

## Artigos

# Effect of stem height in variation of bark, heartwood, sapwood and physical properties of wood in *Dipteryx panamensis* Pittier in a provenance/progeny test

Efeito da altura do tronco na variação da casca, cerne, alburno e propriedades físicas da madeira de *Dipteryx panamensis* Pittier em um ensaio de procedências/progênie

Dalina Rodriguez-Perez<sup>1</sup>   
Roger Moya<sup>1</sup>   
Olmán Murillo<sup>1</sup> 

<sup>1</sup>Instituto Tecnológico de Costa Rica, Cartago, Costa Rica

## ABSTRACT

*Dipteryx panamensis* is used in reforestation in Costa Rica and a genetic improvement program has been recently started in the country. The objective of the present study was to study the effect of tree trunk height on the variation of bark, sapwood, heartwood, green density (GD), specific gravity (SG) and green moisture content in green condition (MC-G), in a collection of 8-year-old provenances/progenies planted in the town of Florencia in San Carlos in the northern region of Costa Rica. The wood of each of 17 families were studied based on 3 of their progenies, evaluating the properties relative to 0, 25%, 50%, 75% and 100% of the commercial height. According to the results, tree diameter and bark thickness showed no statistical differences in their values across trunk. Significant differences were found in diameter and percentage of heartwood and sapwood between provenances and families. The thickness and percentage of sapwood, thickness and percentage of bark, diameter, pith percentage and percentage of pith eccentricity, showed no significant differences between families. SG and the MC-G presented significant variation between provenances, while GD registered differences at above 25 % commercial height. The variation of physical properties, especially SG, between families within each provenance, shows selection potential for genetic improvement, focusing particularly on the bottom section of the tree.

**Keywords:** Almendro; Camurú; Genetic improvement; Tropical forestry

## RESUMO

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A madeira de *Dipteryx panamensis* é usada no reflorestamento na Costa Rica, tendo um programa de melhoramento genético iniciado recentemente no país. O objetivo do presente estudo foi estudar o efeito da altura do tronco das árvores na variação de casca, alburno, cerne, densidade verde (GD), densidade básica (SG) e teor de umidade na condição verde (MC-G) em uma coleção de procedências/progênes aos 8 anos de idade, plantados na vila de Florencia no município de San Carlos na região nordeste da Costa Rica. De cada uma das 17 famílias, a madeira foi investigada em três progênes e as propriedades foram avaliadas em 0, 25, 50, 75 e 100 % da altura comercial. Os resultados mostraram que o diâmetro das árvores e a espessura da casca não apresentaram valores com diferenças estatísticas nas diferentes alturas da árvore. Houve diferenças significativas em diâmetro e porcentagem de cerne e alburno entre procedências e famílias. A espessura e porcentagem de alburno, espessura e porcentagem de casca, diâmetro, porcentagem e porcentagem de excentricidade da medula não registraram diferenças significativas entre as famílias. Nas propriedades físicas da madeira, determinou-se que o SG e o MC-G apresentaram uma variação significativa entre procedências em todas as alturas das árvores. Enquanto o GD registrou diferenças ao 25 %. A variação nas propriedades físicas, especialmente a SG, entre famílias dentro de cada proveniência, mostra o potencial de seleção para melhoramento genético, com ênfase na seleção com base na parte mais basal do tronco das árvores.

**Palavras chaves:** Almendro; Cumarú; Melhoramento genético; Silvicultura tropical

## 1 INTRODUCTION

*Dipteryx panamensis* Pittier has become popular in reforestation projects in Costa Rica (MOYA, 2018). This wood is known as almendro in central America, Panama and Colombia and *D. odorata* wood (same family and similar wood characteristics wood) is known as camurú. It belongs to the family Fabaceae-Papilionaceae; its natural distribution is from the lowland forests of Nicaragua to Colombia (CLARK; CLARK, 1987). In Costa Rica, it is abundant in the northern and Caribbean regions (HANSON *et al.*, 2007). The tree trunks in this species are cylindrical and uniform (CLARK; CLARK, 1987). Delgado (2003), Redondo-Brenes (2007), and León *et al.* (2017) have reported the potential of this species for commercial reforestation. Plantation trees of *Dipteryx panamensis* produce wood with suitable characteristics, such as high specific gravity and adequate mechanical properties for structural uses, in addition to good energy properties (MOYA *et al.*, 2018; TENORIO *et al.*, 2016a). *Dipteryx panamensis* is part of a select group of native species of Costa Rica recently defined as priority species research (MURILLO, 2018).

The satisfactory growth of *Dipteryx panamensis* in plantations and its suitable wood characteristics encouraged works on genetic improvement in the country (LEÓN *et al.*, 2017; MARTÍNEZ-ALBÁN *et al.*, 2015). In this regard, high quality seed sources were sought (ASSIS; RESENDE, 2011) through abundant collection in natural populations. These seeds were then established in provenance/progeny trials of a wide genetic variety of selected superior material. The improvement programs seek to identify individuals capable of adapting to different environments, as well as individuals with better growth characteristics and wood quality (LEÓN *et al.*, 2017; MARTÍNEZ-ALBÁN *et al.*, 2015).

In this initial stage of genetic improvement of *Dipteryx panamensis*, provenances and families were evaluated based on open pollination in natural populations to capture the greatest genetic diversity possible (MARTÍNEZ-ALBÁN *et al.*, 2015). The first results showed that through adequate selection of the best individuals within the best families, up to 20 % genetic progress of the commercial volume can be achieved (LEÓN *et al.*, 2017). Researches with *Dipteryx panamensis* determined that the greatest genetic variability is found among individuals and among families within each provenance and among populations to a lesser extent (LEÓN *et al.*, 2017; MARTÍNEZ-ALBÁN *et al.*, 2015). The studies conclude that it is possible to create a single improvement population to continue with the genetic improvement program of the species and thus supply the best plantation genetic material in Costa Rica in the coming 15 years.

Despite the progress in genetic improvement of *Dipteryx panamensis* in terms of growth rate and quality of the trunks, no observations have been made regarding the wood quality, in spite of the importance of including this issue in forest genetic improvement (ZOBEL; JETT, 1995). In general, there are few works on genetic improvement doing research on variation of the properties of the wood along the trunk. According to reports, the heartwood diminishes with increasing trunk height (BERROCAL *et al.*, 2020). Moreover, a reduction in bark thickness and in the pith dimensions due to physiological processes that occur at different heights is frequently

observed (ZOBEL; VAN BUIJTENEN, 1989; PFAUTSCH *et al.*, 2018), possibly linked to aspects of genetic control of the tree. Determining and understanding the patterns of variation in the characteristics of the wood relative to height is essential in genetic improvement and management of trees in plantations under intensive management. The degree of genetic control over this variation with respect to trunk height is part of the usual knowledge gap regarding these topics. A good improvement program, in addition to advance towards improved growth and volume in trees, requires enhancing some of the wood properties that are essential from the point of view of commercial use.

Given the importance of *Dipteryx panamensis* in the production of wood for structural use in Costa Rica, the aim of this study was to determine the variation, relative to height of the trunk, of the bark thickness, the sapwood/heartwood proportion and pith dimension, as well as the variations in the physical properties, i.e., green wood density, specific gravity and green moisture content. The study was based on 8-year-old trees from three provenances native to Costa Rica, distributed in 17 families. Knowledge of these variations relative to height will make it possible to fully potentiate the genetic improvement program for this important native species of the country.

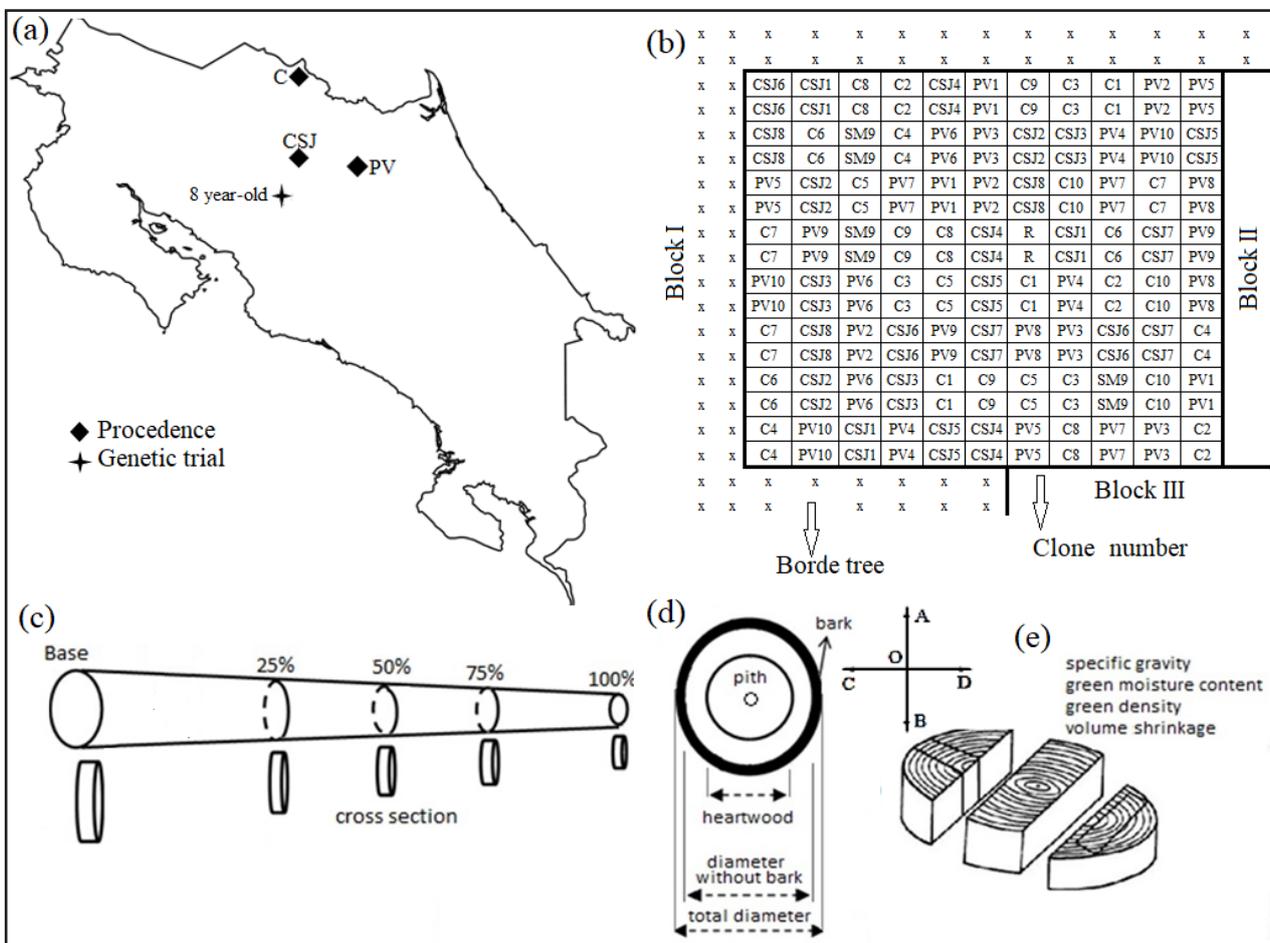
## **2 MATERIALS AND METHODS**

### **2.1 Study site**

The analyzed provenance/progeny trial (8 years-old) is located in the town of Florencia in San Carlos in northern Costa Rica (10° 21' N and 84° 30' O) (Figure 1a). The life zone in this area is Very Humid Premontane Forest transition to Basal (HOLDRIDGE, 1967), with average temperature and rainfall between 18-24°C and 3800-4000 mm respectively, which is Tropical rainforest climate (BECK *et al.*, 2018). The site soils are reddish, acidic and clay-rich ultisols, deep and well drained (LEÓN *et al.*, 2017), presenting average nutritional characteristics with the following data: 4.68 pH, 3.30

cmol(+)/L for Ca, 1.57 cmol(+)/L for Mg, 0.07 cmol(+)/L for K, 31 mg/L for Cu, 22 mg/L for Mn, 105 mg/L for Fe, 4.38 mg/L for Zn and 9.93 mg/L for P.

Figure 1 - (a) Geographic location of the provenance/progeny trial of 8 years-old of *Dipteryx panamensis*, northern Costa Rica (b) distribution of families of the different provenances of the block (c) sampled cross-section extraction from trunk, (d) dasometric parameters measured in cross-section and (e) cut pattern of cross-section for the physical property determinations



Source: Authors (2021)

## 2.2 Genetic material of the trials

The genetic material for the provenance/progeny trials came from a collection of 17 families of *Dipteryx panamensis* from three provenances in northern Costa Rica:

5 families from Coope San Juan of Cutris of San Carlos (CSJ), 7 families from Crucitas of Pocosol of San Carlos (C) and 5 families from Puerto Viejo of Sarapiquí (PV) (Figure 1a). These provenances are geographically separated by 50 to 70 km. From each of the provenances, open-pollinated seed was collected from 10 mother trees (half-sib families), separated from each other by more than 500 m (LEÓN *et al.*, 2017).

### **2.3 Trial establishment and management**

The trial was set up in June 2010 and sampled in April 2018, then the age of trial was approximately 8 years old. The experimental design consisted of six complete random blocks (LEÓN *et al.*, 2017). Three pairs from each family were randomly distributed within each block (Figure 1b) ( $n = 6$  as experimental unit or plot). The trees were planted using a 3x3 m spacing, at an initial density of 1111 trees/ha. Filler trees (indicated with R in Figure 1b) and two border rows around the entire trial were used. The site had no preparation or control of soil acidity. The weed control was performed every 2-3 months until the age of 3 years. The first thinning was performed at 50 % intensity at four years of age. It consisted of removing the tree with the smallest diameter and the worst trunk quality from each pair in each block.

### **2.4 Trial sampling**

Four individuals were selected from each of the 29 families present in the trial, with diameters from 13 to 17 cm, which corresponded to the average diameter of the trial. The selected trees had to be codominant individuals in order to leave the dominant tree standings. Because of this, the database was reduced to only 17 of the 29 families present, as they were the only ones that complied with the sample size (conditions of DAP dimensions and leaving the dominant tree). Four trees were sampled from each family, making 68 individuals in total: 20 individuals from CoopeSanJuan (CSJ), 20 individuals from Puerto Viejo (PV) and 28 individuals from Crucitas (C), the three from the canton of San Carlos.

## 2.5 Sampling trees

All trees were cut down and measurements were taken as follows: cross-section sampling within the trees, 3.0 cm thick discs obtained at the base, at 25, 50, 75 and 100 % of the commercial height of the tree (Figure 1c).

## 2.6 Dasometric variables

For each cross-section wood disc, tree diameter, bark (thickness and total area percentage), sapwood (thickness and total area percentage) and heartwood (diameter and total area percentage) were determined using ruler. Two perpendicular lines were drawn crossing the centre of each disc, one in the A-B direction and the other in C-D direction. Total diameter, diameter without bark and heartwood diameter were measured in both directions drawn on the disc (Figure 1d). The averages of the two transversal measurements were calculated to obtain both total diameter and heartwood diameter. Bark and sapwood thickness were obtained as the difference between total diameter and diameter without bark (in the case of the bark), and heartwood diameter (in the case of sapwood). Diameters were calculated assuming a geometric circle. The percentages of bark, sapwood and heartwood were calculated relative to the area of each disc section and the total disc area.

## 2.7 Physical properties

The physical properties determined were green density (GD), specific gravity (SG) and moisture content in green condition (MC-G). These properties were determined in each cross-section from the trunk and for each percentage of commercial height (0, 25, 50, 75 and 100 %). A 3.0 cm-wide wood-piece was cut in each cross section, pith included (Figure 1e). These sections were divided at the pith, obtaining two samples from each one (Figure 1e). GD was calculated by the ratio of green weight/green volume, whereas SG, TVS and green MC-G according to ASTM D-143 and ASTM D-2395 procedures (ASTM, 2016a, 2016b).

## 2.8 Statistical analysis

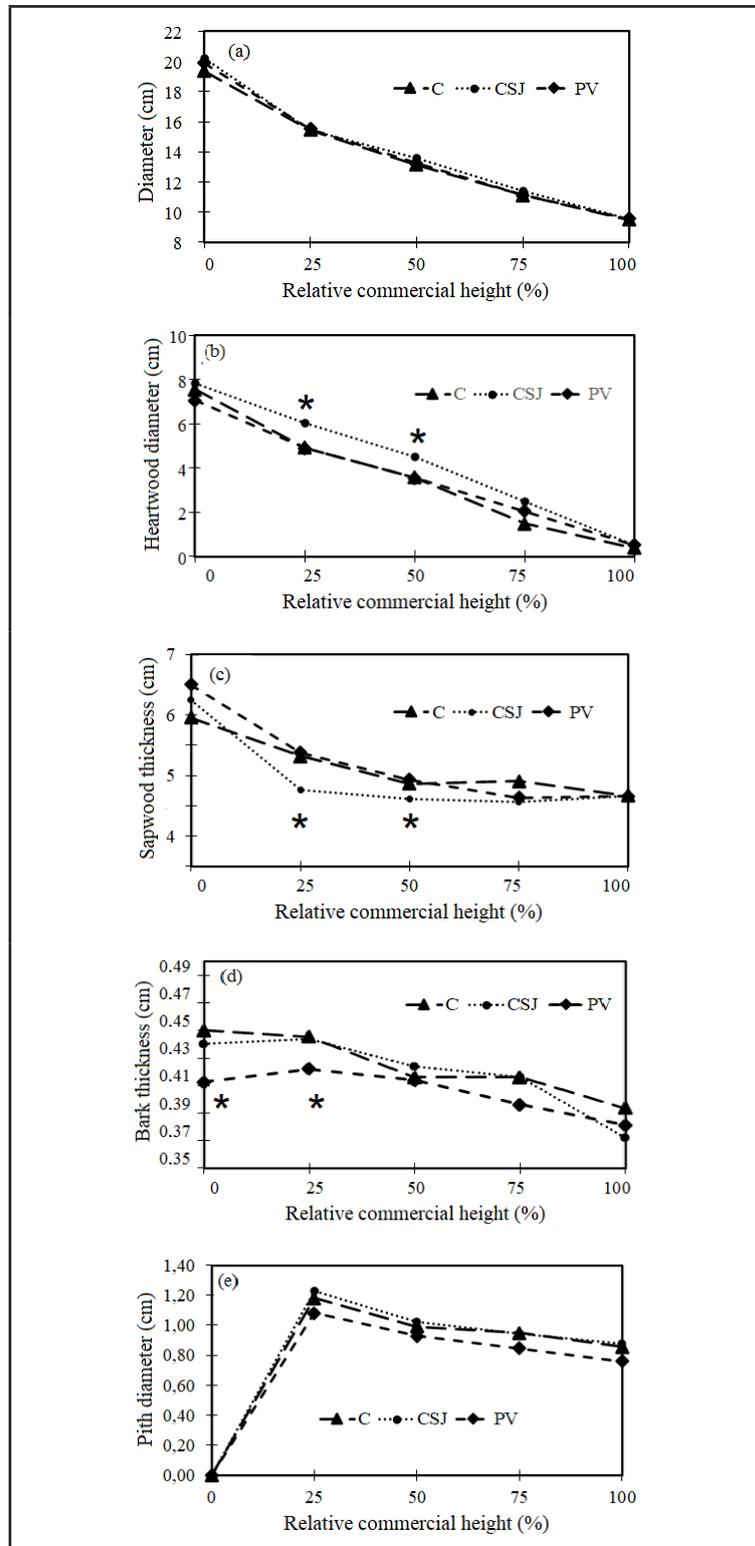
A general statistical description (average and coefficient of variation) was applied for all wood properties in each tree height. Concerning the variation of the properties that were determined for each height, only their variation was presented, and their behaviour observed. An ANOVA (analysis of variance) was performed to determine the effect of family on wood properties. This analysis was applied first for each height, then the heights were removed from the model, in order to test differences among all wood properties. An analysis of means was applied using the Tukey multiple range test ( $P$ -value $<0.05$ ). The statistical programs used were SAS and Info Stat.

## 3 RESULTS

### 3.1 Morphological characteristics

Variation at different tree heights in the dasometric characteristics of the different populations of the 8-year-old genetic trial showed that the diameter and the heartwood proportion decrease with the increase in tree height (Figure 2a-b), result that was already expected. No significant differences were determined regarding variation of the diameter, the thickness of the bark and the diameter of the pith in relation with the tree height (Figure 2a, 2d-e). For heartwood diameter, the three provenances – C, CSJ, and PV – were on average equal to each other in the samples of the bottom sections of the tree. At the height of 25 and 50 % of the commercial height, differences in the heartwood diameter were determined between the CSJ provenance, and C and PV provenances, while these last two provenances were statistically the same. At 100 % commercial height, there were no statistical differences between provenances (Figure 2b). Regarding the sapwood thickness (Figure 2c) at the base of the tree, at 75 and 100 % height, no significant differences were observed, whereas at heights 25 and 50 %, statistical differences were recorded between provenances C and PV, with CSJ.

Figure 2 – Variation in trunk diameter (a), heartwood diameter (b), sapwood thickness (c), bark thickness (d), pith diameter (e), in relation to the commercial tree height of *Dipteryx panamensis* for three provenances from northern Costa Rica



Source: Authors (2021)

In where: (\*) statistically significant at  $\alpha < 95$ .

As for the percentage of heartwood, sapwood, bark and pith in provenances, significant differences occurred only in the heartwood percentage (Table 1). There was no significant difference between provenances at the bottom section of the tree. At 25 and 50 % height, the C and PV provenances were equal to each other, but different from the CSJ provenance. Provenance C registered significant differences at height 75 % compared to CSJ and PV. At 100 % height there were significant differences between CSJ and C and PV (Table 1). The percentage of sapwood, bark and pith did not show differences at different heights between the three studied provenances (Table 1).

Table 1 – Variation at relative tree height for heartwood, sapwood, bark and pith percentage, specific gravity, green density and moisture content in green condition in provenances of *Dipteryx panamensis* tested in northern Costa Rica

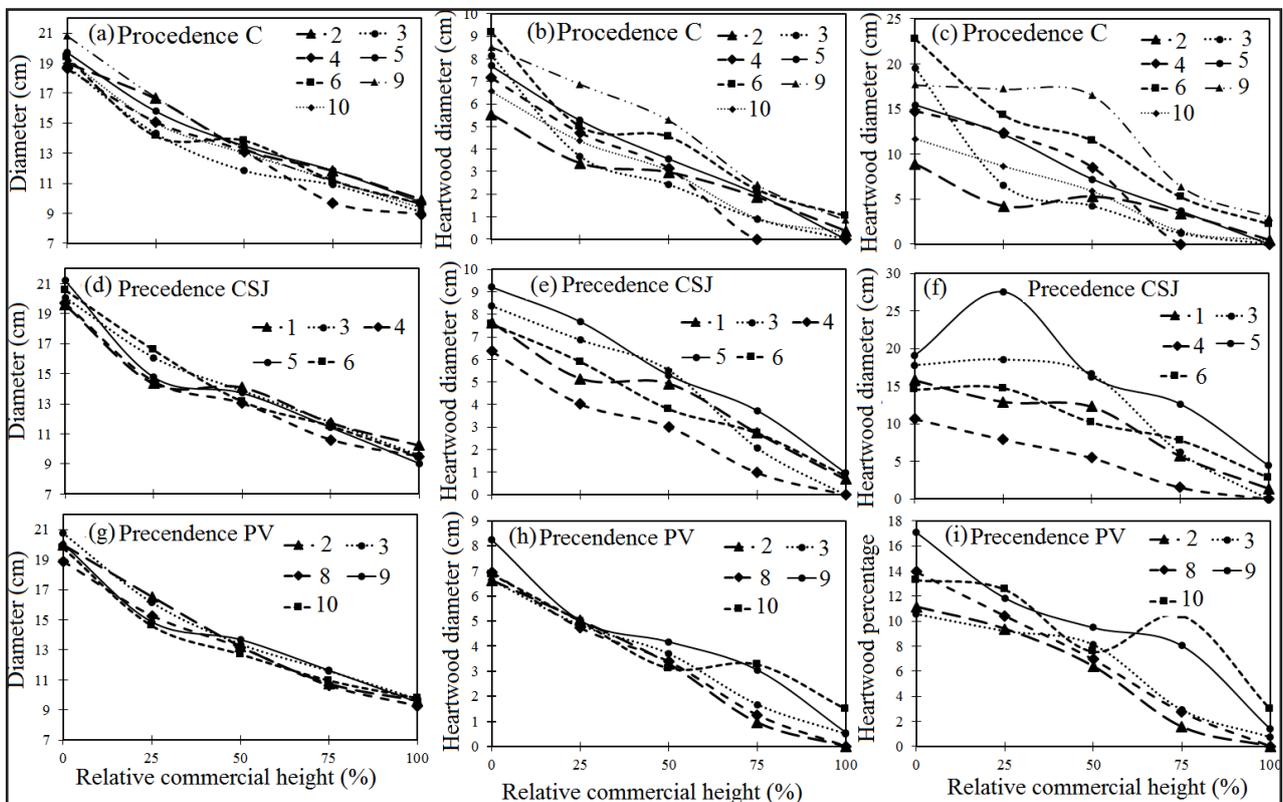
Relative commercial tree height (%)	Provenance	Heartwood (%)	Sapwood (%)	Bark (%)	Pith (%)	Specific gravity	Green density (g/cm <sup>3</sup> )	Moisture content (%)
0	C	15.8 <sup>A</sup>	75.1 <sup>A</sup>	9.1 <sup>A</sup>	0.0 <sup>A</sup>	0.89 <sup>A</sup>	1.27 <sup>A</sup>	42.80 <sup>A</sup>
	CSJ	15.6 <sup>A</sup>	75.9 <sup>A</sup>	8.6 <sup>A</sup>	0.0 <sup>A</sup>	0.90 <sup>A</sup>	1.26 <sup>A</sup>	41.41 <sup>A</sup>
	PV	13.2 <sup>A</sup>	78.8 <sup>A</sup>	8.1 <sup>A</sup>	0.0 <sup>A</sup>	0.92 <sup>B</sup>	1.28 <sup>A</sup>	39.05 <sup>A</sup>
25	C	11.2 <sup>A</sup>	77.6 <sup>A</sup>	11.3 <sup>A</sup>	0.6 <sup>A</sup>	0.66 <sup>A</sup>	1.13 <sup>A</sup>	60.9 <sup>A</sup>
	CSJ	16.6 <sup>B</sup>	72.2 <sup>A</sup>	11.2 <sup>A</sup>	0.7 <sup>A</sup>	0.66 <sup>A</sup>	1.10 <sup>A</sup>	68.29 <sup>B</sup>
	PV	10.6 <sup>A</sup>	78.8 <sup>A</sup>	10.6 <sup>A</sup>	0.5 <sup>A</sup>	0.69 <sup>B</sup>	1.11 <sup>A</sup>	62.29 <sup>A</sup>
50	C	8.5 <sup>A</sup>	79.3 <sup>A</sup>	12.3 <sup>A</sup>	0.6 <sup>A</sup>	0.58 <sup>A</sup>	1.11 <sup>A</sup>	63.39 <sup>A</sup>
	CSJ	12.2 <sup>B</sup>	75.7 <sup>A</sup>	12.1 <sup>A</sup>	0.6 <sup>A</sup>	0.64 <sup>B</sup>	1.08 <sup>A</sup>	70.30 <sup>B</sup>
	PV	7.7 <sup>A</sup>	80.2 <sup>A</sup>	12.1 <sup>A</sup>	0.5 <sup>A</sup>	0.64 <sup>B</sup>	1.07 <sup>A</sup>	65.35 <sup>AB</sup>
75	C	3.0 <sup>A</sup>	82.5 <sup>A</sup>	14.4 <sup>A</sup>	0.8 <sup>A</sup>	0.65 <sup>A</sup>	1.06 <sup>A</sup>	63.89 <sup>A</sup>
	CSJ	6.8 <sup>B</sup>	79.1 <sup>A</sup>	14.1 <sup>A</sup>	0.7 <sup>A</sup>	0.62 <sup>B</sup>	1.05 <sup>A</sup>	70.27 <sup>B</sup>
	PV	5.1 <sup>B</sup>	81.1 <sup>A</sup>	13.8 <sup>A</sup>	0.6 <sup>A</sup>	0.62 <sup>B</sup>	1.05 <sup>A</sup>	69.49 <sup>B</sup>
100	C	0.9 <sup>A</sup>	83.2 <sup>A</sup>	15.9 <sup>A</sup>	0.9 <sup>A</sup>	0.63 <sup>A</sup>	1.00 <sup>A</sup>	59.57 <sup>A</sup>
	CSJ	1.7 <sup>B</sup>	83.3 <sup>A</sup>	14.9 <sup>A</sup>	0.9 <sup>A</sup>	0.60 <sup>A</sup>	0.97 <sup>A</sup>	62.99 <sup>A</sup>
	PV	1.0 <sup>A</sup>	83.7 <sup>A</sup>	15.3 <sup>A</sup>	0.7 <sup>A</sup>	0.61 <sup>A</sup>	0.98 <sup>A</sup>	61.49 <sup>A</sup>

Source: Authors (2021)

In where: Different letters mean statistically different at 99 %. CSJ=CoopeSanJuan of Cutris of San Carlos, C=Crucitas of Pocosol of San Carlos and PV=Puerto Viejo of Sarapiquí.

The evaluation of the differences between families of the same provenance showed that tree diameter, heartwood diameter and heartwood percentage decrease with increasing tree height (Figure 3). Heartwood diameter and heartwood percentage are the variables that present more differences as the tree height increases (Figure 5). No significant differences were observed for the remaining morphological variables studied (Table 2), namely, sapwood thickness, sapwood percentage, bark thickness, bark percentage, pith diameter and percentage of eccentricity. However, pith diameter at 50 % tree height registered differences, although only in the families 3 and 4 of provenance C (Table 2). The families with any statistical differences are presented in the second line. For example, in 0% of relative stem height for C precedence is indicated 2=3=4=5=6=9=10, this means that the families 2, 3, 4, 5, 6, 9 and 10 any differences were found between them.

Figure 3 - Variation with relative tree height for diameter, heartwood diameter and percentage of *Dipteryx panamensis* for three provenances in northern Costa Rica: (a-c): Crucitas-C, (d-f) CoopeSanJuan-CSJ and (g-i) Puerto Viejo-PV



Source: Authors (2021)

In where: (\*) Statistical and significant ( $\alpha < 95$ ) differences among provenances.

Table 2 – Variation with relative tree stem height for sapwood thickness, sapwood percentage, bark thickness, bark percentage, pith diameter and pith percentage of *Dipteryx panamensis* for three provenances in the northern region of Costa Rica

Relative stem height (%)	Provenance	Sapwood thickness (cm) (family number)*	Sapwood (%) (family number)*	Bark thickness (cm) (family number)*	Bark (%) (family number)*	Pith diameter (cm) (family number)*	Pith (%) (family number)*
0	C	4.71-6.8	68.96 – 81.71	0.50 – 0.43	7.67 – 10.37	- 0.00	-0.00
		2=3=4=5=6=9=10*	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10
	CSJ	6.07 – 6.21	73.13 – 80.15	0.42 – 0.48	7.76 – 9.51	0.0 – 0.0	- 0.0
		1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6
	PV	5.46 – 6.63	74.53 – 81.10	0.37 – 0.46	7.32 – 8.93	0.0 – 0.0	- 0.0
		2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10
25	C	4.19 – 6.20	71.95 – 85.53	0.41 – 0.51	10.25 – 13.05	0.80 – 1.40	0.54 – 0.97
		2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10
	CSJ	3.13 – 4.88	61.50 – 74.41	0.42 – 0.48	10.75 – 12.81	1.10 – 1.43	0.55 – 00.86
		1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6
	PV	4.37 – 5.28	75.82 – 80.63	0.37 – 0.48	9.57 – 11.65	0.90 – 1.23	0.39 – 0.63
		2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10
50	C	3.62 – 4.74	71.44 – 82.97	0.38 – 0.48	11.05 – 13.59	0.80 – 1.15	0.52 – 0.79
		2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=5=6=9=10, 3#4
	CSJ	3.75 – 4.58	71.64 – 81.73	0.39 – 0.43	11.20 – 12.79	0.85 – 1.13	0.38 – 0.66
		1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6
	PV	4.35 – 4.51	79.21 – 80.77	0.38 – 0.45	11.30 – 13.14	0.80 – 1.10	0.42 – 0.69
		2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10
75	C	3.98 – 4.69	80.18- 84.76	0.39 – 0.46	12.67 – 15.24	0.80 – 1.10	0.62 – 1.01
		2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10
	CSJ	3.46 – 4.43	74.57 – 84.57	0.38 – 0.46	13.11 – 14.94	0.78 – 1.15	0.52 – 0.97
		1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6
	PV	3.47 – 4.53	76.55 - 84.08	0.36 - 0.46	12.15 – 16.31	0.80 – 1.03	0.37 – 0.79
		2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10
100	C	3.97 – 4.49	81.57 – 84.88	0.35 – 0.43	13.89 – 17.97	0.78 – 0.95	0.66 – 1.08
		2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10	2=3=4=5=6=9=10
	CSJ	3.93 – 4.41	81.92 – 85.25	0.34 – 0.41	14.63 – 15.25	0.68 - 1.03	0.66 – 1.15
		1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6	1=3=4=5=6
	PV	3.75 – 4.40	81.70 – 84.97	0.38 –	13.63 – 16.17	0.65 – 0.88	0.51 - 0.88
		2=3=8=9=10	2=3=8=9=10	0.412=3=8=9=10	2=3=8=9=10	2=3=8=9=10	2=3=8=9=10

Source: Authors (2021)

In where: the first line shows the value range, \*and the second line the family number without any statistical difference, for example: in 0% of relative stem height for C precedence is indicated 2=3=4=5=6=9=10, this means that the families 2, 3, 4, 5, 6, 9 and 10 any differences were found between them; CSJ=CoopeSanJuan of Cutris of San Carlos, C=Crucitas of Pocosol of San Carlos and PV=Puerto Viejo of Sarapiquí.

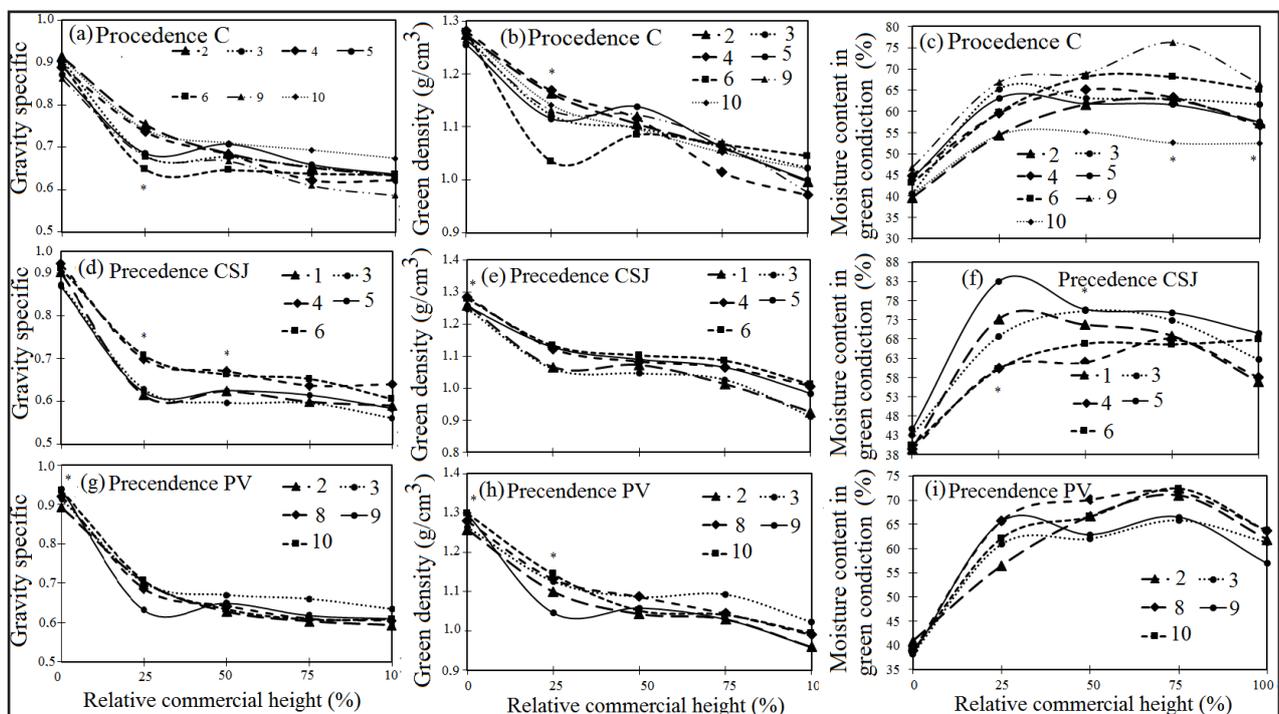
### 3.2 Physical properties

As for the physical properties at the different heights of the trunk, the specific gravity (SG) and moisture content in green condition (MC-G) showed significant differences between the three provenances in all cases (Table 1), while regarding green density (GD) no significant statistical differences were observed at any height of the trunk (Table 1). At the bottom section of the tree, there were significant differences between the provenances PV and CSJ and between PV and C for SG (Table 1). Differences were also determined between provenances C and PV in MC-G (Table 1). At 25 and 50 % trunk heights there were differences between C and CSJ, both for SG and for MC-G (Table 1). For 75 % trunk height, provenance C was statistically different from provenances CSJ and PV in SG, while MC-G was different between provenances C and CSJ. Finally, at 100 % height, there were no differences in any of the evaluated physical properties (Table 1).

Figure 4 shows the variation of the physical properties of the families of each provenance at different tree heights. SG tends to decrease with trunk height and is significantly different at 0, 25 and 50 % tree height (Figure 4a, 4d and 4g). At the bottom section of the tree, differences in SG were recorded between families 2 and 9 and between families 2 and 10 of provenance PV (Figure 4g). Differences were also observed in provenance C between families 6 and 10 (Figure 5a); in provenance CSJ between families 1 and 6, families 3 and 6, families 5 and 6 and 4-5 at 25 % trunk height. At 50 % trunk height, meanwhile, there were differences between families 3 and 4 from the CSJ provenance (Figure 4d). GD exhibits a decreasing pattern with trunk height (Figure 4b, 4e, and 4h), also showing significant differences at the bottom section of the tree between families 3 and 4 of CSJ provenance (Figure 4e) and families and between families 2 and 9, and 2 and 10 of PV (Figure 4h). At 25 % trunk height, differences were observed between families 2 and 6, 4 and 6, 6 and 9 and families 6 and 10 of provenance C (Figure 4b), as well as between families 8-9 and 9- 10 of PV (Figure 4h).

As for the MC-G, an upward trend was observed up to approximately 75 % trunk height, then decreasing towards 100 % height (Figure 4c, 4e and 4i). The statistical differences of this parameter were recorded between families 4 and 5 and families 5 and 6 of the CSJ provenance, at 25 % trunk height; and at 50 % trunk height, between families 3 and 4, 4 and 5 of CSJ provenance (Figure 4f). At 75 % trunk height, differences were also observed between families 2 and 9, 3 and 9, 5 and 9, 6 and 10 and between families 9 and 10 of C provenance (Figure 4c). Finally, there were significant differences between families 6 and 10, 9 and 10 from C provenance at 100 % trunk height (Figure 4c).

Figure 4 – Variation with relative tree height in specific gravity, green density and moisture content in green condition of *Dipteryx panamensis* for three provenances in the northern region of Costa Rica: (a-c): Crucitas-C, (d-f) CoopeSanJuan-CSJ and (g-i) Puerto Viejo-PV



Source: Authors (2021)

In where: (\*) Statistically different among provenances at indicated stem height.

## 4 DISCUSSION

### 4.1 Morphological characteristics

The decrease in diameter, heartwood diameter and bark thickness (Table 1, Figure 3) and the increase in sapwood relative to stem height (Table 1) is a pattern observed in trees of tropical species developing in fast-growing plantations (MOYA; MUÑOZ, 2010; TENORIO *et al.*, 2016a). The decrease or increase of these parameters with stem height is associated with the variation of the physiological processes of trees (PFAUTSCH *et al.*, 2018).

The study of families showed that in *Dipteryx panamensis* the heartwood is present up to 75 % commercial height (Figure 2b), reaching values less than 10 % at the base of the tree and decreasing to 4 % at 75 % stem height at 8 years of age in plantations (Table 1). Other tropical species of commercial importance report values of heartwood above 30 % (TENORIO *et al.*, 2016a). However, despite the difference in diameter and heartwood percentage, the values in this work could be considered acceptable, since *Dipteryx panamensis* has a high specific weight (greater than 0.6), high aesthetic value in the market, high durability (TENORIO *et al.*, 2016b) and good growth in plantations (REDONDO-BRENES, 2007).

The bark tissue protects the tree, while the greatest source of variation in the tree is along the stem height (PAINE *et al.*, 2010). This behavior is consistent with results found in *Dipteryx panamensis* trees from families from different provenances, where bark thickness decreased along the stem height (Figure 2d), but bark percentage increased with height (Table 1). This behavior is consistent with reports from several tree species by Tenorio *et al.* (2016a) in trees from 13-year-old plantations. Another important result is that bark pattern at different stem heights (thickness and percentage) is similar in the three provenances evaluated (Figure 2d, Table 1). According to Wilson and Witkowski (2003), it has been observed that bark variation is low during the first years of growth before flowering. This suggests that there is no need for the tree to invest such energy

in creating a thick tissue. Contrariwise, bigger trees need more tissue protection and to produce elements for conduction. This physiological behavior can also explain the little variation in thickness and percentage of bark among different provenances and families, as found in this research.

The pith diameter and the percentage among families presented values under 1.5 cm and 1 % of the area (Figure 2e, Table 1-2) respectively, along the commercial stem, which is advantageous in wood industrialization. Low pith values increase the quality and quantity of sawn wood in the future, with greater lumber recovery factor (MOYA *et al.*, 2008). Low variability recorded in the pith dimensions at 8 years, except for the older trees that present low percentage (Figure 2e, Table 1-2), shows a pattern of high stability in this parameter. This pattern was present in the analysis among families, provenances and stem height. Therefore, the results suggest low genetic control in this parameter, which therefore should not be considered in future programs of genetic improvement.

León *et al.* (2017) report that selection of individuals and provenances is a viable strategy for the improvement of *Dipteryx panamensis* for forest production. As part of the genetic improvement strategies, the genetic stability of materials under different environmental conditions (genotype x environment interaction) has been investigated, with the aim of reducing its impact on the expected genetic gain (MURILLO, 2018). The results recorded in this research on the variation in the properties of the wood and the tree tissue behavior, associated with its genetic origin (family and provenance), are an important input to continue with the genetic improvement and with the ongoing works on the silvicultural management of the species (LEÓN *et al.*, 2017).

## 4.2 Physical properties

Studies that relate the genetic origin of trees with wood properties are often reported (HUANG *et al.*, 2015), less frequently those that relate to tropical hardwoods. Some of the latter are *Guazuma crinita* Lam (WEBER; SOTELO-MONTES, 2008),

*Calycophyllum spruceanum* (Benth.) Hook.f. ex K.Schum. (SOTELO-MONTES *et al.*, 2007) and *Bombacopsis quinata* (Jacq.) W.S.Alverson (HODGE *et al.*, 2002).

The values found for SG, MC-G and GD (Table 1) for 8-year-old families of *Dipteryx panamensis* from different provenances are consistent with those reported by Tenorio *et al.* (2016a) for trees of *Dipteryx panamensis* from 13-year-old plantations, where values of 0.63 g/cm<sup>3</sup>, 59 % and 1 g/cm<sup>3</sup>, respectively, are reported. These authors report a similar pattern of variation of these three physical properties with the stem height. That is, high values of SG and GD at the bottom section of the tree, then a severe decrease up to 25 % of the commercial height, and then a stable value with the increasing stem height (Table 1). In the case of MC-G, a low value is recorded at the tree bottom, a rapid increase up to 25 % stem height, then stable values between 25 and 75 % of the commercial height. Finally, the value of MC-G decreases up to 100 % of the commercial height (Table 1).

Significant differences were found between provenances in the physical properties of the wood at different heights of the tree trunk (Table 1). Specifically, there were significant differences between PV with CSJ provenances and between PV with C for SG at the base of the tree (Table 1). There were also differences in MC-G between C and CSJ provenances at 50 % stem height (Table 1), suggesting an important genetic effect attributable to the provenance of the materials (ZOBEL; JETT, 1995). Regarding the green density (GD), no significant statistical differences were observed at any height of the trunk (Table 1). This was already expected, considering that the green density of the wood varies little between species, when compared to specific gravity (ZOBEL; VAN BUIJTENEN, 1989).

Likewise, it is important to note that wood formation is regulated by molecular aspects, which vary with age (PAN *et al.*, 2018). The differences in the properties of the wood between provenances can be due to high competition after growing in very small spacings (3x3m in this case) (WEBER; SOTELO-MONTES, 2008). Despite the young age of the trees in this research, it is already possible to observe the variation patterns that will guide the *Dipteryx panamensis* improvement program as regards the physical

wood properties, the improvement of SG above all, as it influences a great majority of the mechanical properties (WILLIAMSON; WIEMANN, 2010).

The variation of the physical properties of the wood between families within each provenance (Figure 4), shows once more the potential to select genotypes with favorable conditions to improve the properties of the wood (ROCHON *et al.*, 2007). There are important differences between families within the same provenance at the lower part of the tree (Figure 4), which could orient the selection work of the superior individuals towards achieving a greater effect of the genetic improvement on the wood properties of greater interest. The bottom section of the tree not only shows greater genetic control and variation: its dimensions give this section higher economic value for the production of wood and higher added value products (SERRANO; MOYA ROQUE, 2011). If SG is considered the most important physical property due to its influence on other properties of wood (WILLIAMSON; WIEMANN, 2010), families 2, 4 and 10 of C provenance (Figure 4c), families 4 and 6 of the CSJ provenance (Figure 4d) and families 2, 3, 8 and 10 of the PV provenance (Figure 4g), are the materials with the greatest potential to establish a program for genetic improvement of physical properties. These same families generally registered low MC-G values, which has been reported as appropriate in drying processes of wood from planted tropical trees (TENORIO *et al.*, 2016b).

## **CONCLUSION**

The results obtained in 8-year-old trees of *Dipteryx panamensis* show a high potential for genetic control of wood characteristics such as sapwood, heartwood, bark and physical properties.

The variation of the properties of the wood between families within each provenance occurs mainly in the lower part of the tree. Thus, this section becomes the most efficient section of the tree for selecting genetically superior individuals as regards their physical properties.

Specific gravity, diameter and heartwood percentage are the variables of greatest relevance due to their influence on other properties of wood. Families 2, 4 and 10 from provenance C, families 4 and 6 from provenance CSJ and families 2, 3, 8 and 10 from PV provenance are those with the greatest potential for selection to continue genetic improvement of these properties. Provenance CSJ exhibits the greatest potential for genetic improvement of the tree heartwood proportion.

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## Authorship Contribution

### 1 – Dalina Rodriguez-Perez

Forestry Engineer

<https://orcid.org/0000-0002-3039-152X> • dalirp.08@gmail.com

Contribution: Conceptualization, Methodology, Formal Analysis, Writing – original draft

### 2 – Roger Moya

Wood Engineer

<https://orcid.org/0000-0002-6201-8383> • rmoya@itcr.ac.cr

Contribution: Conceptualization, Methodology, Formal Analysis, Writing – original draft

### 3 – Olmán Murillo

Forestry Engineer

<https://orcid.org/0000-0003-3213-8867> • omurillo@itcr.ac.cr

Contribution: Conceptualization, Formal Analysis, Writing – review & editing

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