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# Some physical and mechanical properties of wood of Fast-growing tree species eucalyptus (*Eucalyptus grandis*) and radiata pine (*Pinus radiata* D.Don)

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**Abstract.** Fast-growing imported plantation tree species have become an available wood resource for Europe's wood industry in the last decades. This sustainable alternative may reduce the gap between the increasing demand for and decreasing supply of the local tree species. The aim of the study was to determine and compare basic physical and mechanical properties of eucalyptus (*Eucalyptus grandis*) wood from Uruguay and radiata pine (*Pinus radiata* D.Don) wood from New Zealand as an alternative for Scots pine (*Pinus sylvestris* L.) from Latvia, to produce non-structural semi-finished glued laminated timber members for the manufacturing of windows. Such properties as density, swelling, bending strength, bending modulus of elasticity, compression strength and resistance to impact were determined according to ISO 13061 series standards test methods for small clear wood specimens. As the result of this study it was established that there is not significant difference between the majority of radiata pine and Scots pine properties, with the exception of resistance to impact and radial swelling where radiata pine shows significantly higher values. Not surprisingly all the properties of deciduous eucalyptus wood were significantly higher compared to both coniferous tree species. Higher swelling and density properties of eucalyptus compared to radiata pine and Scots pine should be taken into consideration for the design and production of wooden window elements.

**Key words:** *Eucalyptus grandis*, Fast-growing wood, mechanical properties, *Pinus radiata* D.Don, plantation wood.

## INTRODUCTION

Fast-growing imported plantation tree species have become an available wood resource for the European wood industry. Two tree species eucalyptus (*Eucalyptus grandis*) and radiata pine (*Pinus radiata* D.Don) are at the top of interest. These sustainable alternatives may replace some of the local tree species for wooden window and structural element production (Liao et al., 2017).

Radiata pine (*Pinus radiata* D.Don*)* is the most widely spread commercial forestry Fast-growing tree species covering an estimated 1.8 million ha in New Zealand (Palmer et al., 2010) where its rotation period is 28 years for sawlog production and annual growth rate is evaluated as 17 $m^3$ $ha^{-1}$ $year^{-1}$ (Cubbage et al., 2010). In total 13.7 million $m^{-3}$ of radiata pine pulp wood and sawn timber was exported from New Zealand in 2011 (Ministry of Primary Industries, 2020).

Eucalyptus is one of the fastest growing tree species in the world and the most commonly planted forest species in Uruguay (over 0.25 million ha) (Rachid-Casnati et al., 2019). Eucalyptus rotation period is 16 years for saw log production and the annual growth rate is evaluated at 30 $m^3$ $ha^{-1}$ $year^{-1}$ in Uruguay (Cubbage et al., 2010) and up till 50 $m^3$ $ha^{-1}$ $year^{-1}$ in Turkey (Gürses et al., 1995). The availability of eucalyptus sawn timber is evaluated as 0.7 million $m^{-3}$ according to Dieste et al. (2019).

In comparison the most widely spread tree species and typical raw material for wooden window and structural element production in Europe is Scots pine (*Pinus sylvestris* L.). It covers approximately 33% of the total forest stands with 0.85 million ha area in Latvia (Central Statistical Bureau of Latvia, 2019). For Scots pine the cutting age varies from 101 to 121 years for saw log production. The annual growth rate for Scots pine in Latvia has been evaluated as 6.8 $m^3$ $ha^{-1}$ $year^{-1}$ and yield as 245 $m^3$ $ha^{-1}$ on average (Lībiete, 2008). Approximately 4.3 million $m^{-3}$ of Scots pine was harvested in Latvia in 2019 (Ministry of Agriculture, 2020).

The growth region, growth and climate conditions of trees have a great influence on both the forest yield and the quality of timber, thereof physical and mechanical properties of fast growing tree species vary significantly (Álvarez et al., 2013; Elzaki & Khider, 2013; Mederski et al., 2015). Even in one forest stand and within one timber trunk the dispersion of wood properties may vary within wide range (Aleinikovas & Grigaliūnas, 2006; Bal & Bektaş, 2012). The age of tree is one of the factors that affect the physical and mechanical properties of wood. According to Cown (1980) the density of radiata pine wood increases with the increasing the age of tree. The density of the wood in the trunk cross section increases in the direction from pith to bark. In the case of eucalyptus there is a weak but positive correlation between the tree age and density and bending strength, but modulus of elasticity was almost non-correlated with the age of a tree (Lemenih & Bekele, 2004). Wood genetics influence wood competence for growth and the physical and chemical nature of tree growing. There is a correlation between genetic factors and wood density and related physical and mechanical properties of wood. The combination of genetic and environmental conditions is the main factors influencing the changes in wood characteristics (Savidge, 2003; Rocha et al., 2020). Due to the presence of large volume of juvenile wood, the mechanical properties of eucalyptus and radiata pine may vary significantly and they are unstable (Wagenführ 1996; Kojima et al., 2009).

Differences in the macroscopic structure of conifers and deciduous trees most often explain the differences in wood density and mechanical parameters (Wheeler, 2001). In general, the coniferous species have a higher cellulose content (40–45%), higher lignin (26–34%), and lower pentosan (7–14%) content as compared to deciduous species (cellulose 38–49%, lignin 23–30%, and pentosans 19–26%). The angle of the cellulose microfibrils in relation to the fiber axis is one of the most important structural parameter determining the mechanical properties of wood. The reduced cellulose content and high microfibril angle may cause the reduction of mechanical properties of wood (Rowell et.al., 2012).

Radiata pine may be considered as medium density, good structural and general purpose wood according to Elzaki & Khider (2013). In comparison eucalyptus has relatively better properties: average density 650 kg $m^{-3}$; bending strength 103 MPa and modulus of elasticity in bending 15.2 GPa according to Paradis et al. (2011). These properties even exceed average European oak (*Quercus robur*) properties: average density 610 kg $m^{-3}$; bending strength 88 MPa and modulus of elasticity in bending 11.7 GPa (Wagenführ, 1996). Similar density values, comparable mechanical properties and high growth rate of Fast-growing plantation tree species eucalyptus and radiata pine make them an ideal choice for substitution of local wood species European oak and Scots pine in Europe.

Glued laminated timber for wooden window production is a complex process where the physical and mechanical properties of wood determine the main production parameters and end use characteristics of windows. Bending strength, compression strength parallel to the grain and thickness swelling of each individual wood species should be taken into account in self-supporting wood window frame and joint design. Meanwhile, the actual wood density and hardness have to be taken into account in the production process of wood window blanks, as they affect most of the wood processing processes, such as: wood drying, sawing and planing as well as gluing (Kurowska & Kozakiewicz, 2010; Konnerth et al., 2016). The determination of the properties of wood allows the manufacturer of wooden window blanks to declare the properties of the raw material to the end-user. Therefore, appropriate manufacturing regimes and bonding parameters should be established for Fast-growing tree species if different physical and mechanical properties would be observed comparison to conventional European wood species.

The physical and mechanical properties of wood of the same tree species can differ significantly in different growth regions and climate conditions according to literature. Therefore direct data from testing with well recognised international standard test procedures were used to compare wood properties of Fast-growing plantation tree eucalyptus and radiata pine from a particular region with the reference wood of Scots pine from Latvia.

The aim of this study was to determine and directly compare basic properties of plantation wood: eucalyptus (*Eucalyptus grandis*) from Uruguay and radiata pine (*Pinus radiata* D.Don) from New Zealand as an alternative for Scots pine (*Pinus sylvestris* L.) from Latvia to produce non-structural semi-finished glued laminated timber members for windows manufacturing.

## MATERIALS AND METHODS

For this study wood of two Fast-growing plantation tree species eucalyptus (*Eucalyptus grandis*) from Uruguay ('Rivera' Department) and radiata pine (*Pinus radiata* D.Don) from New Zealand ('Taupo' region) were used. As a reference species Scots pine (*Pinus sylvestris* L.) from Latvia ('Vidzeme' region) was tested. The age of the trees at harvesting was following: 20–22 years for eucalyptus, 31–32 years for radiata pine and 112–118 years for Scots pine. The raw material was kiln dried sawn timber (moisture content 12 ± 3%) with nominal cross section dimensions of 35×150 mm and length of 4 m for all three species. Initial moisture content at the timber delivery was measured by electrical resistance moisture meter Brookhuis FMD6 and the average moisture content was as follows: 10.2% for eucalyptus; 13.8% for radiata pine and 14.3% for Scots pine. A total of 30 boards were randomly selected and cut into test specimens according to the standard ISO 3129 (ISO 3129, 2012) for each wood species. A set of 9 specimens was cut from a single board to determine the following physical and mechanical parameters: moisture content (ISO 13061-1, 2003), density (ISO 13061-2, 2014), swelling in radial and tangential directions (ISO 13061-15, 2017), bending strength and modulus of elasticity (ISO 13061-3, 2017 and ISO 13061-4, 2017), compression strength (ISO 13061-17, 2017) and resistance to impact in radial and tangential directions (ISO 13061-11, 2017). The set of the specimens were produced 300 mm from the sawn timber end and 50 mm from the edge. Smooth surfaces of specimens were obtained by planing operation. In total, 30 specimens were tested to obtain 30 valid test results for each physical and mechanical property of Fast-growing and reference wood species.

All parameters were determined after the conditioning of specimens to a constant mass in the standard climate (air temperature 20 ± 2 °C; air humidity 65 ± 2%). Radiata pine test specimens at the conditioning presented in the Fig. 1. In the same way eucalyptus and Scots pine specimens were produced and tested.

**Figure 1.** Example of radiata pine specimens: 1 – bending strength and modulus of elasticity specimens 2 – moisture content, density and compression strength specimens; 3 – resistance to impact specimens and 4 – swelling specimens.

The width and depth of all specimens was 20 mm. The length of specimens was: 5 mm for swelling specimens, 30 mm for moisture content, density and compression strength specimens; 150 mm for resistance to impact specimens and 320 mm for bending strength and modulus of elasticity specimens. All specimens were defect free without cracks, splits, knots, resin pockets, cross grain or other defects.

Three point bending strength and modulus of elasticity tests were carried out on the electromechanical testing device Zwick Z100, with a support span of 280 mm and a test speed 6 mm $min^{-1}$. Compression test was carried out with a test speed of 0.6 mm $min^{-1}$. Resistance of wood to impact was determined with steel ball (diameter 25 mm, density 7.8 g $cm^{-3}$) and dropping height of 500 mm. The diameter of indentation was measured by sliding calliper. Linear swelling was calculated from the measurement of dimensions of specimens at the absolutely dry condition and after fully saturated with water condition. Dimensions were measured by sliding calliper. For each wood species and each property the average value and standard deviation were calculated (ISO 3129, 2012). To compare the average values for all three species the Student's $t$-test with $p$-value method ($\alpha$ = 0.05) was used.

## RESULTS AND DISCUSSION

The average physical and mechanical properties of Fast-growing eucalyptus and radiata pine plantation wood species in comparison to Scots pine characteristics are presented in Table 1.

**Table 1.** Eucalyptus and radiata pine physical and mechanical properties in comparison to Scots pine wood (average values and standard deviations)

| Property | | Wood species / Origin<br>Eucalyptus (*Eucalyptus grandis*)/ Uruguay | radiata pine (*Pinus radiata* D.Don)/ New Zealand | Scots pine (*Pinus sylvestris* L.)/ Latvia |
|---|---|---|---|---|
| Moisture content, (%) | | 12.0 (0.513) | 12.7 (0.438) | 12.8 (0.795) |
| Density, (kg m$^{-3}$) | | 588 (97.2) | 504 (37.2) | 485 (68.3) |
| Bending strength, (MPa) | | 97.5 (16.7) | 89.5 (10.9) | 86.0 (11.8) |
| Modulus of elasticity in bending, (GPa) | | 11.9 (1.8) | 10.8 (1.7) | 10.3 (1.3) |
| Compression strength, (MPa) | | 54.1 (8.13) | 42.8 (6.37) | 43.8 (6.67) |
| Resistance to impact,(kJ m$^{-2}$) | tangential | 8.46 (1.30) | 7.46 (1.22) | 6.71 (0.794) |
| | radial | 7.35 (1.08) | 7.01 (0.599) | 5.96 (0.928) |
| Swelling, (%) | tangential | 11.7 (3.03) | 8.17 (1.16) | 8.43 (1.14) |
| | radial | 6.34 (1.68) | 4.39 (1.05) | 3.57 (0.535) |

The results of the study show that after conditioning of specimens in the standard climate the target equilibrium moisture content 12% (Forest Products Laboratory, 2010) was reached for all three wood species. The average moisture content of both coniferous wood species did not differ significantly ($p = 0.22$). Radiata pine obtained 12.7% and Scots pine 12.8% moisture content after conditioning of specimens in the standard climate. For the deciduous eucalyptus wood species the moisture content was 12.0% and it was significantly lower ($p < 0.05$) compared to both coniferous wood species. It can be explained by the differences in the initial moisture content and water sorption hysteresis effect in wood (Patera et al., 2016).

The average density of radiata pine varied from 436 to 568 kg m$^{-3}$ (504 kg m$^{-3}$ on average) but for Scots pine from 372 to 666 kg m$^{-3}$ (485 kg m$^{-3}$). Four percent difference between the average density values of fast growing radiata pine and conventional Scots pine wood species was not significant ($p = 0.10$). In comparison 14 to 18% higher average density 588 kg m$^{-3}$ was observed for deciduous eucalyptus wood within the range from 394 to 738 kg m$^{-3}$. The average density differences in both cases were significant ($p < 0.05$) compared to the above mentioned coniferous wood species. Since samples were randomly chosen from different boards, the considerable variability in density was not surprising.

The estimated bending strength and modulus of elasticity of radiata pine (89.5 MPa and 10.8 GPa) compared to Scots pine (86.0 MPa and 10.3 GPa) did not differ significantly ($p = 0.12$ and $p = 0.16$). As it was expected from literature (Paradis et al., 2011), the bending strength and modulus of elasticity of eucalyptus (97.5 MPa and 11.9 GPa) in both cases were significantly higher ($p < 0.05$).

A similar situation was observed with the compression strength parameters. The average compression strength values for radiata pine and Scots pine 42.8 MPa and

43.8 MPa did not differ significantly ($p = 0.28$). For eucalyptus grandis the compression strength value 54.1 MPa was evaluated as significantly higher ($p < 0.05$) compared to both coniferous wood species.

The parameters of the resistance to impact varied between wood species and loading directions. The highest resistance to impact values was observed in the tangential direction: 8.46 kJ $m^{-2}$ for eucalyptus, 7.46 kJ $m^{-2}$ for radiata pine and 6.71 kJ $m^{-2}$ for Scots pine. For all three wood species the tangential direction provided significantly higher resistance to impact values compared to the radial direction ($p < 0.05$). In the radial direction the values were as follows: 7.35 kJ $m^{-2}$ for eucalyptus; 7.01 kJ $m^{-2}$ for radiata pine and 5.96 kJ $m^{-2}$ for Scots pine. In both directions eucalyptus provided significantly higher resistance to the impact values compared to both coniferous wood species, with the exception of resistance to the impact of eucalyptus and radiata pine in the radial direction, where a significant difference was not observed ($p = 0.08$).

The thickness swelling parameter was evaluated and compared as the last parameter. The highest thickness swelling values were observed in the tangential direction: 11.7% for eucalyptus; 8.4% for Scots pine and 8.2% for radiata pine. For all three species the thickness swelling values in the tangential direction were approximately two times higher than in the radial direction and the difference was significant ($p < 0.05$). In the radial direction the swelling values were as follows: 6.3% for eucalyptus; 4.4% for radiata pine and 3.6% for Scots pine. For both directions eucalyptus provided significantly higher thickness swelling values compared to both coniferous wood species. The difference between radiata pine and Scots pine tangential thickness swelling was not significant ($p = 0.19$), but in the radial direction radiata pine provided significantly higher swelling ($p < 0.05$).

Differences in the macroscopic structure of conifers and deciduous trees most often explain the differences in wood density and mechanical parameters. Softwood species consists of single cell longitudinal tracheids, their arrangement is more regular with functions for both support and conduction. In comparison deciduous trees have a porous vascular system with large vessel elements for water conduction and fibers to provide most of the structural support. Wood that has a high proportion of thick–walled fibers is hard and heavy while wood with a high proportion of vessels are soft and light (Wheeler, 2001).

Physical and mechanical properties of Fast-growing wood species eucalyptus and radiata pine in comparison to Scots pine according to the literature are presented in Table 2. Only a small number of results representing different sites have been included in this comparison.

The data from the study showed that the average density for both coniferous wood species and deciduous wood species mostly corresponded to the data reported in the literature.

Eucalyptus from Uruguay showed slightly lower density 588 kg $m^{-3}$ compared to the data from Australia 650 kg $m^{-3}$ (Paradis et al., 2011), but slightly higher data compared to the data from Turkey, where density of 555 kg $m^{-3}$ was evaluated (Bal & Bektaş, 2012). For comparison European oak density is 610 kg $m^{-3}$ (Wagenführ, 1996). The bending strength 97.5 MPa and compression strength 54.1 MPa from the study were slightly lower compared to the corresponding literature data 103 MPa and 59 MPa (Paradis et al., 2011). The modulus of elasticity in bending 11.9 GPa for Uruguay were observed much lower compared to 15.2 GPa for Australia (Paradis et al., 2011). Average bending strength 88 MPa and average modulus of elasticity 11.7 GPa were reporteds by Wagenführ for European Oak (1996). No literature data were found about the resistance to impact for the assessed wood species.

**Table 2.** Eucalyptus and radiata pine properties compared to Scots pine parameters according to the literature

| Properties | Wood species, literature source and timber origin | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Eucalyptus (*Eucalyptus grandis*) | | Radiata pine (*Pinus radiata* D.Don) | | | | Scots pine (*Pinus sylvestris* L.) | | |
| | Bal & Bektaş (2012) / Turkey | Paradis et al. (2011) /Australia | Wagenführ, (1996) / [1] | Cockrell (1959) / California, USA | versus Australia | Elzaki & Khider (2013) / Sudan | Wagenführ (1996) / [1] | Paradis et al. (2011) / Europe | Mederski et al. (2015) |
| Density (kg m$^{-3}$) | 555 | 650 | 450–580 | 490 | 450 | 529–600 | 510 | 550 | 455 |
| Bending strength (MPa) | - | 103 | 60–91 | 91 | 79 | 78–81 | 80 | 97 | 85–87 |
| Modulus of elasticity in bending (GPa) | - | 15.2 | 8.5–3.6 | 12.4 | 10.0 | 11.6–12.7 | 12.0 | 12.9 | - |
| Compression strength (MPa) | - | 59 | 36–65 | 51 | 39 | 42–45 | 55 | 50 | 41–46 |
| Swelling (%) Tangential | 7.7 | 10 | | 7.0 | 6.3 | - | 7.5–8.7 | 8.3 | - |
| Swelling (%) Radial | 4.4 | 5.8 | _ | 5.2 | 4.0 | _ | 3.3–4.5 | 5.2 | _ |

[1] No data about the origin of the wood species origin were given.

[2] Resistance to impact data for the studied wood species were not found in the literature.

The tangential and radial swellings were observed as 11.7% and 6.34% in the study, and these values were slightly higher compared to the corresponding data reported by Paradis et al. (2011): 10.0% and 5.8%. The greatest thickness swelling differences were observed when the results were compared to the data reported by Bal & Bektaş (2012) 7.7% and 4.4%, where the origin of eucalyptus timber was Turkey.

The fast growing radiata pine wood from New Zealand showed the average density 504 kg m$^{-3}$ while according to the literature this parameter may vary from 450 kg m$^{-3}$ in Australia (Cockrell, 1959) to 600 kg m$^{-3}$ in Sudan (Elzaki & Khider, 2013).

Radiata pine bending strength 89.5 MPa and compression strength 42.8 MPa from the study corresponded to the most values cited by the literature. According to Cockrell, radiata pine bending strength in Australia was 79 MPa and compression strength value was 39 MPa but in California (USA) the values were the following: 91 MPa and 51 MPa (Cockrell, 1959). The modulus of elasticity in bending 10.8 GPa for radiata pine from New Zealand was slightly lower compared to 12.4 GPa for California, USA (Cockrell, 1959) and 11.6–12.7 MPa for Sudan (Elzaki & Khider, 2013), but the result was comparable with 10.0 MPa for Australia (Cockrell, 1959).

The tangential swelling was observed as 8.2% for radiata pine in the study and this value was slightly higher compared to the corresponding data reported by Cockrell (1959):

7.0% (California, USA) and 6.3% (Australia). Radial swelling 4.4% was comparable with the average literature data: 5.2% (California, USA) and 4.0% (Australia) (Cockrell, 1959).

Local reference wood species Scots pine from Latvia showed slightly lower density value 485 kg $m^{-3}$ compared to the general literature data 510 kg $m^{-3}$ (Wagenführ, 1996) and 550 kg $m^{-3}$ (Paradis et al., 2011), but higher value compared to 455 kg $m^{-3}$ reported from Poland by Mederski et al. (2015). All other physical and mechanical properties of Scots pine from Latvia were slightly lower compared to general data (Wagenführ, 1996; Paradis et al., 2011), but they were comparable with the data reported from Poland by Mederski et al. (2015) according to Table 2. Genetic and environmental conditions are the main factors influencing the changes in wood characteristics within the same species from different origins (Savidge, 2003; Rocha et al., 2020).

## CONCLUSIONS

Direct data from testing with well recognised international standard test procedures were used to compare wood properties of fast-growing plantation tree eucalyptus and radiata pine with the reference wood of Scots pine.

All determined properties of the fast-growing plantation wood species obtained in the study correspond to the certain range of properties cited in the literature.

As a result of the study it was established, that there was no significant difference between the majority of coniferous radiata pine (from New Zealand) and Scots pine properties (from Latvia), with the exception of the resistance to impact and radial swelling where radiata pine shows significantly higher values. Therefore, the use of radiata pine instead of Scots pine is highly potential.

All properties of the deciduous wood eucalyptus grandis (from Uruguay) were significantly higher compared to radiata pine and Scots pine properties. Higher swelling and density of eucalyptus should be taken into consideration for wood windows element design and production.

Due to the fast growth rate and similar physical and mechanical properties to European oak, eucalyptus has a great potential as a substitute for some deciduous wood species, while Scots pine can be substituted by radiata pine to manufacture wooden window and structural elements in Europe.

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