced by crops,
87 meadows or plantations of other forest species. The lack of interest of the forest managers towards the
88 conservation of the laurel may be partially explained by the low prices its wood has, substantially lower than
89 other domestic hardwoods.

90

91 There are other factors contributing to the deterioration of the laurel stands: the fragility of these forests due to
92 their usual fragmentation, riverbed channelling, dam construction, landscaping of the riverbanks, drainage or arid
93 extraction (Rigueiro Rodríguez 2003).

94

95 Any measure aimed to the preservation of the genetic diversity of the laurel tree starts with its characterization,
96 including the study of the laurel wood. No such studies have been published in Spain. In a European level the
97 information is scarce, despite the species is being harvested both in mature and juvenile stages. A pioneering
98 study of physical properties of laurel wood has to comprise gravimetric properties (specific gravity and density),
99 since they are common indicators of wood quality (e.g. Forest Products Laboratory 2010; Zobel and Buijtenen
100 1989). What is more, the laurel wood density affects the hydraulic conductance (e.g. Li et al. 2016; Savi et al.
101 2017) and the ecological strategies in woody plants by controlling the proportion of carbon invested per unit
102 stem volume (e.g. Martínez-Cabrera et al. 2009). Likewise, wood stability should be addressed by means of the
103 variables that quantify the volumetric shrinkage, and the shrinkage in the main directions of wood, since the final
104 destination of the material is influenced by how its dimensional stability faces changes in the air humidity.

105

106 Finally, the unstable juvenile wood abounds in young trees, which limits their logging exploitation. The
107 assessment of the shrinkage on the wood fibre direction (longitudinal shrinkage and longitudinal shrinkage
108 coefficient) can be used to detect juvenile wood, since both variables in juvenile wood show high values and
109 dispersion (e.g. Forest Products Laboratory 2010; Panshin and de Zeeuw 1980; Zobel and Buijtenen 1989).

110

111 The main objective of this study is to assess the density and dimensional stability of the laurel wood, and their
112 inter-tree and intra-tree variation.

113

114 **Material and methods**

115 In a stand located in the Ermo parish, municipality of Ortigueira (Latitude: 43.624552, Longitude: -7.893340,
116 WGS 84; altitude: 197 MASL), an inland area of Galicia (north-western Spain), 17 individuals of *Laurus nobilis*
117 L. were selected and felled for investigation taking advantage of a commercial laurel tree harvest that it was been
118 performed in a coastal eucalypt plantation (*Eucalyptus globulus*) where laurel tree was mainly part of the
119 accompanying ground vegetation. The number of trees accomplished with the Spanish standard UNE
120 56528:1978 (IRANOR 1978a) and with the European standard EN 384:2016 (CEN 2016). The stand was located
121 by its coordinates with a gps navigator. The altitude was calculated with a barometric altimeter. Breast height
122 diameter was measured by averaging two rectangular tree calliper measurements (to the closest millimetre) and
123 total height with a Blume-Leiss hypsometer. The over bark and under bark trunk volume were obtained by the
124 two-entry merchantable volume equations for the species in the province of La Coruña (DGCONA 2001). The
125 age of each tree was established in laboratory by growth ring count on basal slices of the stems. The sample was
126 formed by juvenile trees, judging by their age distribution and dimensions (Table 1).

127
128 From each felled laurel, cross section slices were obtained, at the stem base, at 1 and 2 m stem height, and
129 further if the stem diameter was big enough. Slices were cut with an approximate thickness of 15 cm and were
130 sawn to obtain two types of prismatic specimens: 2 cm × 2 cm × 4 cm and 4 cm × 4 cm × 2 cm as radial,
131 tangential and longitudinal target dimensions respectively (Fig. 2). The slices were sawn when they were fairly
132 dry because sawing wet laurel wood yields fibrous, fuzzy surfaces and measurement on the irregular faces of the
133 specimens leads to errors. The drying of slices was slowly carried out in the hygrothermal conditions of the
134 laboratory but the laurel wood is very prone to crack, and the occurrence of fissures did not allow to cut
135 prismatic specimens under a planned pattern (from the pith to the bark, for instance). Instead of that, the
136 complete discs were cut out and afterwards only clean wood specimens were selected for tests. On defect-free
137 specimens, with negligible fibre deviation, growth rings parallel to the specimen axis and with low curvature
138 rings (which indicates separation from the pith), the mass and the three main dimensions were measured at three
139 successive wood moisture contents: saturation, ca. 12% wood moisture (air-dry wood or wood in equilibrium
140 with the moisture content in the laboratory environment) and 0% moisture (oven-dry wood). The weight of each
141 specimen was measured with an accuracy of one-hundredth gram, and the volume was obtained considering each
142 specimen as a perfect prism and multiplying the measurement of each dimension with an accuracy of one-
143 hundredth millimetre. The physical properties displayed on Table 2 were then determined according to the
144 Spanish standards UNE 56531:1977 (IRANOR 1977a), UNE 56532:1977 (IRANOR 1977b), UNE 56533:1977

145 (IRANOR 1977c), UNE 56528:1978 (IRANOR 1978a) and to the European standards EN 13183-1:2002 (CEN
146 2012a) and EN 408:2011 (CEN 2012b). The variables related to longitudinal stability were only obtained on 2
147 cm × 2 cm × 4 cm specimens in order to detect on the longest dimension the small variations inherent to the axial
148 direction. Similarly, the variables related to radial and tangential stability were only measured on 4 cm × 4 cm ×
149 2 cm specimens to perceive variations in transversal direction on the longest dimensions. The width of annual
150 growth rings was assessed in each saturated specimen and was calculated as the dimension of the longest radial
151 segment in the transversal section divided by the number of rings, and averaging the measurements made on
152 both faces. The air-dry density was referred to the 12% moisture content according to the correction equation in
153 UNE 56531:1977 (IRANOR 1977a). The sampled specimens per tree were 74 on average, with a minimum of 23
154 specimens in a particular tree.

155

156 The analysis of small, defect-free specimens allows to characterize the wood and to compare wood from
157 different origins, since the presence of defects or singularities in the wood is a source of variation which would
158 impede to detect the influence of other factors on the properties of the material (Riesco Muñoz and Remacha
159 Gete 2011).

160

161 The descriptive statistics of the physical properties (Table 2) were obtained after validating and refining the test
162 results. The wood properties assigned to the laurel wood were calculated as the arithmetic mean values of all the
163 valid data from the specimens obtained from the sampled trees, considering specimens as sampling units, all of
164 which had the same weight in the sample. The dispersion of the results for the properties analysed was quantified
165 by means of the coefficient of variation (standard deviation/mean quotient, expressed as a percentage). The
166 coefficient of variation represents an estimate of relative dispersion, which was useful in this case to compare the
167 dispersion of results among variables of different nature.

168

169 In order to find relationships between quantitative variables (those in Table 2) and qualitative variables (namely,
170 tree and height in the stem) a one-way analysis of variance was performed.

171

172 Any p-value lower than 0.05 was considered statistically significant. Values below 0.01 were considered highly
173 significant.

174

175 All statistical analyses were carried out using IBM SPSS Statistics software (version 20).

176

177 **Results and discussion**

178

179 **Basic descriptive statistics**

180 Table 2 shows the main statistics of the studied physical properties. The mean width of the growth rings leads to
181 consider the laurel as a slow growing species according to the Redington classification (1999). The wood density
182 is intermediate-high: density at 12% moisture content was 699 kg m^{-3} , which is in the range of the semi-heavy
183 hardwoods ($510\text{-}700 \text{ kg m}^{-3}$), following the UNE 56540:1978 interpretation criterion (IRANOR 1978b). It is
184 possible that in maturer trees the wood may be characterized as heavy, as it is cited in García Esteban and
185 Guindeo Casasús (1989), since there is usually a positive relation between wood density and cambial age (e.g.
186 Desch and Dinwoodie 1996). The density was very even, with coefficients of variation around 6-7% (typical of
187 conifers) and lower than those of hardwood species with porous growth ring (e.g. Riesco Muñoz et al. 2009;
188 Riesco Muñoz and Remacha Gete 2011). The density was homogeneous in each tree even considering that ring
189 width variability increased in bigger trees (Fig. 3).

190

191 The low density heterogeneity vs. ring width heterogeneity allows speculating about a weak link between density
192 and ring width in a stand-level scale. Additionally, it must be taken into account that the ring width attributed to
193 every specimen was the averaged width of the group of rings counted on the transversal section (between 1 and
194 27 rings per specimen in the sample). Because of that, it is expected a higher ring width variability if smaller
195 specimens, as regards transversal section, are considered.

196

197 The hygroscopicity is normal and the wood is volumetrically unstable according to the UNE 56540:1978
198 interpretation criterion (IRANOR 1978b), although judging by the Koehler volumetric constant (Koehler 1931)
199 laurel wood is significantly more stable than it should be, given its high density.

200

201 The longitudinal stability is highly variable, which is a characteristic trait of immature trees, where juvenile
202 wood is abundant. Taking into account that specimens near the pith (juvenile wood) were intentionally rejected
203 for tests, it is possible that most of the wood analysed was juvenile. Additionally, longitudinal shrinkage is
204 significantly lower than expected, given the density the wood presents (Koehler 1931).

205

206 The fibre saturation point or cell wall saturation point is normal according to Gutiérrez Oliva and Plaza Pulgar
207 criterion (1967). Nevertheless, the fibre saturation point in the longitudinal direction (21% on average) is low
208 under the same criterion. This trait indicates that wood distortions (bow, spring and twist) start to occur only if
209 the wood humidity drops below 21%, which is a practical threshold to consider because sawn wood is usually
210 dried below that level, according to commercial standards.

211

212 The transversal stability of wood (radial and tangential shrinkage) is moderate, and with somehow low
213 variability. Radial shrinkage and tangential shrinkage are significantly lower than expected, given the density of
214 wood (Koehler 1931). Despite the absolute anisotropy is high and variable, the coefficient of anisotropy is low
215 under the Rijdsdijk and Laming (1994) interpretation criteria, which leads to conclude that radial and tangential
216 shrinkages are somehow similar. This is a positive feature of this wood as raw material for sawing, because
217 distortion of the square or rectangular cross section of the planks after drying will be less visible.

218

219 The relative error in the estimation of the variables was always lower than 5%, upper threshold proposed by
220 UNE 56528:1978 standard (IRANOR 1978a), except for some of the variables related to longitudinal stability
221 (because of their high coefficient of variation).

222

223 Due to the absence of previous results about the wood properties of *Laurus nobilis*, the values in Table 2 were
224 compared with those in the early work of Peraza Oramas and López de Roma (1967) for *Laurus canariensis*
225 Webb & Berthel., a species of the same genus, with similar shape and height, and similar wood as regards
226 macroscopic characteristics. The results revealed that sampled wood of *Laurus nobilis* is 5-7% denser and more
227 unstable than wood of *Laurus canariensis*.

228

229 **Inter-tree variation in the characteristics of wood**

230 The analysis of variance using tree as a factor shows that every assessed physical property of the laurel wood
231 presents a very significant ($p < 0.01$) variance among trees (Table 3). The inter-tree variation was not attributed
232 to genetics because genetic diversity was not expected to be high among trees sampled in close proximity in the
233 same stand. Surely, there would be a reasonable degree of relatedness among individuals growing next to each

234 other in the same plot. Additionally, environmental conditions were almost constant for all sampled trees as there
235 were not any remarkable differences in site quality.

236

237 The inter-tree variation in wood characteristics may be therefore attributed to tree factors such as age,
238 dimensions and growing. The correlation matrix between average tree wood properties and dendrometric tree
239 characteristics (not included here) showed that, on the basis of Pearson's correlation coefficient, the most
240 remarkable relationships were those related to density and mean growth (in mm year⁻¹), and volumetric stability
241 of wood and tree breast height diameter or slenderness. The highest Pearson's correlation coefficients were:

242

243 - $r = -0.67^{**}$ between volumetric shrinkage coefficient and breast height diameter

244 - $r = 0.69^{**}$ between volumetric shrinkage and slenderness.

245

246 Since the breast height diameter increases with age, and slenderness reduces, it is expected that for ages of
247 felling older than those of this study (24-41 years) the high volumetric shrinkage coefficient values would
248 diminished. Therefore, with a later age of felling the volumetric stability of the laurel wood would improve,
249 which in turn would facilitate its use in the industry. In Figures 3 and 4 the box plots of representative variables
250 distributed by tree or position in the stem are presented.

251

252 **Wood characteristics variation along the stem**

253 The analysis of variance using stem height as a factor shows that, similarly to the previous section, every
254 assessed physical property of the laurel wood presents a very significant ($p < 0.01$) variance in different positions
255 along the stem, except for a few variables (Table 3). As the noted variability of density along the stem was
256 actually rather small, it has no practical interest (Fig. 4) and, from the harvesting point of view, the wood density
257 may be considered constant along the stem. On the other hand, the reduction of the volumetric shrinkage from
258 the root collar to 3 m height is 16.3%, which indicates that the higher logs present a more dimensionally stable
259 wood (Fig. 4).

260

261 **Conclusion**

262 The laurel wood is moderately heavy, and also moderately stable if its high density is taken into account. The
263 physical properties vary significantly from one individual to another. The dimensional stability is higher in thick

264 and slenderless trees, which are usually maturer, so it is expected that in trees older than those used in this study
265 the dimensional stability would increase. Commercial exploitation of the complete trunk is recommended as
266 wood density is very homogeneous along the stem and wood dimensional stability is higher at upper positions in
267 the stem.

268

269 **References**

270 Akbas S, Temiz A, Terziev N, Alma MH, Palanti S, Feci E (2016) Effects of bio-oil obtained from laurel
271 (*Laurus nobilis*) residues on biological, physical, and mechanical properties of treated wood. Proceedings of The
272 International Research Group on Wood Protection 2016. IRG, Lisbon.

273

274 CEN (2012a) EN 13183-1:2002. Moisture content of a piece of sawn timber - Part 1: Determination by oven dry
275 method. European Committee for Standardization, Brussels

276

277 CEN (2012b) EN 408:2011. Timber structures. Structural timber and glued laminated timber. Determination of
278 some physical and mechanical properties. European Committee for Standardization, Brussels

279

280 CEN (2016) EN 384:2016. Structural timber -Determination of characteristic values of mechanical properties
281 and density. European Committee for Standardization, Brussels

282

283 Desch HE, Dinwoodie JM (1996) Timber. Structure, properties, conversion and use. MacMillan Press Ltd,
284 Houndmills

285

286 DGCONA (2001) Tercer Inventario Forestal Nacional 1997-2006. Galicia. A Coruña. Ministerio de Medio
287 Ambiente, Madrid

288

289 Ertaş M, Alma MH (2016) Evaluation of influence of two different catalysts on the pyrolysis of laurel (*Laurus*
290 *nobilis* L.) extraction residues. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 38 (3),
291 384 – 390. DOI: 10.1080/15567036.2013.783656

292

293 Forest Products Laboratory (2010) Wood handbook. Wood as an engineering material. USDA For. Serv. Gen.
294 Tech. Rep. FPL-GTR-113, Madison
295
296 García Esteban L, Guindeo Casasús A (1989) Anatomía de las maderas de frondosas españolas. AITIM, Madrid
297
298 Gutiérrez Oliva A, Plaza Pulgar F (1967) Características físico-mecánicas de las maderas españolas. Instituto
299 Forestal de Investigaciones y Experiencias, Madrid
300
301 IRANOR (1977a) UNE 56531:1977. Determinación del peso específico. Instituto Nacional de Racionalización y
302 Normalización, Madrid
303
304 IRANOR (1977b) UNE 56532:1977. Determinación de la higroscopicidad. Instituto Nacional de
305 Racionalización y Normalización, Madrid
306
307 IRANOR (1977c) UNE 56533:1977. Determinación de las contracciones lineal y volumétrica. Instituto Nacional
308 de Racionalización y Normalización, Madrid
309
310 IRANOR (1978a) UNE 56528:1978. Preparación de probetas para ensayos. Instituto Nacional de
311 Racionalización y Normalización, Madrid
312
313 IRANOR (1978b) UNE 56540:1978. Interpretación de los resultados de los ensayos. Instituto Nacional de
314 Racionalización y Normalización, Madrid
315
316 Koehler A (1931) Longitudinal shrinkage of wood. Transactions of the ASME. 53, 17-20.
317
318 Li S, Lens F, Espino S, Karimi Z, Klepsch M, Jochen Schenk H, Schmitt M, Schuldt B, Jansen S (2016)
319 Intervessel pit membrane thickness as a key determinant of embolism resistance in angiosperm xylem. IAWA
320 Journal. 37, 152 – 171. DOI: 10.1163/22941932-20160128
321

322 Martínez-Cabrera HI, Jones CS, Espino S, Jochen Schenk J (2009) Wood anatomy and wood density in shrubs:
323 responses to varying aridity along transcontinental transects. *Am J Bot* 96:1388-1398.
324

325 Panshin AJ, de Zeeuw C (1980) Textbook of wood technology. Mc Graw Hill, New York
326

327 Peraza Oramas C, López de Roma A (1967) Estudio de las principales maderas de Canarias. Instituto Forestal de
328 Investigaciones y Experiencias, Madrid
329

330 Redington M (1999) Fast growth wood. In Cost Action 508 Wood Mechanics (1990-1996). Final Report. Eds.
331 Morlier P, Castéra P, pp. 59-64.
332

333 Riesco Muñoz G, Álvarez Álvarez P, Rego Vázquez L (2009). La calidad estructural de la madera aserrada de
334 castaño en función de las características de las trozas. Actas del V Congreso Nacional y II Congreso Ibérico
335 AGROINGENIERÍA 2009. Sociedad Española de Agroingeniería, Lugo
336

337 Riesco Muñoz G, Remacha Gete A (2011). Relationships between mechanical properties of oak timber (*Quercus*
338 *robur* L.). *Holzforschung*, 65 (5):749-755. DOI: 10.1515/HF.2011.053
339

340 Rigueiro Rodríguez A (2003) Bosques y masas arboladas. In Reflexiones sobre el medio ambiente en Galicia. Ed.
341 Casares Long JJ, Xunta de Galicia, Santiago de Compostela
342

343 Rijdsdijk JF, Laming PB (1994) Physical and related properties of 145 timbers: information for practice. Kluwer
344 Academic Publishers, Dordrecht
345

346 Ruiz de la Torre J (1979) Árboles y arbustos de la España peninsular. Fundación Conde del Valle de Salazar.
347 Escuela Técnica Superior de Ingenieros de Montes, Madrid
348

349 Savi T, Love VL, Dal Borgo A, Martellos S, Nardini A (2017) Morpho-anatomical and physiological traits in
350 saplings of drought-tolerant Mediterranean woody species. *Trees* 31:1137-1148.
351

352 Zobel BJ, Van Buijtenen JP (1989) Wood variation. Its causes and control. Springer Verlag, Berlin

353 Table 1. Dendrometric characteristics of the 17 sample laurel trees. *CV* (%) = coefficient of variation.

| | minimum | maximum | mean | <i>CV</i> (%) |
|---|---------|---------|------|---------------|
| breast height diameter, <i>dbh</i> (cm) | 13.7 | 28.9 | 20.8 | 25 |
| total height, <i>h</i> (m) | 5.1 | 13.1 | 8.6 | 26 |
| age (years) | 24 | 41 | 32 | 15 |
| slenderness (<i>h/dbh</i> ratio) | 0.21 | 0.77 | 0.44 | 37 |
| over bark volume (dm ³) | 43 | 263 | 146 | 49 |
| under bark volume (dm ³) | 34 | 210 | 116 | 49 |
| mean growth (dm ³ year ⁻¹) | 1.3 | 8.4 | 4.5 | 44 |
| mean growth (mm year ⁻¹) | 2.3 | 4.5 | 3.2 | 21 |

354

355

356 Table 2. Descriptive statistics of the assessed physical properties of the laurel wood. n = number of valid tests;
 357 CV (%) = coefficient of variation; e (%) = relative error in the estimation of the mean.

| | n | minimum | maximum | mean | CV (%) | e (%) |
|--|------|---------|---------|------|----------|---------|
| ring width (mm) | 1212 | 1.2 | 14.8 | 4.8 | 45 | 2.5 |
| density at 12% moisture (kg m^{-3}) | 1249 | 441 | 826 | 699 | 7 | 0.4 |
| oven-dry density (kg m^{-3}) | 1250 | 415 | 792 | 668 | 7 | 0.4 |
| basic density (kg m^{-3}) | 1250 | 370 | 676 | 566 | 6 | 0.3 |
| hygroscopicity (kg m^{-3}) | 1249 | 0.3 | 5.8 | 2.9 | 19 | 1.0 |
| volumetric shrinkage (%) | 1250 | 8.8 | 29.8 | 17.9 | 12 | 0.7 |
| volumetric shrinkage coefficient (%) | 1249 | 0.18 | 0.95 | 0.59 | 14 | 0.8 |
| radial shrinkage (%) | 225 | 2.6 | 8.7 | 5.5 | 17 | 2.2 |
| radial shrinkage coefficient (%) | 225 | 0.08 | 0.28 | 0.19 | 19 | 2.4 |
| tangential shrinkage (%) | 225 | 5.8 | 15.7 | 10.9 | 14 | 1.8 |
| tangential shrinkage coefficient (%) | 225 | 0.17 | 0.40 | 0.31 | 13 | 1.7 |
| longitudinal shrinkage (%) | 706 | 0.0 | 3.9 | 0.4 | 86 | 6.3 |
| longitudinal shrinkage coefficient (%) | 706 | 0.00 | 0.14 | 0.02 | 82 | 6.1 |
| anisotropy coefficient | 225 | 1.1 | 3.1 | 2.0 | 17 | 2.2 |
| absolute anisotropy (%) | 225 | 0.9 | 10.7 | 5.3 | 27 | 3.5 |
| fibre saturation point, in volume (%) | 1249 | 17 | 53 | 31 | 12 | 0.7 |
| radial fibre saturation point (%) | 225 | 23 | 43 | 29 | 12 | 1.6 |
| tangential fibre saturation point (%) | 225 | 27 | 44 | 35 | 9 | 1.1 |
| longitudinal fibre saturation point (%) | 649 | 9 | 44 | 21 | 28 | 2.1 |
| Koehler volumetric constant | 1249 | 13.5 | 42.5 | 26.8 | 9 | 0.5 |
| Koehler radial constant | 225 | 4.8 | 13.2 | 8.2 | 14 | 1.8 |
| Koehler tangential constant | 225 | 10.8 | 21.8 | 16.2 | 11 | 1.4 |
| Koehler longitudinal constant | 706 | 0.0 | 5.2 | 0.7 | 86 | 6.3 |

358

359

360

361

362 Table 3. F-values (*F*) and significance levels (*p*-values) in the one-factor analysis of variance for physical
 363 properties of laurel wood with the variables tree and height in the stem as factors.

| quantitative variable | tree factor | | height in the stem | |
|---|-------------|--------|--------------------|--------|
| | <i>F</i> | Sig. | <i>F</i> | Sig. |
| ring width (mm) | 43.346 | < 0.01 | 29.614 | < 0.01 |
| air-dry density (kg m ⁻³) | 43.868 | < 0.01 | 30.308 | < 0.01 |
| oven-dry density (kg m ⁻³) | 38.530 | < 0.01 | 28.759 | < 0.01 |
| basic density (kg m ⁻³) | 44.290 | < 0.01 | 25.998 | < 0.01 |
| hygroscopicity (kg m ⁻³) | 14.800 | < 0.01 | 29.745 | < 0.01 |
| volumetric shrinkage (%) | 20.064 | < 0.01 | 43.882 | < 0.01 |
| volumetric shrinkage coefficient (%) | 20.223 | < 0.01 | 27.502 | < 0.01 |
| radial shrinkage (%) | 11.548 | < 0.01 | 15.252 | < 0.01 |
| radial shrinkage coefficient (%) | 9.882 | < 0.01 | 13.893 | < 0.01 |
| tangential shrinkage (%) | 6.645 | < 0.01 | 6.911 | < 0.01 |
| tangential shrinkage coefficient (%) | 7.394 | < 0.01 | 3.828 | < 0.05 |
| longitudinal shrinkage (%) | 10.429 | < 0.01 | 13.467 | < 0.01 |
| longitudinal shrinkage coefficient (%) | 10.186 | < 0.01 | 8.947 | < 0.01 |
| anisotropy coefficient | 5.529 | < 0.01 | 5.321 | < 0.01 |
| absolute anisotropy (%) | 4.508 | < 0.01 | 1.939 | 0.124 |
| fibre saturation point, in volume (%) | 10.862 | < 0.01 | 6.197 | < 0.01 |
| radial fibre saturation point (%) | 4.644 | < 0.01 | 7.399 | < 0.01 |
| tangential fibre saturation point (%) | 3.358 | < 0.01 | 3.414 | < 0.05 |
| longitudinal fibre saturation point (%) | 7.297 | < 0.01 | 10.604 | < 0.01 |

364
 365
 366
 367
 368
 369
 370

371 **Fig. 1** Laurel trees (*Laurus nobilis*) in the edge of eucalypt stands (Lugo, Spain)

372

373 **Fig. 2** Laurel wood. a) log from a felled laurel tree; b) sampled slice for this study; c) prismatic specimens 2 cm
374 × 2 cm × 4 cm rejected for testing because of the presence of checks

375

376 **Fig. 3** Box plots for the physical properties of laurel wood in each separate tree. Boxes are ordered by increasing
377 breast height diameter of the tree, but not on a continuous scale

378

379 **Fig. 4** Box plots for the physical properties of laurel wood at different stem heights

380







