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Director: DrC. Marta Bonilla Vichot
Email: mbon@upr.edu.cu

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Original article

Influence of some factors on the warping of Pinus *caribaea Morelet var. caribaea* Barret and Golfari sawn wood

Influencia de algunos factores en el alabeo de la madera aserrada de *Pinus caribaea Morelet* var*. caribaea* Barret y Golfari

Influência de alguns fatores no empenamento da madeira serrada de *Pinus caribaea Morelet* var*. caribaea* Barret e Golfari

Inés González Cruz[1*] https://orcid.org/0000-0001-7900-8547

Luisberys Velázquez Abad[2] https://orcid.org/0000-0001-6303-9664

Daniel Álvarez Lazo[1] https://orcid.org/0000-0001-7627-0152

[1]University of Pinar del Río "Hermanos Saíz Montes de Oca". Pinar del Río, Cuba.

[2]Academic Universidad Católica del Norte. Antofagasta, Chile.

*Corresponding author: nes@upr.edu.cu

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ABSTRACT

The quality of sawn wood is affected by the warping that it presents after drying, it is important then, to understand the mechanisms that regulate this deformation. Consequently, this work offers results of the influence of the variation and sawing patterns, dimensions and drying time of the pieces, on the warping of the sawn wood of *Pinus caribaea* var *caribaea*. The sawn pieces come from trees of the same origin, diameter and age. The study of the sawing variation was carried out with a methodology similar to that proposed Center of Forestry Studies, samples were taken with the same length and width but, of different thickness to every third of the selected piece. For the analysis of sawing schemes, sawn pieces were used taking into account the position of

the medulla on the face, edge and center of the piece and pieces that do not contain it. The influence of the dimensions, were studied from taking pieces in different positions in radial direction with different dimensions (13 x100x3000) mm and (75x100x3000) mm were coded as: A, B and C by the distance to the medulla. Warpage measurements were made at 25, 60 and 90 days of drying. According to simple analysis of variance, the sawn pieces that experience less warpage are those that not contain medulla, those that do not experience variations in sawing, and those with greater thickness. Warping increases with drying time.

Keywords: Warp sawn scheme; Medulla; Variation.

RESUMEN

La calidad de la madera aserrada, es afectada por el alabeo que presenta posterior a su secado, es importante entonces, entender los mecanismos que regulan esta deformación. En consecuencia, este trabajo, ofrece resultados de la influencia de la variación y esquemas de aserrado, dimensiones y tiempo de secado de las piezas, sobre el alabeo de la madera aserrada de *Pinus caribaea* var *caribaea*. Las piezas aserradas provienen de árboles de igual procedencia, diámetro y edad. El estudio de la variación de aserrado se realizó con una metodología similar a la propuesta por el Centro de Estudios Forestales de la Universidad de Pinar del Río, Cuba, se tomaron muestras con igual largo y ancho, pero de diferente espesor para cada tercio de la pieza seleccionada. Para el análisis de esquemas de aserrado, se utilizaron piezas aserradas teniendo en cuenta la posición de la médula en cara, canto y centro de la pieza y piezas que no la contienen. La influencia de las dimensiones, se estudiaron a partir de tomar piezas en diferentes posiciones en dirección radial con diferentes dimensiones (13 x100x3000) mm y (75x100x3000) mm fueron codificadas como: A, B y C por la distancia a la médula. Se hicieron mediciones de alabeo a los 25, 60 y 90 días de secado. De acuerdo, con análisis de varianza simple, las piezas aserradas que experimentan menor alabeo son, las que no contienen médula, las que no experimentan variaciones de aserrado, y las de mayor espesor. El alabeo, aumenta con el tiempo de secado.

Palabras clave: Alabeo aserrado esquema; Médula; Variación

SÍNTESE

A qualidade da madeira serrada é afetada pela teia após a secagem. Por isso, é importante compreender os mecanismos que regulam esta deformação. Conseqüentemente, este trabalho oferece resultados sobre a influência da variação e esquemas de serragem, dimensões e tempo de secagem das peças na teia de madeira serrada de Pinus caribaea varibaea. As peças serradas provêm de árvores da mesma origem, diâmetro e idade. O estudo da variação da serragem foi realizado utilizando uma metodologia semelhante à proposta pelo Centro de Estudos Florestais da Universidade de Pinar del Río, Cuba. As amostras foram retiradas com o mesmo comprimento e largura, mas com espessuras diferentes para cada terço da peça selecionada. Para a análise dos padrões de serragem, foram utilizadas peças serradas, levando em conta a posição da medula na face, borda e centro da peça e peças que não a contêm. A influência das dimensões foi estudada tomando peças em diferentes posições na direção radial com diferentes dimensões (13 x100x3000) mm e (75x100x3000) mm foram

codificados como: A, B e C pela distância até a medula. As medidas de empenamento foram feitas aos 25, 60 e 90 dias de secagem. De acordo com a simples análise de variância, as peças serradas que experimentam menos deformação são aquelas sem medula, aquelas sem variações de serragem e aquelas com maior espessura. A deformação aumenta com o tempo de secagem.

Palavras-chave: Warpage; esquema de serragem; Pith; Variação

INTRODUCTION

Cuba carries out a broad forestry development program, which includes, among others, the production of sawn wood. This responds to the development of some society sectors such as agriculture and tourism that, together with the need for industrialization and the increase in life expectancy, elevate the demand of the product.

However, in sawn pieces, the remaining stresses cause cracks and warping (Silva *et al.* 2016) and the lack of straightness in the wood is one of the main reasons that limit the satisfaction of wood products in the world (Eastin *et al.* 2001).

Warpage, the main deformation, is a serious problem for sawmills and wood dryer. Because of this deformation the wood loses quality, the most important item in the budget of sawmills where increasing the conversion efficiency in the industry of the sawing is a primary need.

One way to face this problem is with the understanding of the mechanisms that regulate the deformations. A study in this regard can lead to the identification of the most important factors and parameters that have a direct influence on the quality of the product, and therefore help an adequate selection of the material before sawing and drying to optimize the use of each log received in the sawmill.

The sawmill industry consists of a series of operations that are necessary for the conversion of logs into sawn wood to be a feasible process, at least from an economic point of view (Álvarez *et al.* 2010). This author himself states that some factors inherent to the species are essential to obtain quality and yield in the logs, including factors intrinsic to the species and extrinsic factors such as the curvature of the log; coinciding with Ferreira *et al.* (2004) cited by Carvalho *et al.* (2019).

Latorraca *et al.* (2015), consider that the improvement of sawing techniques, together with the proper use of wood drying techniques, are of fundamental importance to obtain a better performance of the species.

Other researchers have studied the effect that the application of one or another sawing method has on the yield of sawn wood (Álvarez *et al.* 2020).

Some works have reported that tangential sawing schemes with successive cuts and alternative tangential sawing schemes are used, with the tendency to reduce the release of internal growth stresses in cutting, which can cause defects of often impressive magnitudes due to the loss of compensation of these in some parts of the wood (Melo *et al.* 2019).

According to López *et al.* (2016), dimensional variability affects the wood brush performance of *Eucalyptus saligna*. Returning to this study, it can be argued that dimensional variation is a factor that affects the workability of wood.

In particular, in Pinar de Rio province, sawmills mainly process *Pinus caribaea.* var*. caribaea*, a species with a great economic perspective in the territory. It is also the main species processed in the sawmill industry in Cuba, however, the deformations it acquires after drying, with a marked incidence specifically in warping, limit its efficient use in the construction sector (González *et al.* 2019).

Accordingly, the objective of the present study is related to the determination of the influence of some factors such as the dimensions of the sawn pieces, sawing variations, sawing schemes and drying time on the magnitudes of the deformations of the sawn wood of *Pinus caribaea* var*. caribaea* after drying.

MATERIALS AND METHODS

Working conditions

The work is carried out at the Albaro Barba sawmill, belonging to the Pinar del Rio Agroforestry Company, Pinar del Rio province. This company is part of the Ministry of Agriculture and it is located on the road to San Juan, Pinar del Rio. In the lumber storage yard of the establishment, measurements related to the quality of the lumber are made; thus, it is important to define that the research is done in real time.

Methodology used

Determination of sample size and sampling intensity

The data were taken from a population of 100 sawn pieces of *Pinus caribaea* var *caribaea*; from logs obtained from the Pinar del Rio Agroforestry Company, in the homonymous province. The thickness of the sawn pieces was used as a variable of interest to state the number of representative units for the study, based on the equation presented by Chacko (1965), Freese (1967) and Álvarez *et al.*, (2020) (Equation 1):

$$n = \frac{t_{\acute{a}}^2 * S^2}{E^2} \quad (1)$$

In which: n-sample size; $t^2_{\acute{a}}$ - tabular value of t with (n-1) degrees of freedom; S^2 Estimated variance; EAdmissible error.

Dimensions of the pieces

100 samples were taken from each position in the radial direction, from 200 trees from the same site and of the same age. The pieces have different dimensions (13x100x3000) mm and (75x100x3000) mm and were coded as: A, B and C. Type A pieces are those obtained in the log from the position closest to the pith, B, from the area between the

pith and the bark and the type C pieces are those obtained from the part of the log closest to the bark, exposed to the drying process, in the open air for 90 days.

Sawing variation

The experiment to study the sawing variation was undertaken with a methodology similar to that proposed by Simpson and Schernitz (1997). 100 samples were taken that form a group (A) and an equal number of them form group B. Both groups are made up of sawn pieces obtained from the closest position to the marrow (without containing it), with the same orientation of growth rings and outline of sawing. The dimensions of the pieces in group A are (13×100×3000) mm. Group B underwent sawing variations, for which pieces of the same length (3000mm) and width (100mm) were taken, but of different thickness for each third of the piece, meaning, 1/3 with a thickness of 13mm, 1/3 thickness of 35mm and 1/3 of 50mm.

Sawing schemes

In correspondence with the determined sample number, 100 sawn pieces of trees of equal diameters and origin, with dimensions (13×100×3000) mm, were used. The pieces were coded as: A, B, C, D and E. Type A are those with the medulla located on one side of the face, B in the center of the face, C in the edge, D and E do not contain the medulla. The difference between the last ones is that the orientation of the rings is dissimilar, they were exposed to the drying process in the open air for a period of 90 days and deformation measurements were made (warp). Each pile during storage for drying was made with the pieces that were sawn with the same pattern.

To make the statistical evaluation of the results obtained in each experiment, the SPSS 10.0 software is used. A simple analysis of variance was performed with a significance level of 5 %. To determine the groups between which the difference exists, a multiple comparison test was performed. The statistics were calculated: mean, standard deviation, error of the standard deviation of the mean.

RESULTS AND DISCUSSION

Warping behavior in pieces of sawn wood with different dimensions

The results of the deformation (warping) experienced by pieces of dimensions (13x100x3000) mm and (75x100x3000) mm after being subjected to drying for a period of 90 days, are shown in Tables 1 and 2 below.

Table 1. – Duncan test from the analysis of the comparison of warping means in pieces of different dimensions

radial position	Warp (mm)	
	p 1	p2 _
A	0.57308[a]	0.4715[b]
B.	0.53116[a]	0.4274[b]
C.	0.48423[a]	0.3781[b]

Results with the same letter, there is no significant difference between them for * p ≤ 0.05 P 1 — (13x100x3000) mm P 2 — (75x100x3000) mm

Coincidentally, in pieces of different dimensions, the warping decreases towards the cortex, that is, it presents a gradient towards the medulla (Table 2).

Table 2. – Analysis of variance of warpage-dimensions of the piece

Position	Mean	Variance	N
A_{p1}	0.57308	0.000810	**101**
A_{p2}	0.46683	0.00458	**101**
F = 211.69163 P= 0			
B_{p1}	0.53166	0.0009.32	**101**
B_{p2}	0.42317	0.00502	**101**
F = 199.72641 P = 0			
C_{p1}	0.48423	0.00131	**101**
C_{p2}	0.37436	0.06618	**101**
F=162, 79034 P=0			

At the 0.05 level, the means are significantly different

Regarding the deformations depending on the dimensions, the results show that the thickest pieces experience the smallest deformation, a result that coincides with studies carried out by Simpson and Schernitz (1997) in *Pinus elliotii plantations* in which for the boards of greater thickness, smaller values of twisting were determined.

This warping behavior in the different positions can be explained taking into account that the wood coded with position A corresponds to juvenile wood and the one coded with position C corresponds to adult wood, and between both the anatomical characteristics are markedly different. According to Changging *et al.* (2021), juvenile wood is characterized by a high variability of its anatomical and physical properties. Adult wood presents smaller angles of the microfibers that together with the narrow dimensions of the cell wall and the longer and thicker tracheids provide greater stability of the sawn wood; coinciding with Tumenjargal *et al.* (2022).

In the analysis of variance and mean comparison according to SNK, for a significance level of 0.05, the difference in warpage values in pieces of different dimensions for the positions studied is significant.

Influence of sawing variations on warpage

In tables 3 and 4 it can be seen that the sawing variation has a marked influence on the dimensions of the warping of the wood after drying. This result corroborates the statements made by Barrera *et al.* (2016); defining the need to take into account the control charts in the sawmills to increase the yields and quality of the sawn wood obtained.

Table 3. - Analysis of variance for warpage-variation of sawing

Deformation	N	Minimum	Maximum	Mean	Standard Deviation
Warp (sv)	52	0.29	0.86	0.5726[a]	0.1335
Warp (cv)	52	0.46	1.04	0.6418[b]	0.1896

Results with different letters present a significant difference for *p≤0.05

In the case of the pieces subjected to sawing variation, warping presents a higher value, compared to the group that does not present variation, a result that coincides with studies carried out on *Pinus elliotii* (Simpson and Schernitz 1997).

Table 4. - Analysis of mean comparison according to SNK for the warpage-variation of sawing

	Variable	No.	subset for alpha=0.5	
			1	2
Student-Newman-Keuls [to]	2,0000 (sv)	100	0.5726 _	
	1.0000 (hp)	100		0.6418
	Next		1,000	1,000

It can be assessed that there is a significant difference between the warping values for the group with sawing variation and the group without sawing variation, for a significance level of 0.05.

Analysis of deformations (warping) and sawing schemes

The result obtained from warping in different sawing schemes is shown in (Table 5 and Table 6).

Table 5. - Analysis of variance for warping-sawing schemes

Scheme	N	Mean	Variance
B	130	0.8707[d]	0.1246
A	130	0.6540[c]	0.0598
E	130	0.54 07[b]	0.0624
D	130	0.4947[a]	0.0456
C	130	0.5533[b]	0.0487

Results with different letters present a significant difference for *p ≤0.05

Table 6. - Results of the mean comparison analysis for warping for the different sawing schemes

Scheme sawn	Minimum	Maximum	Mean	Standard Deviation
B	0.55	1.04	0,8707[d]	0.1246
A	0.52	0.81	0,6540[c]	0.0598
E	0.29	0.65	0,5407[b]	0.0624
D	0.38	0.60	0,4947[a]	0.0456
C	0.49	0.70	0,5533[b]	0.0487

Results with the same letter do not present a significant difference, *p≤0.05

The position of the medulla in the sawn piece determines the degree of deformation that it experiences, an assessment similar to that proposed by Shmulsky and Dahlen (2007). In scheme B, in which the pith is in the center of the sawn piece, it experiences the greatest deformation.

The schemes coded as A, B and C contain the medulla, but this is not the case in scheme D, in which the orientation of the growth rings is transversal to the longitudinally oriented face and undergoes the least deformation.

Taking into account the statistical analysis, it can be seen that there is a significant difference between the warping values for the different sawing schemes; coinciding with González *et al.* (2010) and Peña *et al.* (2011), which establish that the sawing scheme itself defines the quality of the sawn wood and the deformations that are derived during its drying.

On the other hand, it can also be defined in correspondence with the results obtained that there are no significant differences for the warping of the sawn wood in schemes C and E.

Drying time and deformations

The deformations vary with the drying time, increasing with it, but this occurs after a certain period. 20 days after of being subjected to this process, very small deformations are registered. This behavior is explained by the moisture content at which the pieces are found. If it is below the saturation point of the fiber, in this state the water that is lost by drying is the free water (Table 7 and Table 8).

Table 7. - Mean comparison analysis, according to SNK of the warping behavior with drying time

Positions	drying time _		
	20 days	60 days	90 days
	Warp		
A	0. 2951[a]	0.5128[a]	0.5731[a]
B	0.1918[b]	0.4921[b]	0.5316[b]
C	0.1730[c]	0.4130[c]	0.4842[c]

Results with the same letter, there is no significant difference between them * p ≤ 0.05

Table 8. - Analysis of variance of alabeo-drying time

Tiempo	Mean	Variance	N
twenty	0.173	0.000136	100
60	0.4135	0.0026667	100
90	0.4843	0.0026667	100

F = 1501, 9003 p=0

The stresses that occur in a piece of wood during drying are of a different nature, depending on whether their moisture content is above or below the saturation point of the fibers. Above the saturation point of the fibers, capillary tension is responsible for the stresses that occur in the wood and in extreme conditions can lead to cell crushing, also known as collapse.

Below the saturation point of the fibers, drying stresses, responsible for the normal shrinkage of wood, develop in the cell walls and are a consequence of the moisture content gradient that occurs between the surface layers and the center of the piece of wood. Under extreme conditions, these forces can lead to the appearance of defects such as hardening, surface cracks and internal cracks; coinciding with González *et al.* (2020).

CONCLUSIONS

In *Pinus caribaea* var*. caribaea,* the sawing variation causes a significant increase in the magnitude of warping from a decrease in moisture content.

There is a marked influence of the sawing schemes on the magnitude of the deformations. Pieces that contain the pith in the center of their cross section are those that present the highest levels of warpage.

Warping increases as the drying time increases, but more intensely after 20 days.

The pieces of less thickness present greater deformations, being the pieces close to the bark, the ones of the highest quality for first and second transformation works in the wood industry.

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Authors' contribution:
The authors have participated in the writing of the work and analysis of the documents.