Floresta Ambient., Rio de Janeiro, 2024; 32(1): e20240042
https://doi.org/10.1590/2179-8087-FLORAM-2024-0042
ISSN 2179-8087 (online)

Floresta e Ambiente

ORIGINAL ARTICLE – Forest Products Science and Technology

Wood Basic Density Variation Along *Pinus occidentalis*, Swartz, and *Pinus caribaea*, var. Caribaea, Morelet tree stems

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Abstract

Pinus occidentalis and *Pinus caribaea* are important conifers in La Sierra, Dominican Republic, used to recover degraded ecosystems. A study on their wood density obtained from stem discs at three relative heights (RH) as a composite sample showed that wood density increased with age class for both species and decreased with RH in the stem. A mixed repeated measures analysis of variance, followed by a regression approach to the effects model, indicates a statistically significant interaction between species, age class (AC), RH, [, $P \leq 0.000$, partial =0.814]. Simple bidirectional interactions between factors and all simple main effects are statistically significant. Basic density (BD) increased with age class for both species and decreased with RH in the stem. *Pinus occidentalis* had a 14.6% higher average wood density and is endemic. Therefore, efforts must be made to provide better silvicultural practices so that its population continues to be a viable asset.

Keywords: analysis of variance, conventional densitometry, repeated measures analysis, wood physical properties.

1. INTRODUCTION

In "La Sierra", Dominican Republic (DR), two conifer species, *Pinus occidentalis*, Swartz, and *Pinus caribaea* var. caribaea, Morelet play very important roles, economically, ecologically, and socially. *P. occidentalis* is endemic of La Hispaniola (Hubbel et al., 2018), and is considered highly suitable for structural timber applications and developing value-added solid timber products (Klotz & Torres 1991). *P. caribaea* original habitat is in Pinar del Rio Province and Isla de la Juventud, western Cuba. It was introduced to the Sierra region around 1980, mostly replacing the endemic *P. occidentalis* in plantation establishment operations at lower elevations. Both species are classified within the genus *Pine*, Subgenus *Pinus*, Section Trifoliae, and Subsection Australes.

Little is known about the interaction between species, age, and RH with respect to their effects on basic density (BD) traits along the stem in *P. occidentalis* and *P. caribaea* in the study region. Therefore, detailed quantitative knowledge of variation in BD among these species and individual trees is required and should be valuable information for local forest managers.

Wood density (WD) varies among tree species (Li et al., 2024). Oliveira et al. (2022), as cited in Guo et al. (2024), state that even in the same region, WD varies between and within trees due to different environments. Density was correlated with mean annual precipitation, temperature, evapotranspiration, and soil water storage capacity (Lima-Costa et al., 2020; Oliveira et al., 2022). Gonçalves-Rocha et al. (2020) observed water deficit in the soil being the most significant variables with potential to estimate the BD in eucalyptus clones. Within a tree, WD usually increases from juvenile to mature wood in the radial direction and decreases from root to branch in the axial direction (Venega et al., 2023), although there are exceptions.

Conifer species from the *Picea*, *Pinus*, or *Pseudostuga* genera used in plantations worldwide have overall denser wood than most planted angiosperms (McCulloh et al. 2019). Topanotti et al. (2021) evaluated WD at different stem heights of *Pinus taeda*, L. managed under shelterwood silviculture and found that this treatment affected WD. Within a tree, WD usually increases from juvenile to mature wood in the radial direction and decreases from root to branch in the axial direction (Venega et al., 2023), but there are exceptions. The same effect has been reported by Beets et al. (2020) in *Pinus radiata*, D., although these authors also report an inverse effect for *Pseudotsuga menziesii*, (Mirbel) Franco in New Zealand.

Earlywood density of conifer species remains stable, whereas latewood density increases with age and from pith to bark (Moreno-Fernández et al., 2018). Morgado-González (2019) investigated radial changes in WD of *Pinus hartwegii*, Lindley. Their results indicate that changes in WD are influenced by altitude, but the level of change depends on exposure. Vaughan et al. (2019) informed of climatic fluctuations having a strong effect on *Pinus ponderosa*, Engelm density. For *Pinus halepensis* Miller, Hevia et al. (2020) found that climate at provenance and not planting site was more relevant for WD fluctuations. In *Pinus elliottii*, Engelm. temperature displayed higher correlations with WD than precipitation (Li et al., 2020).

We were interested in assessing the effects of these two species and the factors, age class (AC) and RH on the variation of BD along tree stems. The overall objective of this study was to assess inter-tree, intra-tree, and inter-species BD variation within the stem of *P. occidentalis* and *P. caribaea* trees planted in La Sierra, Dominican Republic (DR), as an initial assessment of the quality of their wood and timber potential. Specifically:

- BD variation between species.
- BD variation within trees at three RHs in each species.
- BD variation within trees belonging to three different age classes from each species.
- The presence of any interaction effects between these three factors.

To our knowledge, no information concerning *P. occidentalis* in this respect exists, and there are no records of BD comparisons between these two species.

2. MATERIALS AND METHODS

2.1. Study Area

Data for this comparative observational study was collected in six plantations of *P. caribaea* and *P. occidentalis,* growing side by side within La Sierra, DR, aged between 5 and 34 years. La Sierra is located between UTM coordinates 251748 m E - 325795 m E and 2116888 m N - 2156996 m N. Slopes range from zero to 70 percent. The elevation ranges from 400 m to 1000 meters above sea level. The average annual temperature is 24 °C, varying between maximum and minimum of less than 10 °C (Bueno & Bevilacqua, 2013).

2.2. Destructive sampling

Thirty trees were selected, 15 for each species and 5 per species in each age class (AC). Three ACs were considered: 5-14, 15-24, and 25-34 years. The trees selected for destructive sampling were healthy and without apparent defects. For sampling at 0.1, 0.5, and 0.8 relative heights, the total tree height of the stem was considered from 0.1 meters on the stump to the treetop (Figure 1). For each tree, one-inch-thick discs at the three RH were obtained. On each disc, subsamples were dissected, taking one portion from heartwood wood and two portions from sapwood to form a composite sample at each RH.

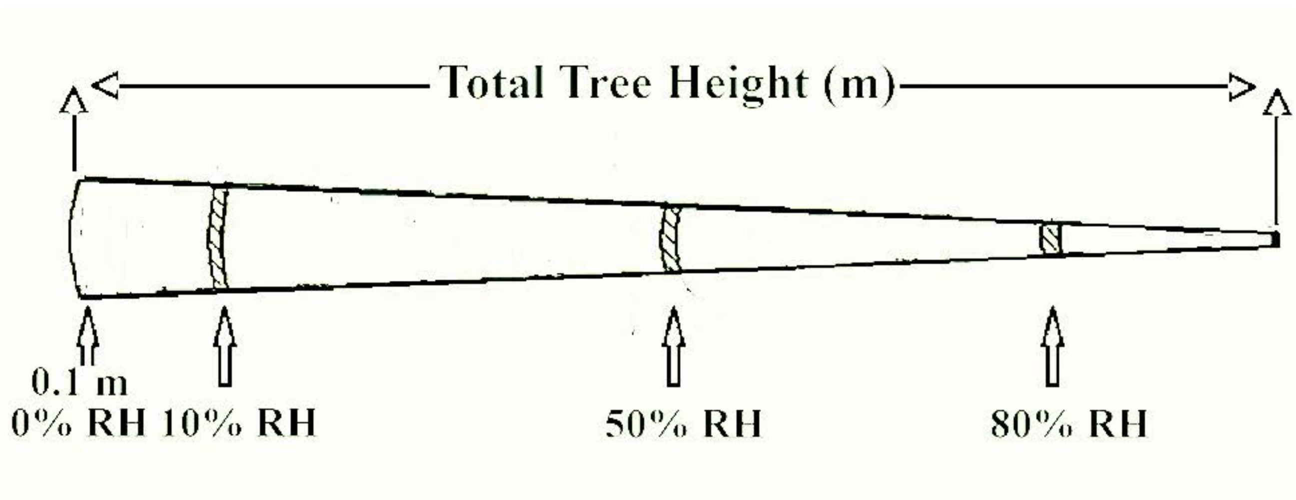

Figure 1. Tree stem scheme showing relative heights 0.1 (10% RH), 0.5 (50% RH), and 0.8 (80% RH), and total tree height (H), considered from 0.1 meters on the stump to the treetop.

A summary of tree characteristics, including normal diameter (d.b.h, cm), tree total height (H, m), and stem height at 0.1, 0.5, and 0.8 relative heights for each species, is presented in Table 1.

Table 1. Summary of tree characteristics for each species**.**

Species	d.b.h (cm)	H (m)	RH-0.1 (m)	RH-0.5 (m)	RH-0.8 (m)
P. caribaea	11.40	4.74	0.47	2.37	3.79
	13.20	8.75	0.88	4.38	7.00
	12.70	11.12	1.11	5.56	8.90
	19.40	15.35	1.54	7.68	12.28
	17.20	13.90	1.39	6.95	11.12
	22.40	13.64	1.36	6.82	10.91
	17.50	17.80	1.78	8.90	14.24
	21.00	19.45	1.95	9.73	15.56
	19.80	19.14	1.91	9.57	15.31
	25.50	21.04	2.10	10.52	16.83
	30.70	27.30	2.73	13.65	21.84
	25.00	18.97	1.90	9.49	15.18
	35.00	22.90	2.29	11.45	18.32
	23.10	21.10	2.11	10.55	16.88
	27.00	22.95	2.30	11.48	18.36
P. occidentalis	10.50	11.50	1.15	5.75	9.20
	12.10	10.80	1.08	5.40	8.64
	16.50	12.80	1.28	6.40	10.24
	10.50	12.25	1.23	6.13	9.80
	17.50	8.70	0.87	4.35	6.96
	17.00	11.50	1.15	5.75	9.20
	15.70	15.60	1.56	7.80	12.48
	22.70	15.30	1.53	7.65	12.24
	23.50	22.00	2.20	11.00	17.60
	19.00	18.17	1.82	9.09	14.54
	23.50	21.20	2.12	10.60	16.96
	27.00	15.90	1.59	7.95	12.72
	27.50	21.80	2.18	10.90	17.44
	21.50	14.53	1.45	7.27	11.62
	21.00	14.65	1.47	7.33	11.72

Although several methods are used to measure wood density, the standard way is to calculate the ratio between the dry weight of wood divided by the green volume of the same wood (Zobel & Jett 1995). The following protocol was used to measure basic density in our samples.

1) One-inch-thick discs at the three RH were obtained for each tree. On each disc, 0.5 x 0.5 x 1-inch subsamples were dissected, taking one portion from heartwood and two portions of sapwood to form a composite sample at each RH, measuring density on each portion and averaging these three

densities to represent the density at each RH, ensuring they represented the wood's variability.

2) The fresh (green) volume (cm^3) was measured by water displacement using an Electronic Densimeter model MD-300S (Advanced Testing Technologies, QMS Inc., 1840 Gateway Drive, Suite 200, San Mateo, CA 94404, USA), after soaking each of the subsamples in water until they reached maximum hydration.

3) The subsamples were oven-dried until a constant weight with a humidity percentage of at least 30% was achieved at an average temperature of 110 °C. Oven-dried weight (g) were obtained using a high-precision analytical balance (Radwag model XA 220.r2, Torunska 5, 26-600 Radom, Poland). Moisture content (%) was obtained using a mini-Ligno model E/D pin moisture meter (Lignomat USA LTD, 14345 NE Morris Ct., Portland OR 97230, USA).

4) Basic density was calculated using the formula, $Basic\ Density = \frac{Oven\text{–}Dry\ Mass}{Green\ Volume}$.

2.3. Statistical analysis

A three-way mixed ANOVA was performed using the GLM procedure for repeated measurements (SPSS IBM Corp. 2017), to understand the effects of species, AC, and RH, on the variability of BD within stem. The main purpose was to understand group differences between intra-subjects factor (RH) and groups formed by combination of two inter-subject factors (Species and AC). Furthermore, we examined the nature of bidirectional interactions and simple main effects. The sum of squares for a factor effect in each instance is the difference between error sums of squares for reduced and full models, and the associated degrees of freedom are the difference between respective degrees of freedom for these error sums of squares.

The assumption of normality was evaluated using Shapiro-Wilk test (Shapiro and Wilk 1965), for each combination of groups of the three factors: species, AC (intra-subjects), and RH (inter-subjects). The homogeneity of variances assumption was evaluated using Levene's test (1960), and the sphericity assumption using Mauchly test (1940). Post hoc tests to assess differences between specific averages were conducted employing the Bonferroni procedure (Bonferroni 1936).

3. RESULTS

BD values were normally distributed as assessed by Shapiro-Wilk's test ($P>0.05$). Inspection of box plots for values greater than 1.5 box-lengths from the edge of the box indicates the absence of outliers in the data. Figure 2 depicts realized BD values at RHs of 0.1, 0.5, and 0.8 for *P. caribaea* (Panel A) and *P. occidentalis* (Panel B), respectively. In Table 2 we present general descriptive statistics of the relationship between within-subject and inter-subject factors on variation of BD in these two species.

We found homogeneity of variances on BD values for factor combinations at 0.1 and 0.8 RHs (P=0.587 and P=0.288), respectively, but not at RH 0.5 (P=0.011), as assessed by Levene's test for equality of variances (Levene 1960). However, we have equal sample size, and the three-way mixed ANOVA is robust to variance heterogeneity in these circumstances. Mauchly's test of sphericity indicated that the assumption of sphericity is not violated, =3.684, P=0.158.

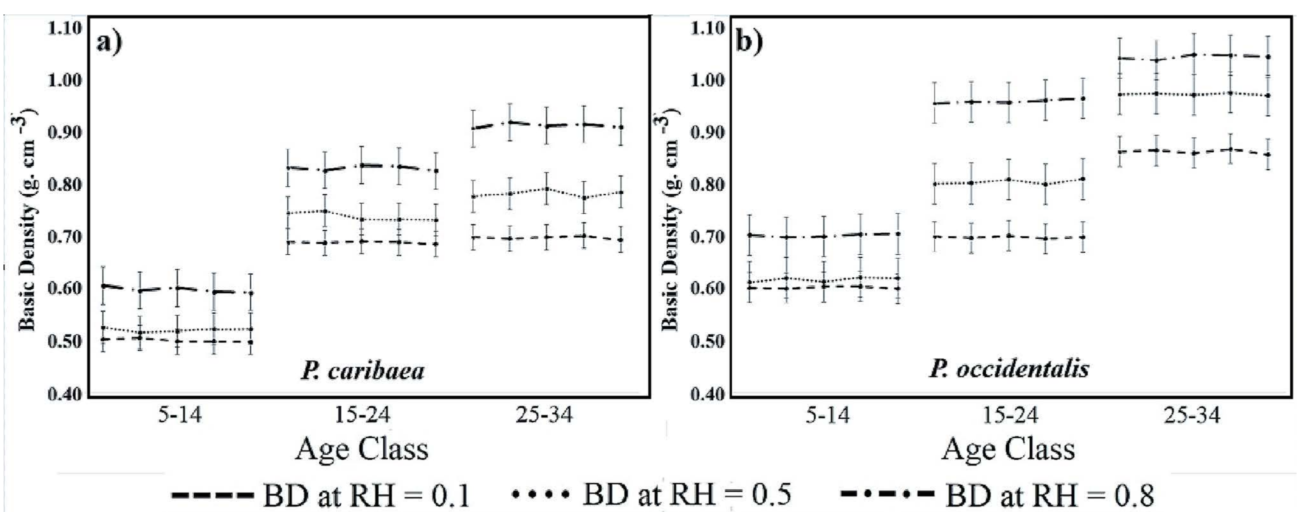

Figure 2. Realized BD values at RH of 0.1, 0.5, and 0.8 and age classes 5-14, 15-24, and 25-34 for *P. caribaea* (Panel A) and *P. occidentalis* (Panel B).

Table 2. General descriptive statistics of the relationship between within-subjects and inter-subjects' factors on the variation of BD in the two species *P. caribaea* and *P. occidentalis*.

Species	AC	RH	Mean	Standard Error	Confidence Interval (95%) Lower Limit	Upper Limit
P. caribaea	5-14	0.1	0.597	0.002	0.593	0.601
		0.5	0.521	0.002	0.516	0.526
		0.8	0.500	0.001	0.498	0.503
	15-24	0.1	0.830	0.002	0.826	0.834
		0.5	0.738	0.002	0.733	0.743
		0.8	0.688	0.001	0.685	0.691
	25-34	0.1	0.912	0.002	0.908	0.916
		0.5	0.781	0.002	0.776	0.786
		0.8	0.697	0.001	0.694	0.700
P. occidentalis	5-14	0.1	0.701	0.002	0.697	0.705
		0.5	0.617	0.002	0.612	0.622
		0.8	0.601	0.001	0.599	0.604
	15-24	0.1	0.958	0.002	0.954	0.962
		0.5	0.803	0.002	0.798	0.808
		0.8	0.698	0.001	0.695	0.701
	25-34	0.1	1.043	0.002	1.039	1.047
		0.5	0.972	0.002	0.967	0.977
		0.8	0.862	0.001	0.859	0.864

AC: Age class; RH: Relative height.

Results in Table 3 indicate that for alpha = 0.05, there is a statistically significant three-way interaction for stem BD, between the factors RH, species, and AC; , $P \leq 0.000$, partial =0.954. It also shows that simple bidirectional interaction RH*species is statistically significant, , $P \leq 0.000$, partial =0.814, as it is also the simple two-way interaction RH*AC, , $P \leq 0.000$, partial =0.954.

Table 3. Inter-subject effect tests for the dependent variable (BD) with assumed sphericity. Intra-subject factor (AR) and its interactions with inter-subject factors are included. Observed Power is calculated for alpha = 0.05.

Origen	Type III sum of squares	df	Avg. Square	F	Sig.		Non centrality Parameter	Obs. Power
RH	0.420	2	0.210	11589.8	0.000	0.998	23663.6	1.00
RH*Specie	0.004	2	0.002	105.2	0.000	0.814	211.7	1.00
RH*AC	0.037	4	0.009	514.9	0.000	0.977	2105.4	1.00
RH*Specie*AC	0.018	4	0.005	250.3	0.000	0.954	1020.0	1.00
Error (RH)	0.001	48	1.8E-5					

RH: Relative Height; AC: Age Class; df: Degrees of Freedom; : Partial Eta Squared: Obs.: Observed

Figure 3 shows that, for the three RHs, BD increases with AC. Lines that identify the species are not parallel. Two-way interactions between "species" and "AC" are different at RHs 0.1, 0.5, and 0.8. suggesting the existence of different two-way interactions amid Species*AC at different levels of RH. BD is higher in all AC and RH for *P. occidentalis*, except when RH is 0.5 in AC 15-24. For AC 25-34 and RH 0.8 (panel A), average BD for *P. occidentalis* differs substantially from that of *P. caribaea*. This pattern is repeated on panel (B). In panel (C), at RH 0.5, species BD averages are similar, and differences are substantial at RHs 0.1 and 0.8.

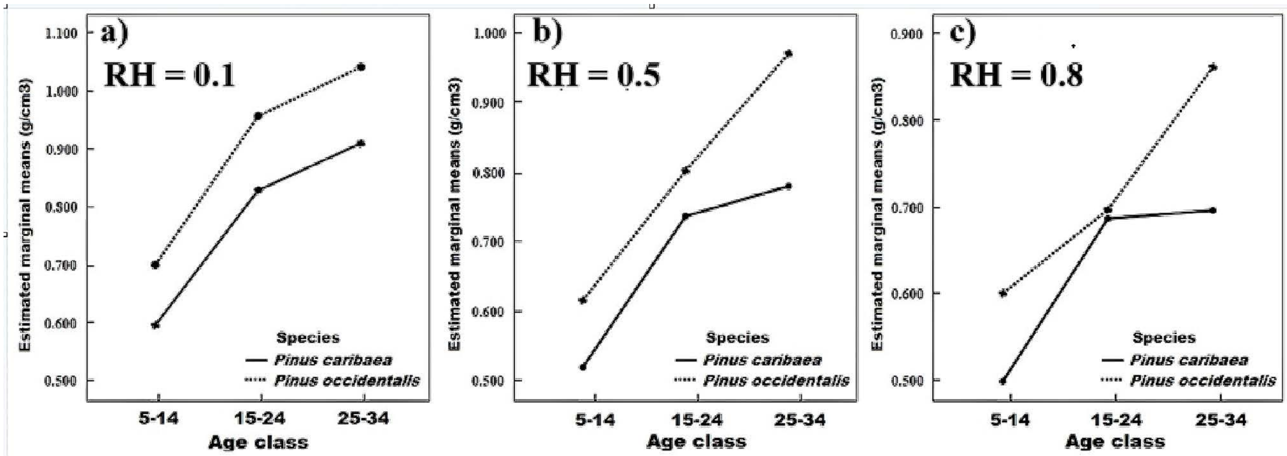

Figure 3. Means plots showing that there is a two-way interaction between "species" and "AC" when either "RH" is 0.1 (panel A), 0.5 (panel B), or 0.8 (panel C). Patterns differences confirmed graphically the presence of a three-way interaction of "species", "AC" and "RH" on "BD" for *P. occidentalis* and *P. caribaea*.

In Table 4 all possible pairwise comparisons for simple main effects between each group average are presented. Regarding species, BD had an average value of 0.696 g.cm^3 for *P. caribaea* and 0.806 g.cm^3 for *P. occidentalis*. Mean differences are statistically significant (-0.110±0.001), *P*≤0.000. All mean comparisons adjusted as a family by the Bonferroni correction, are statistically significant (*P*≤0.000).

Table 4. All possible mean comparisons between each group average, based on estimated marginal means for BD data of *P. caribaea* and *P.* Mean comparisons are adjusted as a family by Bonferroni correction**.**

Species	RH	AC (I)	AC (J)	Mean Difference (I-J)	Stand. Error	Sig.	Confidence Interval (95%) for Mean Difference	
							Lower Limit	Upper Limit
P. caribaea	0.1	5-14	15-24	-0.233*	0.003	0.000	-0.240	-0.226
			25-34	-0.314*	0.003	0.000	-0.321	-0.307
		15-24	25-34	-0.081*	0.003	0.000	-0.088	-0.074
	0.5	5-14	15-24	-0.217*	0.003	0.000	-0.226	-0.208
			25-34	-0.260*	0.003	0.000	-0.269	-0.252
		15-24	25-34	-0.043*	0.003	0.000	-0.052	-0.035
	0.8	5-14	15-24	-0.187*	0.002	0.000	-0.192	-0.183
			25-34	-0.197*	0.002	0.000	-0.201	-0.192
		15-24	25-34	-0.009*	0.002	0.000	-0.014	-0.004
Pinus occidentalis	0.1	5-14	15-24	-0.257*	0.003	0.000	-0.264	-0.250
			25-34	-0.342*	0.003	0.000	-0.349	-0.335
		15-24	25-34	-0.085*	0.003	0.000	-0.092	-0.078
	0.5	5-14	15-24	-0.186*	0.003	0.000	-0.195	-0.178
			25-34	-0.355*	0.003	0.000	-0.363	-0.346
		15-24	25-34	-0.168*	0.003	0.000	-0.177	-0.160
	0.8	5-14	15-24	-0.096*	0.002	0.000	-0.101	-0.092
			25-34	-0.260*	0.002	0.000	-0.265	-0.255
		15-24	25-34	-0.164*	0.002	0.000	-0.169	-0.159

*. The mean difference is significant at the .05 level; AC: Age class; RH: Relative height; Sig.: Stand.: Standard; Statistical significance.

Figure 4 displays all estimated means for both species at different levels of RH and AC. BD is greater in *P. occidentalis* for all combinations of RH and AC except at RH 0.8 and AC 15-24. For both species, BD increases with AC. Within individual trees, it decreases as RH increases.

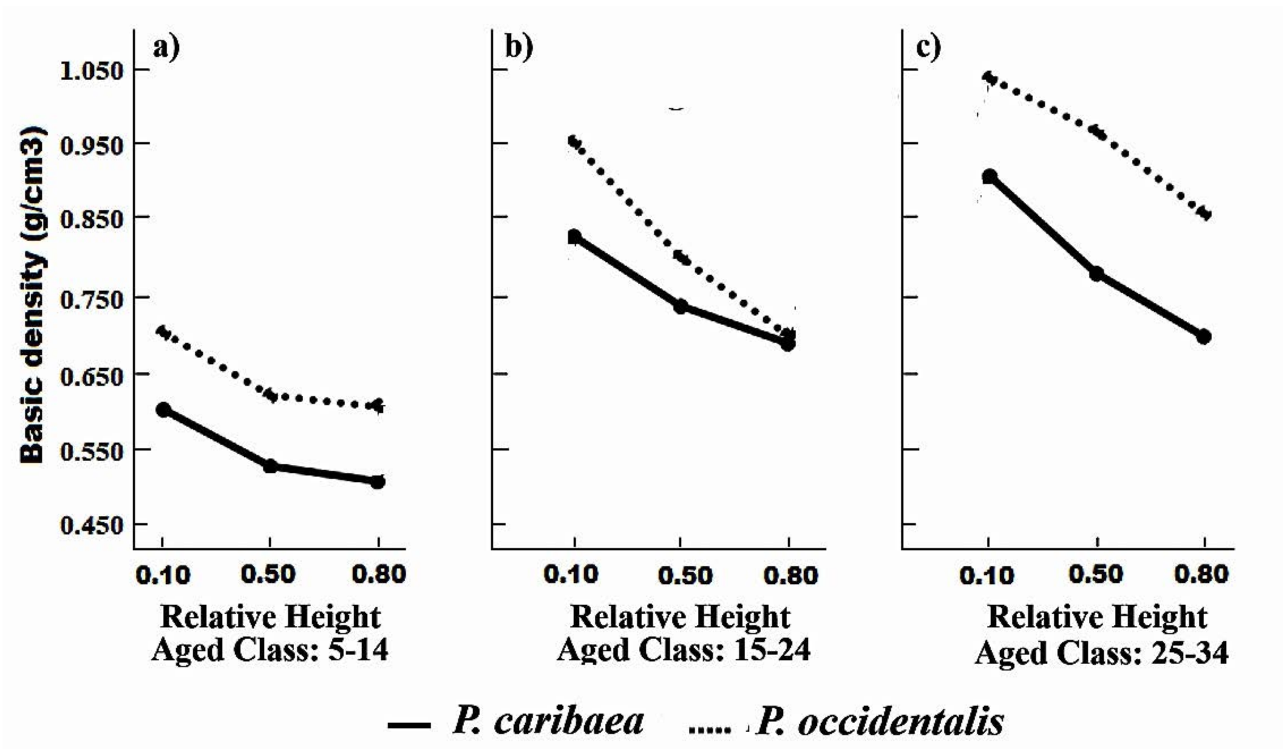

Figure 4. Estimated means for *P. occidentalis* and *P. caribaea* at different levels of the between-subjects factor AC, and the within-subjects factor RH. BD is higher for *P. occidentalis* at all combinations of the above factors except AC 15-24 and RH 0.8.

More significant differences in means (± standard error) were found for *P. occidentalis* at 0.5 RH, between AC 5-14 and 25-34 (-0.355±0.003) g.cm^3 (P≤0.000), followed by mean difference at 0.1 RH, between the same AC (-0.342±0.003) g.cm^3 (P≤0.000). For *P. caribaea* the greatest difference among means was found at 0.1 RH, between AC 5-14 and 25-34 (P≤0.000).

4. DISCUSSION

WD differs among different species. Its allocation in trees depends on many factors, but mainly on the tree species (Jakubowski & Dobroczynski, 2021). Li et al. (2024) study revealed that at a global scale, species explained 7.7% of total WD variation for angiosperms and gymnosperms combined. When gymnosperms were considered separately, species explained 21.3%.

Overall, the average BD was 14.6% higher for *P. occidentalis* (0.806±0.137 g.cm^{-3}) than that for *P. caribaea* (0.696±0.117 g.cm^{-3}). Mean difference ± standard error is statistically significant (-0.110±0.001), P≤0.000. BD is greater in *P. occidentalis* at 0.1, 0.5, and 0.8 RHs, with corresponding values of 0.901±0.150, 0.797±0.150, and 0.720±0.111 g.cm^3; as compared to *P. caribaea*, which attained respective values of 0.780±0.138, 0.680±0.118, and 0.628±0.094 g.cm^3. Higher similar BD values (>0.650 g.cm^{-3}) were found in 62% of 108 species of the northern Brazilian Amazon by Farias et al. (2023). Increased WD relates to greater wood strength and greater ability of the material to resist forces (Horácek et al., 2017).

Sample trees from both species had an average age of 19 years, and both exhibited higher average BD than the equivalent quantity reported by Demol et al. (2021) for *Pinus sylvestris* L in Belgium, who found average wood BD values of 0.461 g.cm^{-3}. Szaban et al. (2023) compared the stem density of several *P. sylvestris* provenances in Poland, finding values ranging from 0.418 g.cm^{-3} to 0.451 g.cm^{-3}. Tomczak et al. (2023) reported *P. sylvestris*'s density values ranging from 0.491±0.083 to 0.495±0.076 g.cm^{-3}.

How do stem wood BD of *P. occidentalis* and *P. caribaea* compare with other species in the same taxonomic group? *Pinus echinata* Mill, *Pinus elliottii* Engelm, *Pinus palustris* Mill, and *Pinus taeda* L, were studied by MacFarlane (2020) who reported values of 0.460, 0.484, 0.497 and 0.464 g.cm^{-3}, respectively, lower than wood BD from both studied species. Kimberley et al. (2016) conveyed an average density value of 0.410 g.cm^3 for genetically improved *P. radiata*, and Pompa-Garcia et al. (2021) reported minimum and maximum WD values of 0.450±0.004 and 0.950±0.014 g.cm^{-3}for *Pinus lumholtzii*, B.L. Robinson et Fernald.

It is well-documented that most *Pinus* and other conifer species exhibit a decrease in BD at increasing heights along the stem. On average, BDs decreased as RHs increased for *P. occidentalis* and *P. caribaea*. Between 0.1 and 0.5 RHs, percentage decreases were 11.54 % and 12.82%; between 0.1 and 0.8 RHs, percentage decreases were 19.49 % and 20.09%, respectively. BD variation ranged in *P. occidentalis* from 0.901±0.002 to 0.720±0.001 g.cm^3 and from 0.780±0.002 to 0.628±0.001 g.cm^3 for *P. caribaea*. This agrees with results reported by Djomo et al. (2017) in tropical African species, where WD variation can be, on average, from 15% to 30% greater at the tree base than the top portion of the stem.

Billard et al. (2021) assessed two softwood species *Abies alba* Mill and *Pseudotsuga menziesii* (Mirbel) Franco, finding that BD was most of the time highest at the tree's base for both species, showing a substantial decrease from the base along with an increase towards the top. of the tree, especially for *A. alba*. Demol et al. (2021) found a general decline in BD from stump to tip in *Fagus sylvatica*, *Larix decidua*, and *P. sylvestris*. These authors reported BD ranging from 0.463 g.cm^{-3} at breast height to 0.391 g.cm^{-3} at the highest height assessed for *P. Sylvestri*. Macfarlane (2020) reported the same decreasing pattern in *Pinus massoniana* Lamb. Rodríguez-Gamir et al. (2021) found a decreasing WD gradient from base to crown in *P. radiata* stands in New Zeeland.

Minini et al. (2022) sampled and measured 576 trees of 83 species in 28 natural ecosystems in the Atlantic Forest ecosystems of Brazil. BWD was the same at normal diameter (DBH) and 0.5 RH within the stem. The variability in density along the stem differs by wood type. It decreases in species with medium- and high-density wood (Romero et al., 2024), this being the case for *P. occidentalis* and *P. caribaea*.

BD increased significantly with the age of trees in both species. Between AC 1 (5 to 14 years) and AC 2 (15 to 24 years) a percentage increase was registered at 27.64% and 39.36% for both *P. occidentalis* and *P. caribaea*, respectively. The percentage increase between AC 1 and 3 (25 to 34 years) was approximately similar for *P. occidentalis* and *P. caribaea* (49.34% and 47.29%), and between AC 2 and AC 3, it was 17.75% and 5.67%. Within *P. massoniana* stems in a similar age range to our sampled trees (5-29 years), WD of each relative height in mature trees was significantly higher than that of younger trees, being 10% higher in the oldest age class compared to the youngest one (Deng et al., 2014). As stated by Dobner et al. (2018), mean density of a tree is, among other factors, directly related to its cambial age. At same harvest age, *P. taeda* WD exhibited mean density of 0.530 g.cm^3. Increases in latewood WD of *P. taeda* related to aging were reported at 0.45 g.cm^3 ± 0.07 (Ortega-Rodríguez & Tomazello-Filho, 2018).

P. taeda averaged whole-tree BD increased from 0.471 g.cm^3 at age 10 to 0.516 g.cm^3 at age 30, being changes with age for the first log more pronounced, with BD increasing from 0.484 g.cm^3 at age 10 to 0.562 g.cm^3 at age 30 (Dahlen et al., 2018). In another study, Schimleck et al. (2018) reported increases from 0.538 and 0.589 g.cm^3 for 13 and 22-year-old *P. taeda* trees. The age of trees compared in both *P. taeda* studies corresponds to our age classes 1 and 2. Related percent increases on density as related to age for both studies were lower (9.55% and 9.48%) as compared to our results between AC1 and AC2 (27.64% for *P. occidentalis* and 39.36% for *P. caribaea*). WD for all heights increases with age, which is the most common pattern in conifers (Topanotti et al., 2021).

The higher stem wood BD value for *P. occidentalis*, compared to *P. caribaea*, corroborates empirical local end users' perception regarding the strength of both species. However, perhaps the main reason is the rapid growth of *P. caribaea*. When comparing the mean annual increment (MAI) of the trees in the study in terms of diameter at breast height, P. caribaea has, on average, 8.83 %, 5.51%, and 21% greater growth than *P. occidentalis* in young, intermediate, and older stands, respectively. In terms of tree height, *P. occidentalis* MAI is 8% higher than *P. caribaea* in young-age stands, but the latter was superior in intermediate and older stands (13% and 31% greater MAI), respectively. Rodríguez-Gamir et al. (2021) found that in *P. radiata,* greater WD was negatively related to growth rates.

5. CONCLUSION

In this study, the effects of "conifer species" and the factors of "age class" and "relative height" on the variation of wood basic density along tree stem growing in forest plantations within La Sierra, Dominican Republic, were assessed using a three-way repeated measures mixed ANOVA. The results indicate a significant statistical effect of these three factors and the presence of statistically significant interactions among them.

The results also indicate that the intrasubject factor "relative height" was the largest, with a Partial Eta Square value of =0.998, followed by the effect of the interaction between "relative height" and "age class" (=0.997), and the tree factors interaction (Species*RH*AC), with =0.954.

Overall, the average BD was 14.6% higher for *P. occidentalis* (0.806 ± 0.137 g/cm3) than that for *P. caribaea* (0.696 ± 0.117 g/cm^3). BD was greater in *P. occidentalis* than *P. caribaea* at 0.1, 0.5, and 0.8 RHs, with a percent difference of 14.40, 15.84, and 13.65, respectively. Realized average values at each of the RHs 0.1, 0.5, and 0.8 were, respectively, 0.780 g/cm^3, 0.680 g/cm^3, and 0.628 g/cm^3 for *P. caribaea*, and 0.901 g/cm^3, 0.797 g/cm^3, and 0.720 g/cm^3, for *P. occidentalis*.

On average, BD decreased as relative height increased. For *P. caribaea*, the percentage decrease differences between 0.1 and 0.5, 0.1 and 0.8, and 0.5 and 0.8 relative heights were 13.70, 21.59, and 7.95. For *P. occidentalis*, the respective percentage decrease differences were 12.25, 22.33, and 10.15. This pattern is common in conifers species.

BD increased significantly with the age of trees in both species. Between AC 1 (5 to 14 years) and AC 2 (15 to 24 years), a percentage increase was registered at 27.64% and 39.36% for both *P. occidentalis* and *P. caribaea*, respectively. The percentage increase between AC 1 and 3 (25 to 34 years) was approximately similar for *P. occidentalis* and *P. caribaea* (49.34% and 47.29%). Between AC 2 and AC 3, it was 17.75% and 5.67%.

Future research should prioritize studying wood density, including analyzing the effects of radial variation and diameter class within the same species. A large sample size that includes individuals from the same and different species will facilitate the analysis of horizontal structure.

ACKNOWLEDGMENTS

We recognize the effort and contribution of the acquisitions department and administrative staff of the Vice-Rectory of Research and Innovation at PUCMM and the contributions of field personnel such as Esclaudys Perez Gonzales, José Reyes, Cristian Goris, and Roque Herrera. We are incredibly grateful to Luis Eduardo Peralta for his support throughout the process and to Pablo Ovalles for his valuable collaboration.

SUBMISSION STATUS

Received: 31 July. 2024
Accepted: 04 Dec. 2024
Associate editor: Fernando Gomes

CORRESPONDENCE TO

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DATA AVAILABILITY

The authors will make the raw data supporting this article's conclusions available upon request.

FINANCIAL SUPPORT

This research was funded by the Ministry of Higher Education, Science, and Technology of the Dominican Republic, National Fund for Innovation and Scientific and Technological Development, grant number FONDOCyT 2018-2019-2B4-088. The APC was funded by Pontificia Universidad Católica Madre y Maestra (No. 121-2019-PUCMM).

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