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VARIABILITY OF SOME WOOD PHYSICAL PROPERTIES OF TEN *CEDRELA ODORATA* L. CLONES

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Abstract: This study investigated the physical properties of wood from branches of 10 selected clones of red cedar (*Cedrela odorata* L.), focusing on determining the basic density, anisotropy ratio, and linear and volumetric shrinkage of the wood samples. The objective of this study was to know the wood properties variation related to wood quality to improve the selection of superior clones for the establishment of forest plantations with this species. Wood samples were collected from the first living branch of three trees per clone. Two sections of 5 cm thickness were obtained from each branch, and 2 cm cubes were taken from each section. These samples were used to determine the volume and dimensions of the wood in saturated and anhydrous conditions. Basic density was calculated by dividing the anhydrous weight (dried at 103 ± 2 °C) by the saturated volume. Total shrinkage was determined by calculating the ratio between the initial and final linear dimensions or volume change. The collected data underwent variance analysis and mean comparison using Tukey's method ($\alpha = 0.05$). The results revealed significant differences ($p \leq 0.05$) in the wood properties among the clones. The average values for basic density ranged from 320.08 to 438.19 kg/m3. The average total linear shrinkage varied between 5.00% and 6.47% in the tangential direction, 2.95% and 4.38% in the radial direction, and 0.25% and 0.46% in the longitudinal direction. The average volumetric shrinkage ranged from 8.07% to 10.88%, and the anisotropy ratio (ANR) ranged from 1.27 to 1.69. Based on the values of wood basic density and ANR, it can be concluded that clones 4 and 8 exhibit the best wood properties. This study confirms that wood basic density, shrinkage, and ANR are additional parameters that contribute to the improved selection of red cedar clones, along with their growth characteristics.

Keywords: Spanish cedar, wood basic density, wood shrinkage, dimensional stability

INTRODUCTION

The heartwood of red cedar (*Cedrela odorata* L.) is renowned for its colour, aroma, and exceptional resistance to fungi and insect attacks. These wood traits make red cedar highly demanded and valued for its commercial uses such as veneers, the manufacture of fine furniture, turned articles, sculptures, boxes and wrappers for cigars, musical instruments and boat building (Pennington and Sarukhán, 2005). Unfortunately, the wood popularity and demand of this species has led to excessive and selective exploitation, resulting in a decline and fragmentation of natural populations (Hernández Ramos *et al*., 2018). As a result, red cedar has been classified as a species "subject to special protection" in the Mexican Official Standard 059 (NOM-059) (SEMARNAT, 2010) and listed in Appendix III of CITES (CITES, 2010).

In Mexico, red cedar is one of the primary timber forest species cultivated in commercial plantations, accounting for 22.6% of the total plantations (CONAFOR, 2015). However, the productivity of red cedar has not met expectations due to challenges such as insufficient control measures, lack of knowledge regarding seed and plant sources, and attacks by the shoot borer *Hypsipyla grandella* (Zeller) (CONAFOR, 2013).

Provenance and progeny trials have been conducted since 1994 in the Yucatan Peninsula and Veracruz (Ward *et al*., 2008; Hernández-Máximo *et al*., 2016; 2021) to address these issues and improve red cedar productivity. These trials aim to select genotypes with desirable characteristics, higher yields, and increased tolerance to borer attacks. Provenances and individual trees exhibiting superior growth in diameter, height, volume, and borer tolerance are selected for cloning and subsequent clonal trials (Sánchez *et al*., 2018).

In genetic improvement programs, the selection of superior genotypes and clones for red cedar focuses not only on rapid growth, adaptation, bole shape, and disease resistance but also on improving wood quality (Hytönen *et al*., 2018; Xiao *et al*., 2021). Wood quality evaluation includes assessing various wood properties, such as basic density, which has high heritability and repeatability (Xiao *et al*., 2021) and is associated with physical properties, wood machining, and wood hardness (Shmulsky and Jones, 2019).

As part of the evaluation process of superior red cedar clones in clonal trials, the present study determined the traits of basic density, anisotropy ratio, and linear and volumetric shrinkage of the wood from branches of 10 clones exhibiting the highest growth in height, diameter, and volume. The objective was to know the variation of wood traits related to wood quality to improve the selection and evaluation of the most promising clones for its use in forest plantation establishments.

MATERIALS AND METHODS

Ten red cedar clones (4, 8, 27, 60, 61, 63, 72, 83, 90, 95) were selected based on a principal component analysis of the variables of normal diameter at 1.30 m, total height, clean stem height, and straight stem height (Sánchez et al., 2018). The variables were measured in October 2017 in two experimental red cedar clonal plantations established in August 2012. They contained 90 clones, with 3 m × 3 m spacing in completely randomized blocks and six replicates. One of the plantations are located within the company "Agropecuaria Santa Genoveva" (19º 33' 26.53" N, 90º 01' 33.96" W) in Campeche, at an elevation of 82 meters above sea level, with an average annual rainfall of 1300 mm and an average annual temperature of 26 °C, and clayey soil of calcareous origin. Another plantation is located in Isla, Veracruz (18º 04'50.21" N, 95º 32' 0.75" W) at an altitude of 52 meters above sea level, with an average annual rainfall of 2000 mm, an average annual temperature of 25 °C, and sandy soil.

For each clone, three trees were selected based on their highest values of the first principal component. The first living branch of each tree was cut, discarding the first 15 cm from the base of the branch to avoid possible influence from reaction wood. Next, a 50 cm long section was obtained, labelled with the tree number and clone to be later transported to the laboratory. A 2 cm thick cross-section (slice) was then cut at both ends of the branches, leaving a 5 cm margin from each.

Each of the slices was marked to obtain 2 cm cubes in the central part of each slice in the shape of a cross. The cubes were labelled according to the clone, slice, and slice location, and then placed in a desiccator filled with distilled water and subjected to vacuum until completely immersed. The saturated volume of each cube was determined using water displacement (ASTM, 2015) on an analytical balance, and their dimensions were measured in the radial, tangential, and longitudinal directions with a digital vernier (±0.01 mm of accuracy). Next, the cubes were dried in the laboratory at room temperature on a plastic mesh for five days and then dried in an oven at 103 ± 2 °C for 48 hours. After drying, the cubes were placed in a desiccator on silica gel for 15 minutes, followed by the measurement of their weight and dimensions.

The wood basic density was calculated as the ratio between the anhydrous weight and the saturated volume of each cube. The total shrinkage and the anisotropy ratio were determined with the following expressions (Suchsland, 2004):

$$TLs\ (\%) = \frac{Change\ of\ dimension\ (T,R,L)}{Initial\ dimension}\ x\ 100 \quad (1)$$

Total volumetric shrinkage (Vs) (%) =

$100[1-(1-0.01Ts)(1-0.01Rs)(1-0.01Ls)]$ (2)

Anisotropy Ratio (ANR) = Ts/Rs (3)

Where TLs refers to the total linear shrinkage (%); T, R, L denote the respective tangential, radial, and longitudinal directions; Vs represents the total volumetric shrinkage (%); Ts, Rs, and Ls are the total tangential, radial, and longitudinal shrinkage, respectively.

An analysis of variance (ANOVA) was performed on the collected data for each of the variables, considering the clone as the source of variation and followed by multiple comparisons of means with the Tukey method ($\alpha = 0.05$), using the SAS software program (SAS, 2009).

RESULTS AND DISCUSSION

The ANOVA results indicated significant differences between clones ($p < 0.05$) for the wood physical properties of basic density, linear and volumetric shrinkage, as well as the wood anisotropy ratio (ANR) (Table 1 and 2). The basic density of wood is an important physical property due to its relationship with mechanical resistance and hardness, while shrinkage and ANR are related to the dimensional stability of wood (Shmulsky and Jones, 2019).

The average wood basic density of the branches of the clones varies from 320.1 to 438.2 kg/m^3 (Table 1), presenting the highest values in clones 72 and 83, followed by clones 8 and 27, with significant differences ($p \leq 0.05$) with respect to the rest of the clones. Clone 90 has the lowest basic density. Clones 60 and 95 also showed low basic density values, while intermediate values were observed in clones 4, 61 and 63. The values with less variation indicate greater clonal uniformity (Cown and Sorensson, 2008), which is given by the amplitude of the normal distribution function and the standard deviation, so that clones 8 (6.8%) and 4 (8.1%) present more excellent uniformity in the basic density. In contrast, clones 61 (15.2%), 90 (15.5%) and 95 (19.3%) have the least uniformity.

The values of wood basic density obtained for the branches of the red cedar clones are greater than or equal to 300 kg/m^3, which are within the range of 340 ± 30 kg/m3 reported by Gutiérrez-Vázquez et al. (2012) for stem wood of red cedar. Lower values of wood basic density of 280 ± 60 kg/m^3 were obtained by De Los Santos (2014) for this species. This difference may be attributed to the effect of the reaction wood present in the branches.

On average, the total linear shrinkage ranges from 5.0 to 6.47% in the tangential direction, 2.95 to 4.38% in the radial direction, and 0.25 to 0.46% in the longitudinal direction (Table 1). Clone 83 exhibits the highest values of wood shrinkage in all three directions, while clone 90 has the lowest values.

Regarding total volumetric shrinkage, the average values fluctuate between 8.07% and 10.88%, with clone 83 having the highest value and clone 90 having the lowest. The ANR values ranges from 1.27 to 1.69 (Table 2), corresponding to clone 4 and 90, respectively.

The dimensional stability of the wood in use mainly depends on the dimensional changes in the tangential and radial directions. Thus, it is more significant to determine the total shrinkage in these directions, as the measurement of volumetric shrinkage may not necessarily provide a good indication of the wood's stability in service. Therefore, the values of tangential shrinkage are crucial for calculating the ANR, which also serves as an index of wood stability, especially during the wood drying process.

Higher values of the ANR indicate that the wood will experience more significant distortions and have low stability. However, the lowest linear shrinkage values do not always guarantee high wood stability. In the case of clone 90, the wood presents the lowest

Clone	Wood basic density (kg/m³), (F=19.07, p < 0.0001)	Lineal shrinkage (%)		
		Radial (F=15.86, p < 0.0001)	Tangential (F=17.7, p < 0.0001)	Longitudinal (F=3.43, p=0.0006)
4	386.37 ± 31.28ǂ c e d†	3.95 ± 0.40 c b	5.09 ± 0.27 f e	0.35 ± 0.14 c b
8	416.40 ± 28.34 a b	4.05 ± 0.64 a b	5.91 ± 0.63 b c	0.39 ± 0.19 a b
27	409.38 ± 48.16 c b	4.05 ± 0.66 b	6.11 ± 0.78 b	0.37 ± 0.18 a b
60	362.26 ± 33.84 e	3.65 ± 0.36 c e d	5.60 ± 0.55 d c	0.40 ± 0.12 a b
61	380.04 ± 57.92 e d	3.41 ± 0.50 e	5.37 ± 0.49 d e	0.46 ± 0.19 a
63	405.52 ± 39.83 c b d	3.57 ± 0.63 e d	5.37 ± 0.63 d e	0.43 ± 0.20 a b
72	438.19 ± 41.64 a	3.78 ± 0.37 c b d	5.94 ± 0.43 b c	0.46 ± 0.19 a b
83	437.03 ± 48.62 a	4.38 ± 0.56 a	6.47 ± 0.47 a	0.46 ± 0.20 a b
90	320.08 ± 49.52 f	2.95 ± 0.34 f	5.00 ± 0.34 f	0.25 ± 0.08 c
95	374.51 ± 72.30 e	3.94 ± 0.66 c b	5.82 ± 0.87 b c	0.40 ± 0.19 a b

Table 1. Average values of basic density and linear shrinkage of the wood of 10 clones.

ǂStandard deviation, †Values with the same letter are not significantly different (p < 0.05)

Clone	Volumetric shrinkage (%) (F=15.83, p < 0.0001)	Anisotropy Ratio (ANR) (F=7.05, p < 0.0001)
4	9.04 ± 0.77ǂ c†	1.27 ± 0.11 e
8	9.66 ± 1.17 b c	1.44 ± 0.13 d
27	10.10 ± 1.20 b	1.56 ± 0.24 d b c
60	9.01 ± 0.53 c	1.46 ± 0.17 d c
61	9.05 ± 1.11 c	1.57 ± 0.21 a b c
63	9.23 ± 1.28 c	1.51 ± 0.24 d c
72	10.08 ± 0.66 b	1.64 ± 0.16 a b
83	10.88 ± 1.02 a	1.49 ± 0.20 d c
90	8.07 ± 0.64 d	1.69 ± 0.19 a
95	10.06 ± 1.57 b	1.48 ± 0.21 d c

Table 2. Average values of volumetric wood shrinkage and anisotropy ratio of 10 clones

ǂStandard deviation, †Values with the same letter are not significantly different (p < 0.05) values of linear and volumetric shrinkage, but its ANR value is the highest, indicating potential distortion problems during drying or in service. In contrast, the wood of clone 4 exhibits the lowest ANR value, suggesting better dimensional stability in service. Clone 8 also demonstrates a low ANR value, and its wood basic density is higher than that of clone 4. Clones 72 and 83 display higher values of wood basic density, volumetric shrinkage, and ANR compared to clones 4 and 8, indicating that the wood of the latter clones is of higher quality due to its high basic density and low ANR.

CONCLUSIONS

The basic density, the linear and volumetric contractions and the anisotropy ratio of the branch wood is significantly different among the red cedar clones studied.

The wood of the branches of clones 4 and 8 present greater uniformity in the basic density and low values in the anisotropy ratio, indicating a better quality of the wood with respect to that of the other 8 clones.

The results indicate that, in addition to tree growth, basic density, shrinkage and anisotropy ratio should be considered as physical properties in the clone selection process.

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