Steaming and Heating *Dipteryx panamensis* Logs from Fast-Grown Plantations: Reduction of Growth Strain and Effects on Quality

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Abstract

Steaming and heating as pretreatments before log sawing reduce the negative effects of growth strain (GS). The object of this work was to study the reduction of GS in logs of *Dipteryx panamensis* from a fast-growth plantation using steaming and heating treatments and evaluate the effects on the lumber quality. According to the results, the maximum temperature in the center of the log was approximately 90°C after 24 hours for both treatments. GS decreased after heating and steaming. The average value of GS for three treatments was 2,085.61 microdeformation units (**με**) before the treatment, decreasing to average value to1,692.14 **με** after the treatments. This reduction in turn produced a reduction of crook due to sawing measured in logs and semilogs and a decrease in the values and incidence of crook, bow, twist, and split. Similarly, color parameters (L*, a*, and b*) were statistically affected by the treatment, except for parameter L* in sapwood. In general, wood darkening was observed. Lastly, both treatments applied to *D. panamensis* logs showed few differences in GS, in crook due to sawing measured in logs and semilogs, and in the values and incidence of crook, bow, twist, and split. Therefore, both treatments achieved GS reduction in *D. panamensis* lumber.

Growth strain (GS) in trees has been widely studied concerning its causes (Archer 1987) and management applied to the trees (Kubler 1988). GS is related to mechanical strain permanently borne by the wood of the living tree while it is growing (Gril et al. 2017). GS is the result of the combined action of two mechanisms: cell wall maturation and the increase of dead weight (Barnett and Jeronimidis 2003). During maturation of the secondary cell wall, the fibers tend to deform in the axial and transversal directions, although these dimensional changes are limited by the already-formed xylem (Archer 1987). Then, the restraint induces a mechanical stress at the outermost surface of the secondary xylem, located beneath the layer of differentiating xylem. It provokes in the older xylem, during each growth increment, a counteractive stress distribution which is superimposed on the preexisting stress (Gril et al. 2017). When GS is measured on the outer surface of the trunk it is called ''longitudinal surface growth strain'' (LGS; Nicholson 1971, Yang et al. 2005).

GS is present in most species (Archer 1987), particularly in fast-growing species in forest plantations, in which GSs are stronger, and which tend to present GS more frequently (Kojima et al. 2009). When the log is sawn, GS becomes evident in the form of warps (crook, bowing, and twisting), splits, and checks in the boards (Entwistle et al. 2016). The magnitude of these defects depends on the species, but it can result in considerable economic losses for foresters and sawmills (Gril et al. 2017).

Different log treatments have been implemented to reduce the effect of GS and thus increase the quality of the lumber (Archer 1987, Kubler 1988, Yang and Waugh 2001, Ratnasinga et al. 2013, Gril et al. 2017). GS relaxation occurs at high temperatures induced by boiling, steaming, and smoking applications on logs (Tejada et al. 1997, Nogi et al. 2003, Severo et al. 2010, Pelozzi et al. 2014, Rodrigues et al. 2018). Direct heat and steaming soften the physical structure of the material as the wood reaches the

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glass transition temperature (Lenth and Kamke 2001, Pelozzi et al. 2014, Li et al. 2020). When the wood reaches this temperature, its polymers are softened, molecular rearrangement and microstructure of the material occurs, and consequently internal strains are released (Nogi et al. 2003, Gril et al. 2017, Rodrigues et al. 2018). The temperature (80°C to 140°C) produces softening of the cellulose and the matrix that forms lignin and hemicelluloses (Salmén 1984, Kelley et al. 1987). During softening, the lignin along and across the fiber direction is shown to be related to the stiffening effect of the cellulose microfibrils preferentially aligned along the fiber (Salmén 1984). Therefore, this softening alleviates the internal strain through the molecular and microstructural reorganization of the wood (Nogi et al. 2003, Gril et al. 2017, Rodrigues et al. 2018, Li et al. 2020).

Moreover, several tropical species are gaining relevance in commercial reforestation projects in Costa Rica due to increased knowledge on their genetics, propagation, and plantation management (Murillo 2018). Fast-growing species with rotation periods of less than 25 years, such as *Dipteryx panamensis* (Almendro), show excellent growth and yields in forest plantations (Delgado et al. 2003, Redondo-Brenes and Montagnini 2006, León et al. 2017). *Dipteryx panamensis* wood presents specify gravity of 0.7 to 08; its porosity is diffuse–porous, stored rays and axial parenchyma are vasicentric, confluent, aliform, lozenge–aliform, and winged-aliform (Moya et al. 2019). Recent research regarding wood quality of this species (Moya and Muñoz 2010; Moya et al. 2011, 2019; Tenorio et al. 2016a, 2016b) showed two types of problems: (1) problems in the primary sawing process and (2) high incidence of wood warping during the drying process.

These problems owe to high GS incidence in logs extracted from plantation trees, therefore warps, checks, and splits are frequent in the boards obtained from the sawing process. Added to this, the drying process accentuates the warps, producing very low-quality lumber (Moya et al. 2013, 2019; Tenorio et al. 2016b).

Few studies on tropical species and on forest plantation species (Gilbero et al. 2019) have quantified the reduction of GS obtained by applying heat or steam treatments to the logs, and how these treatments influence the quality of wood in species in forest plantations. Therefore, the present work aims to study the LGS in sawlogs of *D. panamensis* from fast-growing plantations under heat and steam treatments for 24 hours at 115°C; then, evaluate the effects of those treatments on the quality of the lumber (incidence of warps, checks, and splits) and wood color measured by L*a*b* color systems after log sawing.

Materials and Methods

Site and characteristics of the plantation

Sampling took place in a fast-growth plantation of *D. panamensis* that belongs to the company Reforest the Tropics Inc., located in San Juan Norte, Turrialba, Costa Rica. The site presents moist tropical climate with average annual precipitation of 2,854 mm and a dry season between January and May. The mean annual temperature is 22.9°C. At the time of sampling the plantation was 16 years old. The initial planting density of the plantation was 3 m by 3 m (1,100 trees/ha). At the time of sampling the density of the plantation was 550 *n*/ha.

Tree selection and sampling

Sixty-nine trees were sampled with diameters greater than 13 cm, which corresponded to the minimum diameter for a sawmill (Table 1). For each selected tree, the diameter at breast height and total height were determined and the north–south positions were marked at breast height. A commercial log 2.5 m long and a cross-section 3 cm thick at the base of the tree and at the end of the 2.5-m log were extracted. North and south sides were marked in all logs.

Treatments used to reduce the longitudinal growth strain and increase the quality of lumber

Two treatments were used to reduce the LGS and increase lumber quality: (1) heating, in which the logs were heated for 24 hours at 115°C and (2) steaming, in which the logs were steamed for 24 hours at 70 Pa and where the temperature reached 115°C. Untreated samples (without heating or steaming) were used for comparison.

During heating and steaming, the logs were placed inside a horizontal tank measuring 60 cm diameter and 3 m long, with a 4- to 6-log capacity (Fig. 1a). For heating, three 1,000-W cartridge heaters were placed in the lower part of the tank. For steaming, two sprayer lines were placed 180° one from the other, to allow steam supply at 8 kg/cm^3, 4 L/min, and 115°C temperature.

Parameters measured during the heating and steaming treatments

Moisture content (MC), LGS, and temperature variation inside the log were determined for each log in the different treatments. The MC was determined in the cross-sections obtained at the base of the tree and at 2.5 m tree height. The cross-sections were cut into six radial slices and three of them were chosen to measure the MC, according to the ASTM D-4442-07 standard (ASTM International 2016). The LGS was determined in all the logs before (LGS_{before} and after (LGS_{after}) the heating and steaming and in the untreated logs. The measurements were again performed on the north and south sides, at half the length. The LGS in each side of the logs was measured according to the methodology proposed by Nicholson (Nicholson 1971). This method involves removing an area of the bark (Fig. 1b), placing two Phillips screws with gauge separation, and determining the gauge separation (called initial length) with the help of an extensometer (Hugenberger tensotast). Then, two cuts were made at 6 mm from the point where the screws were placed and 2 minutes later this distance between the points was measured again; this was the final length. Because the fibers of the surface area of the tree or log were under tension, the screw heads tended to get closer after the knife cuts were made. The difference or

Table 1.—Dasometric conditions of Dipteryx panamensis *trees used in heating and steaming treatments of sawlogs.*

Treatment of sawlogs	Diameter at breast height (cm)	Total height (m)	Sampled trees
Heating	14.77 (13.0–18.0)[a]	15.24 (9.3–18.6)	28
Steaming	15.07 (13.0–20.1)	16.75 (2.6–19.4)	21
Untreated	16.29 (12.8–19.0)	15.61 (14.0–20.5)	20

[a] The values in parenthesis correspond to minimum and maximum values.

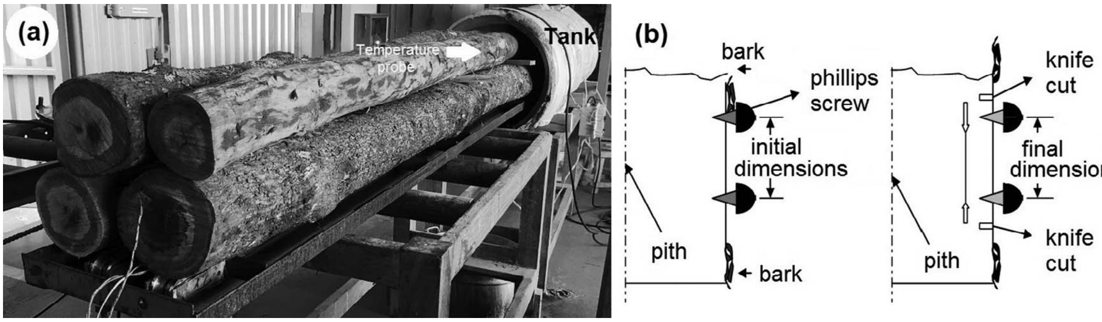

Figure 1.—Horizontal tank for steam and heat application to sawlog (a) and Longitudinal surface growth strain representation of center deflection measuring of microstrain by knife cut (b).

dimensional change of the final length relative to the initial length was expressed in microdeformation units ($\mu\varepsilon$; Eq. 1), which represents the LGS (in $\mu\varepsilon$).

$$\text{Longitudinal surface growth strain (LGS) in } \mu\varepsilon = (\text{initial distance} - \text{final distance}) * 20 \quad (1)$$

The temperature variation was obtained by introducing a probe into three of the four to six logs placed inside the tank, to determine the log's inside temperature. The probe was inserted to half the diameter and at the central area of the log (Fig. 1a). The temperature was monitored in the center of log with the objective of knowing the variation of temperature and the maximum temperature in the center of the log. The temperature was monitored every 5 minutes and the probes were connected to a Testo datalogger, model 177-T175 (Testo SE & Co. KGaA, Titisee-Neustadt, Germany), to record the data. The data temperature collections were used for determination of temperature and time of stabilization. The scatterplot graph between time and temperature was done and where temperature change was low or approximately 1°C, the stabilization was established.

Sawing pattern and crook due to sawing

The logs were sawn using a typical pattern for producing lumber in Costa Rica (Serrano and Moya 2011). Semilogs were obtained and then sawn into 2.5-cm boards. Sawing was done using a band saw and a single-cut resawing saw. The cutting pattern is shown in Figure 2a, where Cuts 1 and 2 were performed with the band saw, while the block cuts (Cuts 3 and 4) were made with the resawing saw. At the time of making the cuts in the logs and semilogs the crook due to sawing were measured (Fig. 2b and 2c). We tried to take a board from every 10 boards from each treatment (heating, steaming, and untreated) to determine the MC after the treatment. A cross-section was extracted from each chosen board, at 27 cm from the end of the board. MC was determined using standard ASTM D-4442-07 (ASTM International 2016).

Lumber quality and color evaluation

Warp (twist, crook, bow, and cup), check, and split as lumber quality parameters were measured in each board. The methods are detailed in Salas and Moya (2014) and Tenorio et al. (2011). Color was determined for all the boards obtained from the logs in each treatment. Where the boards had sapwood and heartwood, color was determined in both types of tissue. A miniScan XE Plus spectrophotometer (HunterLab Inc., New York, USA) was utilized to obtain the values of the CIE L*a*b* standardized chromatological system (Hunter and Harold 1987). The CIE L*a*b* color system estimates the value of three variables: coordinate L* for lightness, representing the position on the black–white axis (L* = 0 for black, L* = 100 for white); coordinate a* for the position on the red–green axis (positive values for red, negative values for green); and coordinate b* for the position on the yellow–blue axis (positive values for yellow, negative values for blue; Hunter and Harold 1995).

Statistical analysis

One-way analysis of variance (ANOVA) was applied to LGS before treatment and LGS after treatment, crook due to sawing, wood color parameters (L*, a*, and b*), and lumber quality (warp, crook, and split) parameters. The Tukey test was used to test the mean difference at a level of significance of $P < 0.01$. The SAS 8.1 statistics program for Windows (SAS Institute Inc., Cary, North Carolina, USA) was used to carry out the analyses.

Results

Temperature variation

Table 2 presents the maximum temperature inside the log and time of the different treatments applied to the logs. Lumber under heating treatment showed a stabilization time and maximum inside temperature lower than lumber under steaming treatment. However, the total time was slightly less than in the steaming (Table 2).

As for variation of the temperature with time inside the logs, differences were observed between heated and steamed logs (Fig. 3). In logs under steaming the diameter influenced internal heating, as logs with smaller diameter presented higher temperatures for the same period than logs with bigger diameters (Fig. 3b). This behavior was not

Table 2.—Temperature variation in heating and steaming for Dipteryx panamensis *logs from a fast-growth plantation.*

Parameters	Heating	Steaming	Average for two treatments
Stabilization time (h)	20.844	23.382	22.500
Maximum temperature reached (°C)	89.00	91.00	90.00
Total time of treatment (h)	26.889	25.278	26.083

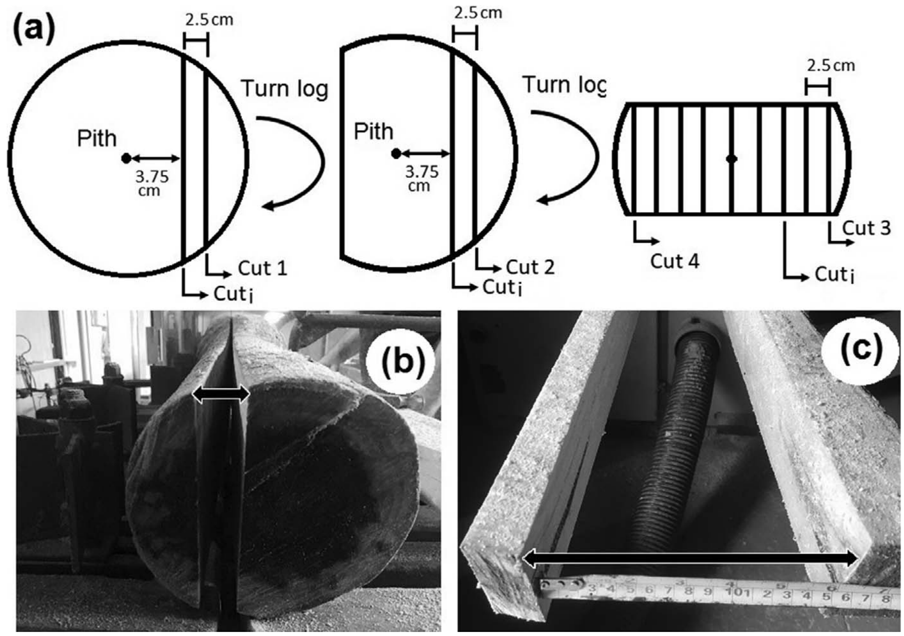

Figure 2.—Sawing pattern utilized in un-treated and heating and steaming for Dipteryx panamensis *logs from a fast-growth plantation (a); crook due to sawing in sawlogs, (b) and crook due to sawing in semi-logs (c).*

observed regarding heating, as small and big diameters presented similar behavior with little internal temperature variation among them (Fig. 3a).

LGS and crook due to sawing

With regard to the effect of the treatment on the LGS of logs before sawing, the ANOVA showed that the log treatment was not statistically significant between in LGS_{before} and LGS_{after} (Table 3); average value of LGS_{before} for three treatments was 2,085.61 με and average value of LGS_{after} was 1,692.14 με for all treatments (Fig. 4a). On the other hand, as expected, the values of LGS were lower in logs after treatment (Fig. 4a).

Regarding the effect of the treatment during log sawing it was statistically significant in the values of crook, meaning that the treatments applied to the logs have an effect relative to untreated logs (Table 3). Figure 4b shows the mean values of crook obtained in logs and in semilogs per treatment. In all cases, untreated logs and semilogs presented the highest values of crook relative to heated and steamed logs. No statistical differences were observed between the logs under heating or steaming treatment (Fig. 4b).

Color evaluation

Color parameters (L*, a*, and b*) for sapwood and heartwood differed. Heartwood presented lower values of L*, higher values of a*, and values of b* similar to those of sapwood (Table 4). As to the effect of the treatment before sawing, most parameters were statistically affected by the treatment, except for parameter L* in sapwood (Table 3). Parameters L* and b* presented values statistically higher for heartwood under heating than untreated and under steaming, while no differences were observed between the latter (Table 4). Parameter a* in wood subjected to heating and steaming treatment showed no statistical differences between them and averages greater than in untreated wood.

There were no differences among treatments regarding parameter L* in sapwood, while parameter a* in untreated wood presented the statistically highest average, followed

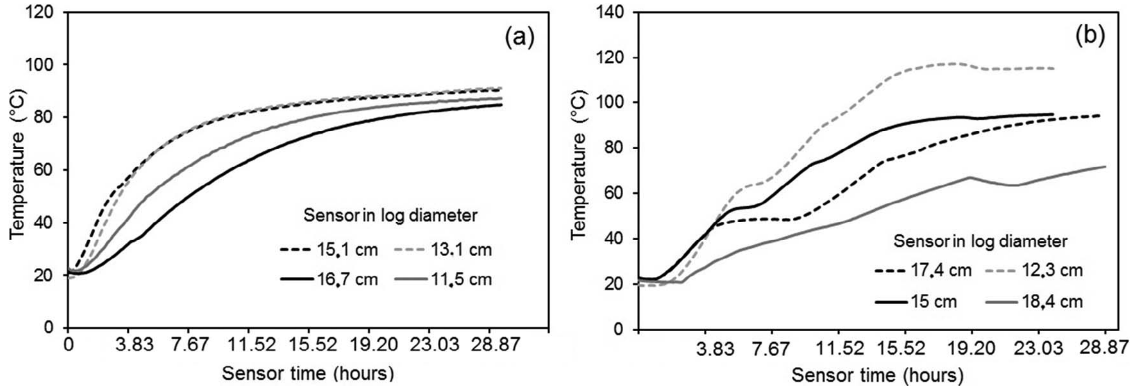

Figure 3.—Temperature variation inside the logs of Dipteryx panamensis *in relation to time for (a) heating and (b) steaming.*

Table 3.—F value of ANOVA for different parameters measured in logs, semilogs and lumber of Dipteryx panamensis.

Parameter	Value[a,b]
LGS before treatment	0.09[a]
LGS after treatment	0.77[a]
Crook in log Side 1	9.85**
Crook in log Side 2	5.76**
Crook in semilog Side 1	11.15**
Crook in semilog Side 2	3.93*
Sapwood color	
L*	1.41[a]
a*	6.50**
b*	8.12**
Heartwood color	
L*	12.62**
a*	8.04**
b*	12.33**
Bow	4.71*
Crook	1.92[a]
Twist	0.92[a]
Check	2.73*
Split	3.00*

[a] Not significant.
[b] * = Statistically significant at 95% ($P < 0.01$); ** = Statistically significant at 95% ($P < 0.05$).

by heat-treated and steam-treated wood. Conversely, parameter b* in untreated wood presented the statistically lowest average, while wood under heating and steaming showed no differences between each other (Table 4).

Lumber quality

Lumber obtained from logs under three different treatments presented three types of warps (bow, crook, and twist), checks, and splits (Table 5; Fig. 5), while cup defects were not present. Incidence of bow defects stood over 85%, crook over 65%; the incidence of twist was around 20% (Table 5) and check and split incidence was over 50% in heating and steaming (Fig. 5b).

The effect of the treatments on the value of the defect was statistically significant only in the case of lumber crook (Table 3), while the differences in the averages showed that the value of bow in untreated lumber were statistically higher, with no statistical differences between heating and steaming (Table 5). As for crook and twist, no statistical differences were observed between the treatments (Table 5).

With respect to the values of checks and splits, the effect of log treatment was statistically significant in both cases (Table 3). The differences in the means indicate that lumber under heating presented statistically lower average crack length, while lumber under steaming showed the highest average crack length and untreated lumber presented no differences relative to the other treatments (Fig. 5a). As for check length, untreated lumber showed the lowest average, while lumbers under heating and steaming presented higher values (Fig. 5a).

Discussion

Steam or heat application contributes to release of LGS in logs (Severo et al. 2010, Pelozzi et al. 2014). Appropriate heating or steaming times soften the structure of the wood (Lenth and Kamke 2001, Pelozzi et al. 2014, Rodrigues et al. 2018) and lessens the LGS altogether (Tejada et al. 1997, Nogi et al. 2003, Severo et al. 2010, Pelozzi et al. 2014, Rodrigues et al. 2018), as was evidenced when the logs of *D. panamensis* were steamed or heated and LGS showed significant reduction after the treatments (Fig. 4a).

The reduction of LGS after steaming or heating (Figure 4a) indicates that the temperature reached in the center of the log during these two treatments, approximately 90°C (Table 2), allows reaching the glass transition temperature, which in many species varies from 80°C to 100°C (Kelley et al. 1987, Kong et al. 2017). The temperature achieved by heating and steaming produce softening of the cellulose and the matrix that forms lignin and hemicelluloses (Salmén 1984, Kelley et al. 1987). Lignin found in the middle lamina and in layer S2 is thermoplastic (Salmén 1984); i.e., it softens at the appropriate temperature (Lenth and Kamke 2001, Pelozzi et al. 2014). Therefore, this softening alleviates the internal strain through the molecular and microstructural reorganization of the wood (Nogi et al. 2003, Gril et al. 2017, Rodrigues et al. 2018).

A source of variation affecting the log's internal temperature and therefore the possibility of reaching the glass transition temperature is log diameter, in particular in logs under steaming (Fig. 3b). In heating, the set target temperature of the tank was 115°C; however, after 24 hours, the internal temperature of the log increased faster in logs with smaller diameters and slower in those with bigger

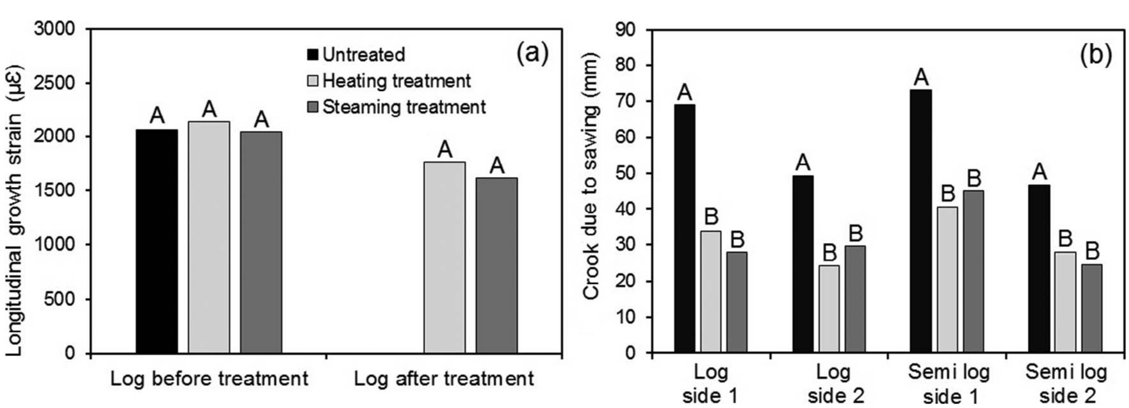

Figure 4.—(a) Longitudinal surface growth strain and (b) crook measured in logs and semilogs of Dipteryx panamensis *wood from a fast-growth plantation under different treatments. Different letters between treatments mean that there are statistical differences (P < 0.05) between log treatments.*

Table 4.—Color parameters measured in Dipteryx panamensis *lumber from a fast-growth plantation under different treatments.*

Treatment	Color parameters in heartwood			Color parameters in sapwood		
	L*	a*	b*	L*	a*	b*
Untreated	51.05 B (14.73)[a,b]	8.23 B (31.36)	24.00 B (20.49)	75.66 A (8.64)	6.30 A (45.17)	24.09 B (18.05)
Heating	56.88 A (14.01)	9.48 A (25.22)	27.56 A (17.68)	74.62 A (6.02)	5.76 AB (24.77)	25.90 A (6.81)
Steaming	53.13 B (10.23)	9.88 A (21.65)	25.04 B (13.37)	74.08 A (6.03)	5.00 B (23.87)	25.73 A (8.42)

[a] The values in parentheses correspond to the coefficients of variation.
[b] Different uppercase letters between treatments means that there are statistical differences ($P < 0.05$).

diameters, but after 21 hours all the logs reached approximately 89°C (Fig. 3a). Meanwhile, in the steaming, logs with smaller diameters reached temperatures close to the target and medium sized logs reached close to 89°C, while logs with bigger diameters reached only 70°C internal temperature after 24 hours (Fig. 3b).

As said, the glass transition temperature of the wood varies from 80°C to 100°C, releasing LGS (Kong et al. 2017). Since *D. panamensis* logs under heating and small-diameter logs under steaming reach a temperature range of 80°C to 90°C, it means the glass transition was achieved. As a result, LGS parameters were reduced in 25%, as shown by the reduction of crook (Fig. 4) and of the magnitude of bow (Table 5; Fig. 5c).

In logs that reach the adequate glass transition temperature such as logs under the heating treatment and smaller logs under steaming, softening of the cellulose and the matrix that forms the lignin (Lenth and Kamke 2001, Pelozzi et al. 2014) and the hemicellulose (Kelley et al. 1987, Kong et al. 2017) occurs. This softening alleviates the internal strain through the molecular and microstructural reorganization of the wood (Nogi et al. 2003; Gril et al. 2017; Rodrigues et al. 2018). Stress relief produces warp reduction during sawing, as observed in crook in lumber of *D. panamensis* in the present study (Fig. 4; Table 5).

Heating and steaming treatments are used to reduce LGS (Tejada et al. 1997; Nogi et al. 2003; Severo et al. 2010; Pelozzi et al. 2014; Rodrigues et al. 2018), as evidenced in the present study (Fig. 4a). However, these two treatments showed few differences regarding *D. panamensis* lumber. The values of LGS (Fig. 4a), crook measured in logs and semilogs (Fig. 4b), color parameter a* in heartwood, the three color parameters in sapwood (Table 4), and values and incidence of crook, bow, twist, and split (Table 5; Figs. 5a and 5b) presented no differences between heating and steaming. Differences were only observed in color parameters L* and b* in heartwood (Table 4), and less presence of checks in lumber under the heating (Fig. 5a).

The above results indicate that for *D. panamensis* logs, steaming and heating treatments are appropriate for reducing LGS and related parameters, such as incidence of warps, splits and checks, contradicting studies on other species, such as *Hieronyma alchorneoides*, *Hevea brasiliensis* or some Eucalyptus (Severo et al. 2010; Pelozzi et al. 2014), which indicate that the steaming treatment creates better conditions for relaxation of the different polymers that compose wood. This is so because the internal conditions of temperature and moisture inside the chamber in the steaming treatment allow moisture saturation of the environment, improving conditions for polymer relaxation in the logs (Kong et al. 2017). In addition, the crystalline zones of the hemicellulose tend to decrease, increasing the amorphous areas (Kong et al. 2017), which translates into improved conditions for relaxation of the growth strain (Li et al. 2020). However, the steaming treatment did not render the expected results in *D. panamensis* logs, probably because the logs are very thin and quickly reach the glass transition temperature inside in both treatments.

A negative aspect of heating is the loss of moisture of the log, especially at its ends, because the conditions that are created (high temperature and low humidity) cause greater incidence of checks during the sawmill process, as warping problems or additional growth strains problems (Nogi et al. 2001, 2003), as occurred in this work (Fig. 5).

The variation that occurred in the color parameters, mainly in heartwood of lumber coming from steam- and heat-treated logs in relation to wood from untreated logs (Table 4), is attributed to the effect produced by the temperature on the chemical composition (Kocaefe et al. 2008, Salca et al. 2016), specifically the hydrolysis of hemicelluloses and extractives in this type of wood (Salca et al. 2016). The increase in temperature due to steam or heat causes an increase in the white and yellowish hue (increase in L* and b*), specifically in heartwood (Table 4), which is attributed to degradation or modification of the more abundant extractive agents in heartwood, through reactions such as oxidation, dehydration, decarboxylation, and hydrolysis (Kocaefe et al. 2008), and the darkening of lignin, associated with the parameter a* (increase in a*), which is associated with the generation of chromophore

Table 5.—Magnitude and incidence of crook, bow and twist defects in lumber from Dipteryx panamensis *logs from a fast-growth plantation under different treatments.*

Log treatment	Board total	Bow		Crook		Twist	
		Value	Incidence (%)	Value	Incidence (%)	Value	Incidence (%)
Untreated	88	11.88 A (76.82)[a,b]	86.36	9.41 A (69.98)	75.76	2.48 A (69.98)	21.21
Heating	66	11.26 A (79.30)	88.64	7.60 AB (77.62)	67.05	3.58 A (30.90)	20.45
Steaming	57	8.75 A (87.85)	85.96	5.70 B (69.13)	70.18	3.01 A (35.52)	22.81

[a] The values in parentheses correspond to the coefficients of variation.
[b] Different uppercase letters between treatments means that there are statistical differences ($P < 0.05$).

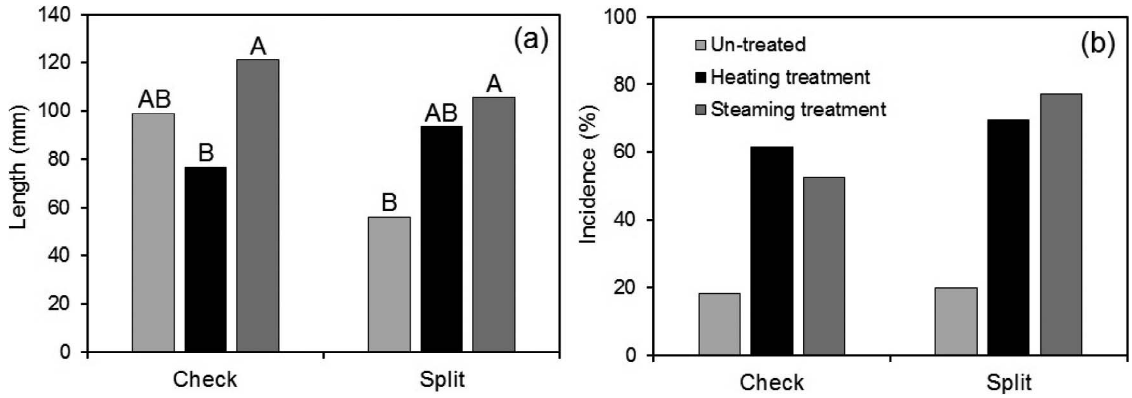

Figure 5.—Length (a) and incidence (b) of check and split defects in Dipteryx panamensis *wood from a fast-growth plantation. Note: Different letters between treatments mean that there are statistical differences ($P < 0.05$) between log treatments.*

groups (Salca et al. 2016), which causes darker color changes at high temperatures (Table 4).

The values of the parameters L* and b* in heartwood extracted from steam-treated logs surpassed those of -reated lumber (Table 4). This was probably due to slightly higher steaming temperature than heating temperature which results in changes in wood components associated with L* and a* parameters.

Although previous researchers presented different methods for reducing the effects of the presence of GS in trees on wood quality, few have been presented in a tropical commercial wood species with importance in the market, such as *D. panamensis* with its high density and many problems associated with GS. Likewise, this work presents a practical, industrially viable, and economical option to reduce GS, and thus has real effects on wood quality. The reactor (tank) built with steaming or heating applications can be utilized in sawlogs from fast-grown trees from commercial plantations in tropical regions, which have few options for such trees.

Conclusion

LGS diminishes in steam- and heat-treated logs. Quality of the lumber obtained from these logs increases. Specifically, crook due to sawing is reduced in logs and semilogs; there are changes in color parameters and in the value and incidence of warps, splits, and checks in lumber. In both treatments (steaming and heating), the temperature reached probably permitted softening of chemical components, thus promoting LGS diminution. Likewise, both treatments applied to *D. panamensis* logs showed few differences regarding LGS, crook due to sawing measured in logs and semilogs, and in the values and incidence of crook, bow, twist, and split. Therefore, both treatments are appropriate for reducing the LGS and both improve the quality of wood from *D. panamensis*.

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