

Wood properties of *Nothofagus betuloides*

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Abstract

The native forests of Southern Patagonia (South America) are dominated by the genus *Nothofagus*. One species with valuable wood is *Nothofagus betuloides* (Mirb.) Blume. However, the commercial acceptance for higher value utilizations of this species is low due to rather unknown wood properties influencing wood processing.

In a native forest dominated by *Nothofagus betuloides* located in Tierra del Fuego (Chile), 30 trees in sawlog dimension were sampled. Diameters at breast height ranged from 40 to 100 cm, age from 180 to 300 years. A total of 702 samples coming from two tree heights (1.3 and 5.5 m) were cut in radial direction from pith to bark for analysing wood density, dimensional stability and strength properties. The aim of the study is to determine important wood properties and their variation in a sawlog influencing the quality of sawnwood for higher value utilizations of this tree species.

The results show a rather constant density profile in direction from pith to bark for the individual tree. Between trees and different tree heights, a high variability of wood density could be observed. Strength properties show strong correlation with this parameter, resulting in higher modulus of elasticity and rupture (MOE and MOR) for higher wood densities. Dimensional stability shows also strong correlation with wood density, where radial and tangential contraction increases with higher wood density. The results may be useful in adapting processing and drying technologies for *Nothofagus betuloides*.

Keywords: *Nothofagus*, wood density, strength properties, dimensional stability.

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Introduction

The main species of the native forest of the region XII in Southern Chile are *Nothofagus pumilio* (Poepp. et Endl) Krasser and *Nothofagus betuloides* (Mirb.) Blume. Both species are the base of timber production in this region. The latter species takes up the third position of extension with 280,000 ha in the native forest area between the regions X and XII in Chile (Cruz & Caldente, 2007). The species is an evergreen broadleaved tree belonging to the Order of the *Fagales*, with a uniform wood structure. In the last decades *Nothofagus* species have conquered markets in USA and Japan for furniture purposes. Since the wood structure of *Nothofagus pumilio* is suitable for flooring and high value furniture production (Juacida, 2005) and *Nothofagus betuloides* shows a similar appearance (Faura & Geoffroy, 1973; Bahamondes, 1976) the use of this species may be qualified for the same purposes. Nevertheless, problems like collapse, checks and strong deformations appear in the dried lumber of *Nothofagus betuloides*, causing downgrading and low recovery rates. In many hardwoods, stresses inside the tree and the presence of tension wood are related to these defects (Archer, 1986; Kubler, 1987). The differences between the densities from different parts of the tree height as well as the differences in the elasticity may cause cracks and end splitting of the sawn wood (Maeglin, 1987; Vorreiter, 1949). These differences inside and between trees could be related in general to the wood structure and anatomy (i.e. additional presence of tension wood), site quality, growth patterns, and genetic pattern (Bosshard, 1956). Broadleaved trees show a different distribution of the density levels on the stem radius, depending on its wood anatomy and structure.

Nothofagus betuloides is a diffuse microporous wood. Trees with such a hydro-system generally do not show high variations in wood properties along the stem and inside the tree rings (Boyd, 1968). For this kind of wood structure, no significant differences neither in the longitudinal direction along the height of the tree were found (Zobel, 1998; Zobel and Buijtenen 1989). Some other studies analyzed the distribution of the wood density along the stem and the tree radius in correlation with the age. Torelli (1993) found lower values of wood density in trees older than 60 years for European beech (*Fagus sylvatica*).

The behaviour of wood during processing and drying is closely related to wood density. Swelling and shrinking is related to the moisture content of wood below fibre saturation point, which on the other hand depends on quantity of cell wall material available for chemical bond of water. The forces exerted in shrinking and swelling are high and have a marked effect on the permanence and serviceability of anything made of wood (Forest Products Laboratory, 1957). Because of the anisotropy of the wood, the longitudinal, radial and tangential shrinkage of wood samples is significantly different (Lohmann, 1998; Grammel, 1989). The radial shrinkage is lower compared to tangential and longitudinal shrinkage. This behaviour shows a relation of 20:10:1 (tangential : radial : longitudinal). Shrinking of inadequately seasoned structural members in a house may cause cracks, distorted openings, and uneven floors. For furniture products, interior finish, flooring, doors, etc, swelling and shrinking may cause splitting and cracking, warping, opening of joints and marring of finishes (Forest Products Laboratory, 1957).

The goal of the study is to determine important wood properties (density, swelling and shrinkage, and Module of Elasticity) of *Nothofagus betuloides* which could influence the quality of the sawnwood for high value wood utilizations of this tree species.

Material and methods

Nothofagus betuloides occurs mainly on sites with fertile soils, showing there a good growth and bigger dimensions suitable for sawlog production (Thiers and Gerding, 2007). The climate conditions in the region of “Tierra del Fuego” are generally cold oceanic, characterized by lower temperatures, strong winds and precipitation between 800 to 2.000 mm/year, with a mean annual temperature of about 5°C (Donoso, 1993). The 30 trees selected for this study came from an unmanaged native forest of the southern region of Chile (Tierra del Fuego). The trees came from an area of 3.5 hectares of the community “Timaukel”, owned by the Forestal Russfin Company. The selected trees cover the whole range of ages and diameter of trees used for sawlogs in sawmills of the region: the diameter ranged between 40 and 100 cm, tree heights from 23 to 32 m and age between 185 and 354 years old. A total of 702 samples were cut from the 30 logs at 1.3 and 5.5 m tree height as shown in Figure 1.

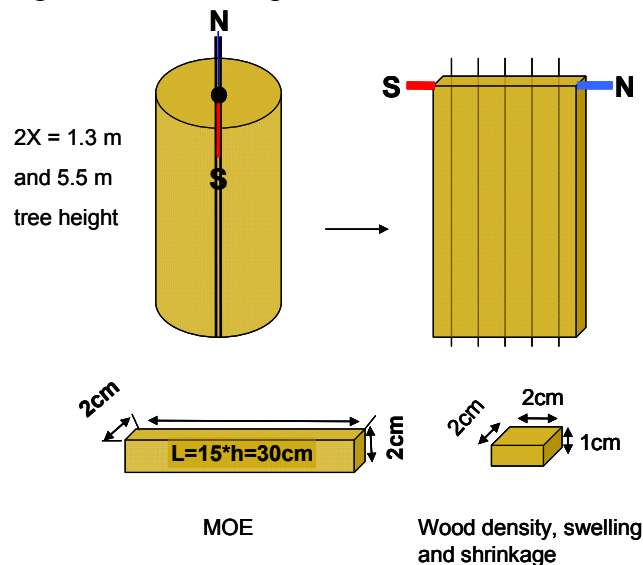


Fig. 1: Samples for wood testing obtained from 1.3 m and 5.5 m tree height for analysis of wood density, swelling and shrinking and MOE after German Standard DIN 52184 and 52186.

From the log sections shown in Figure 1, small samples of 30 x 2 x 2 cm for testing strength properties (Module of Elasticity, “MOE”) and small cubes of 2 x 2 x 1 cm for the testing wood properties (density, swelling and shrinking) were taken. Each sample was numbered after its absolute position in the log, starting from pith. The procedure of the strength measurements followed the standard DIN 52186 “bending test”. Density and shrinkage were measured after the standard DIN 52184 including 5 climatic conditions:

- “normal climate” (20°C and 65% air humidity);
- “moist climate”; (20°C and 85% air humidity);

- “dry climate” (20°C and 35% air humidity);
- “oven dry climate” (oven dried, at 103°C);
- Moisture content > fibre saturation point (FSP);

The statistical analysis was carried out using the software SPSS 15.0 for Windows and SAS 9.1.3.

Results and discussion

Wood density

The data were first tested for a normal distribution by the Kolmogorov- Smirnov test, with significant results for the adjustment. In order to test the differences between the density of the samples from the north and the south orientation, and within the stem radius (by the absolute position) a t-test was carried out. No significant differences were found between these values, neither at 1.3 m nor at 5.5 m height. Therefore the mean of each sample classified after their absolute position were calculated and used for further analysis. Table 1 gives an overview about the average values of wood density at 12% moisture content of the tested material.

Table 1: Descriptive statistics for the wood density at 12% wood moisture content.

Density (u=12%) [g/cm ³]	Orientation	Mean	Min	Max	Std Dev.	Median
Tree height	[5.5m] Both	0,62	0,42	0,74	0,05	0,62
	[1.3m]	0,65	0,47	0,84	0,06	0,65

The densities shown in table 1 are comparable to the findings of other studies with *Nothofagus betuloides*, ranging between 0.612 [g/cm³] (Faura & Geoffroy, 1973) and 0.62 [g/cm³] (Cruz & Caldentey, 2007). Other *Nothofagus* species (i.e. *Nothofagus alpina*) show slightly lower wood densities around 0.55 [gr/cm³] (Lohmann, 1998). For a direct comparison between the sample trees with a wide range of diameters, absolute position was transformed in relative position, where the distance of the radius from pith to bark was taken as 100%. The distribution of the density along the stem and for the both tree heights is shown in the Figure 2.

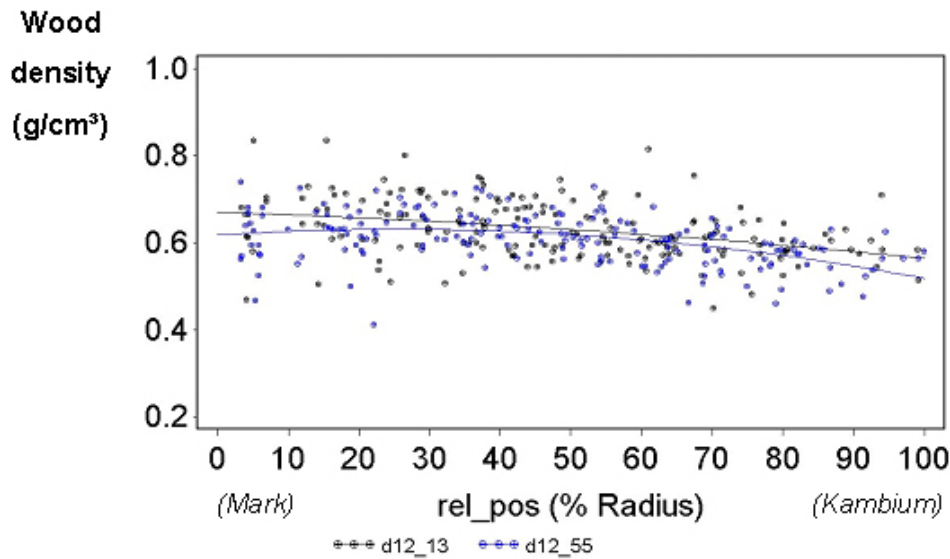


Fig. 2: Distribution of the wood density along the stem radius (d12_13: density at 12% wood humidity at 1.3 m and 5.5 m tree height (d12_55)).

In Figure 2 no clear trends can be shown: the horizontal changes in wood density along the radius show a low variation, giving no advice to statistically significant differences between the positions of the samples in radial direction. Not even the often described influence of juvenile wood in the centre of the tree can be shown (Fukazawa, 1984). A very low but statistically significant difference was found for mean density at 1.3 m and 5.5m tree height ($p < 0.05$). One reason for these differences could be based upon the higher maturation of the cells, more advanced at 1.3 m than at 5.5 m tree height. The assimilation of substances typical on older tissues (tannin agents) in the parenchyma could conduce to higher densities at 1.3 m (Vorreiter, 1949). However, the low variation of density between tree heights is probably of no influence to processing and drying of the wood.

Module of elasticity

The same analysis as for the density was carried out for the MOE. For the 2 directions (North and South) no significant difference for the MOE –values in 1.3 and 5.5 m tree height were found. The descriptive statistics for the MOE from the both tree heights are shown in the Table 2.

Table 2: Descriptive statistics for the Module of Elasticity (MOE).

MOE ($\mu = 12\%$) (N/mm ²)	Orientation	Mean	Min	Max	Std. Dev.	Median
Tree (5.50 m)	Both	9641	5830	13078	1555	9929
height (1.30 m)		10272	3887	13509	1601	10478

The values of the MOE are slightly higher at 1.3 m height than at 5.5 m height (according to the values of the density). The values of the standard deviation show the amplitude between the maximum and minimum values. These values are similar to the findings found by Cruz & Caldenteu (2007) for *Nothofagus betuloides* with 10310 (N/mm²) and by Lohmann (1998) for *Nothofagus pumilio*, with 9700 (N/mm²).

Figure 3 shows next the distribution of the MOE along the stem radius (by relative position) from pith to bark at two tree heights. Lower levels of MOE appear at 5.5 m tree height, particularly close to the pith. In the middle of the radius, the MOE show lower dispersion than closer to the pith and to the bark. No significant changes in the MOE values in direction from pith to bark could be found, but for the different heights the differences were significant at a 5 % level, coinciding with the corresponding results obtained for wood density.

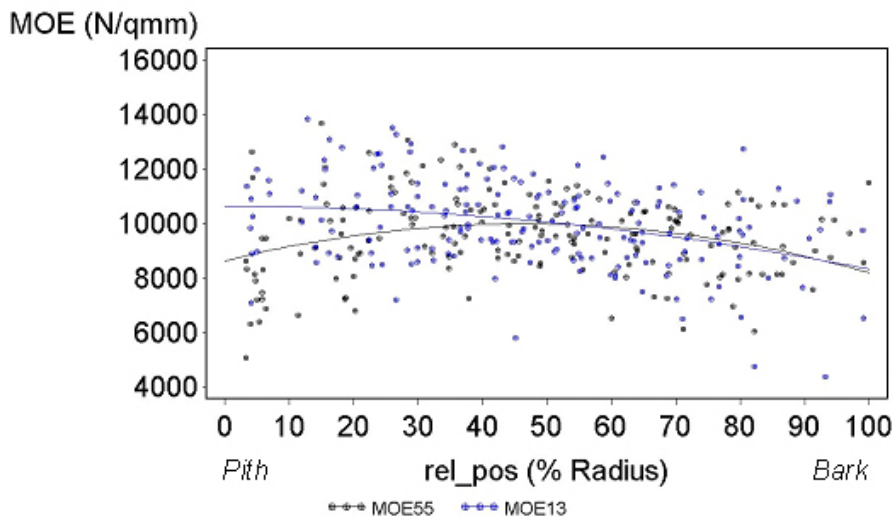


Fig. 3: Distribution of the Module of elasticity (MOE) along the stem radius (MOE55: MOE at 12% wood humidity at 5.5 m height; MOE13: density at 12% wood humidity at 1.3 m tree height).

These differences in density and MOE might result in formation of internal stresses inside the tree and sawn wood and therefore the appearance of cracks or end splits in the sawn wood (Maeglin, 1987; Vorreiter, 1949). However, even being statistically significant the differences probably are of low influence to wood utilization and processing.

Dimensional stability

The wood samples were put under different climate conditions and measured after the standard DIN 52184(Lohmann, 1998) as explained in the material and methods section.

Table 3 shows the results for the swelling and shrinking (in radial and tangential direction) of the *Nothofagus betuloides* samples.

Table 3: Descriptive statistics from the radial and tangential swelling and shrinkage, and the Volume shrinkage for “Nothofagus betuloides”.

(%)	Mean	Std. Dev.	Min	Max	Median
Radial swelling	6.48	2.93	-4.8	23.88	6.06
Tangential swelling	15.24	5.76	3.41	33.74	14
Radial shrinkage	3.24	1.37	0.4	13.17	3.16
Tangential shrinkage	7.28	2.51	-3.51	18.26	6.85
Volume shrinkage	11.59	4.23	3.4	30.03	11.9

The ratio between the mean value of tangential and radial shrinkage shows a values of 2.24. Lohmann (1998) and Grammel (1989) stated a ratio of these values in a range from 1.2 up to 3 as common for hardwoods. The origin of this anisotropy was explained by Bosshard (1956): the micelle distribution in the wood fibre wall produce that the shrinkage and swelling occur radial and perpendicular to the longitudinal direction. The most important parameter for the wood with furniture purposes is shrinkage, since it represents the reduction of the wood volume, depending on the climatic conditions the wood is exposed (Forest Products Laboratory, 1957). Therefore, the shrinkage behaviour of wood is shown in Figure 4.

Tangential shrinkage shows slightly higher values than radial shrinkage. The distribution shows lower values of the shrinkage closer to the bark. The values of the shrinkage at 5.5 m tree height have a higher variability than the ones at 1.3 m height.

The same procedure used by the wood density and MOE was carried out in order to analysed the differences in the shrinkage inside the stem radius and inside the tree (at 1.3 m and 5.5 m height) by a t-test. No statistically significant differences were found inside the stem radius, but for different tree heights at a 5% level.

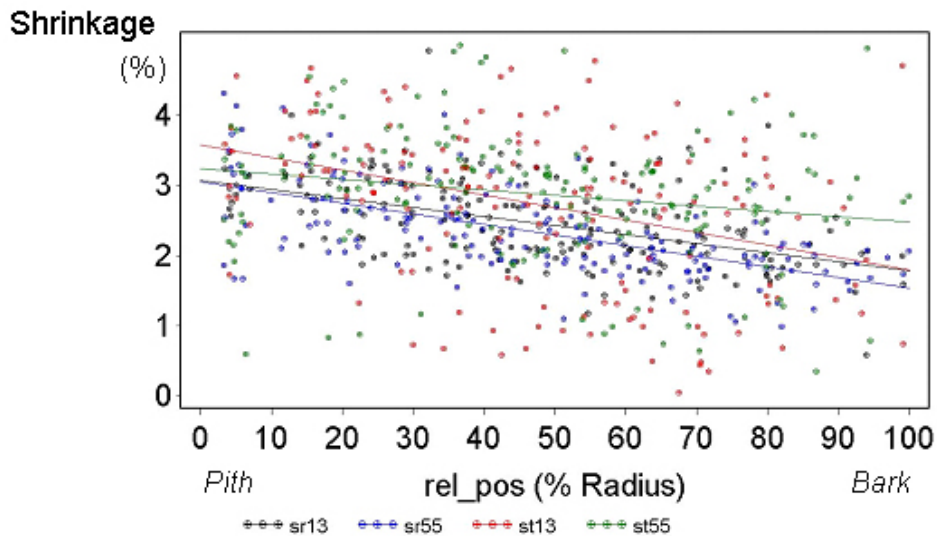


Fig. 4: Distribution of shrinkage (%) along the stem radius (sr13: radial shrinkage at 1.3 m; sr55: radial shrinkage at 5.5 m; st13: tangential shrinkage at 1.3 m; st55: tangential shrinkage at 5.5 m).

Relationship between the wood properties of *Nothofagus betuloides*

Wood density and MOE

Previous studies found positive relationships between the MOE and wood density (Knapic et al, 2007; Grammel, 1989; Vorreiter, 1949; Kollman and Krech, 1960). In these studies, the values of the MOE show a good correlation with wood density and in some cases also position in the stem (i.e. with juvenile or mature wood). For testing the relationship between these two parameters, the data of the MOE are plotted over wood density (see Figure 5)

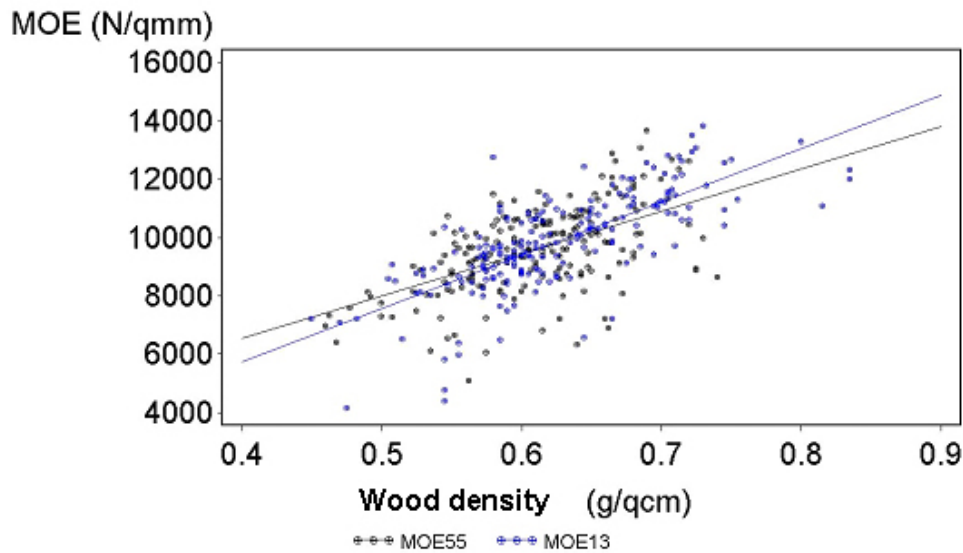


Fig. 5: Relationship between the Wood density and the MOE for the two tree heights.

There is only a slight difference in the relationship between the two tree heights measured related to the position of the sample in radial direction. From the figure can be stated that, with increasing wood density also strength properties increase.

Wood density and Shrinkage.

Since the shrinkage has a strong relationship to the wood density (Siau, 1995), Figures 6 and 7 show the distribution of the shrinkage depending on the values of the wood density. Figure 6 shows radial shrinkage plotted over wood density, while Figure 7 shows tangential shrinkage under different wood moisture contents ($u=0\%$; $u=8\%$; $u=12\%$, and $u=18\%$) over wood density.

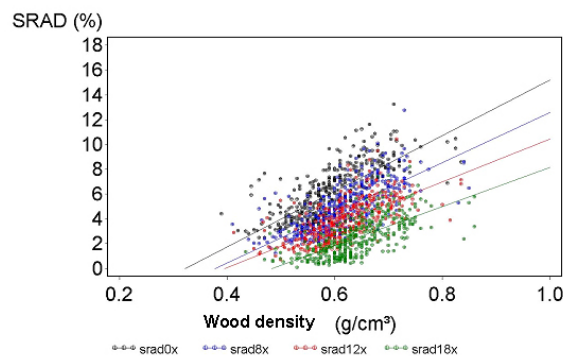


Fig. 6: Radial shrinkage (SRAD) related to the wood density at four wood moisture content (srad: radial shrinkage at the correspondent wood moisture content).

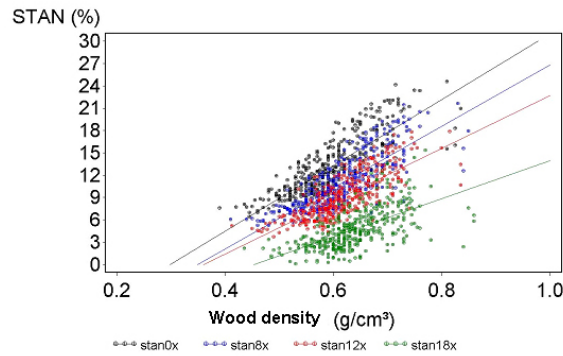


Fig. 7: Tangential shrinkage (STAN) related to the wood density at four wood moisture content (stan: tangential shrinkage at the correspondent wood moisture content).

An increase in wood density causes an increase in shrinkage. The increase of shrinkage values is higher, the lower is the water content in the wood. This is confirmed by Siau (1995). As already stated, tangential shrinkage is nearly twice as high as radial shrinkage. The increase of shrinkage at lower wood moisture content is important for the drying process. During drying, the surface layers begin drying, shrink to a certain extent, and even compress the interior of the piece slightly before that part has reached the fibre saturation point. Thus, the wood may show some shrinkage before the average moisture content reaches this point. The difference in the drying and shrinking at the surface of sawnwood and inner zones tends to set up severe stresses that may cause such seasoning defects as surface and end checking, case-hardening, honeycombing, and collapse (Forest Products Laboratory, 1957).

Conclusions

The wood properties of *Nothofagus betuloides* coming from native forest were analysed in order to describe the behaviour of this species as knowledge for further higher value wood utilizations. The results showed normal ranges wood density compared to other *Nothofagus* species, as well as for Module of Elasticity. Differences between the densities and MOE from two different tree heights were found, but not between the north and south direction. Wood density is positively correlated to MOE and Shrinkage, indicating higher values of these parameters with higher wood density.

The presentation of the mean values of wood density and MOE indicate the high variability of these parameters between trees. There were differences of these parameters and shrinkage between the two tree heights, which are indicators of certain variability inside the trees, common in the structure of a natural forest.

The frequent occurrence of cracks, checks and end-split in kiln-dried *Nothofagus* lumber is originated with high probability by differences in the wood properties between the trees, causing inhomogeneous charges of lumber in the kilns. Since the variation of wood properties inside the trees is much lower than the variability between the trees, a sorting of green sawnwood after wood density is highly recommendable in order to reduce this inhomogeneity in the charges of lumber. This may cause quality problems due to unequal

shrinkage during the drying process. Special drying schedules for each density class may reduce significantly quality problems in kiln-dried lumber.

Nevertheless, further studies about wood properties of the species are necessary to become statistically representative results giving wood industry more background information about how processing the wood of *Nothofagus betuloides* with high recovery rate of high value lumber.

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