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REDUCTION OF EFFECT OF GROWTH STRESS PRESENCE USING ENDLESS SCREW DURING KILN DRYING AND STEAMING AND HEATING TREATMENT IN LOG BEFORE SAWING

RÓGER MOYA, CAROLINA TENORIO
ESCUELA DE INGENIERÍA FORESTAL
COSTA RICA

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ABSTRACT

The relaxation of growth stress in trees growing in fast-growth conditions, as plantation in tropical areas, affects lumber quality during of sawing or drying process. It was evaluated two pretreatments (heating and steaming application) before sawing process and endless screw use to maintain the boards pressed during drying of *Dipteryx panamensis* and *Hieronyma alchorneoides* wood with objective to reduce the effects of relaxation of growth stress. The results showed endless screw is used to maintain the boards pressed, the moisture content (MC) or drying rate did not vary. The use of endless screws with daily adjustment during drying produced a reduction of cup, check and split defects in lumber and this treatment is accompanied with a pre-treatment before sawing (heating or steaming treatment) decreased the incidence of drying defects. Then the use of both treatments is an opportunity to reduce the effects of relaxation of growth stress on the quality of the wood of *D. panamensis* and *H. alchorneoides* from fast-growth plantation conditions.

KEYWORDS: Drying defects, tropical wood, log treatment, drying improvement.

INTRODUCTION

One of the main problems of trees from fast-growth plantations is that the logs extracted from those trees show a high manifestation of growth stress (Kojima et al. 2009), which is evidenced during the sawing process, the wood presents a high incidence of warps, checks and splits and they are accentuated during the drying process, producing dried-lumber of low quality (Moya et al. 2013, 2019, Tenorio et al. 2016).

The effect of growth stress on wood processing has been extensively studied (Yang and Waugh 2001, Gril et al. 2017). Growth stress is referred to the mechanical stress permanently endured by the wood of the living tree during its growth (Gril et al. 2017). The magnitude of these defects depends on the species and can be result in considerable economic losses for the forester and sawller (Gril et al. 2017).

Different treatments on logs and lumber have been implemented in order to increase lumber quality and reduce the effect of growth stress (Ratnasinga et al. 2013). The application of heat and steam are techniques that reduce growth stress during the sawing or drying process (Pelozzi et al. 2014, Rodrigues et al. 2018). Both processes have been applied with a wide variety of purposes, besides of reducing growth stress levels, such as changing color, improving dimensional stability, increasing permeability, improving drying rate, and reducing the initial moisture content and reducing of drying defects (Calonego and Severo 2007, Ratnasinga et al. 2013).

Different techniques have been implemented to reduce drying defects: drying schedule adjusted to relaxed residual growth stress (Kong et al. 2018), drying techniques such as temperature and steaming application (Lenth and Kamke 2001), frequency-vacuum drying systems (Avramidis and Liu 1994), microwave pretreatment (He et al. 2017) and drying schedule with high temperature (Baranski 2018).

Recently, a mechanical system has been tested to reduce drying defects, which consists in the placement of endless screws with plates that traversed the pile of wood from side to side (Fig. 1b). Every 12 hours the nuts on screws are adjusted in order to maintain the pressed boards and to avoid formation of twists in the wood (Berrocal et al. 2017).

On the other hand, several tropical species have acquired importance in commercial reforestation based on the knowledge of their genetics, reproduction, and plantation management in Costa Rica (Murillo 2018). Fast-growing species (with rotation periods of less than 25 years), such as *Dipteryx panamensis* and *Hieronyma alchorneoides* have excellent growth and production in forest plantations (Redondo-Brenes and Montagnini, 2006). Recent research on these species in relation to the quality of wood indicate two types of problems (Moya and Muñoz 2010, Carolina Tenorio et al. 2016, Moya et al. 2019): *(i)* problems during sawing process and *(ii)* high incidence of drying defects after drying process.

There are few studies in tropical species where the effect of the application of heat and steam a priori in logs on the quality of wood after sawing processing or during drying process is evaluated for relaxation of growth stress. Thus, the present work aims to evaluate the effect on the quality of dried-lumber after the application of four treatments, two applied on logs (heating and steaming treatments) and two applied during the drying process (steam application and endless screw is used to maintain the boards pressed), of *Dipteryx panamensis* and *Hieronyma alchorneoides* wood from forest plantations trees.

MATERIAL AND METHODS

Site and plantation characteristics

A plantation of *Hieronyma alchorneoides* and a plantation of *Dipteryx panamensis* were sampled for this study. Plantation age were 12 and 16 years old, respectably. A plantation of *H. alchorneoides* had a density of 450 $N \cdot ha^{-1}$, while the *D. panamensis* plantation had 550 $N \cdot ha^{-1}$

at sampling time. More details on the conditions of the plantations can be consulted in Moya et al. (2021).

Sampling and sawing of trees

Sampled trees were cut close to the average diameter breaks height (DBH) of each plantation. Logs were sawn using a cutting pattern typical for lumber production in Costa Rica (Serrano and Moya 2011), where a semi-log was obtained and this sawn into 2.5 cm thick boards.

Treatments used for relaxation of growth stress in logs

Two treatments were used on the logs with the objective of relaxation of growth stress: *(1)* application of a temperature of 115°C for 24 hours ($Log_{heating}$) and *(2)* application of steaming for 24 hours at a pressure of 70 Pa ($Log_{steaming}$). As a complement and comparison, logs without heating or stemming were used ($Log_{un\text{-}treated}$). 4-6 logs were placed inside a horizontal tank in both treatments. Conditions of application and tank description for heating and steaming are extensively detailed in Moya et al. (2021).

Treatments for relaxation of residual growth stress during drying process

The relaxion of residual growth stress during drying in sawn-lumber were used drying schedules detailed in Tab. 1 for two species studied according to Moya et al. (2019). A conventional kiln with a 2 m^3 capacity pilot chamber (NARDI, Italy) was used for drying. Conventional kiln uses an electrical power source to heat the resistance inside the chamber. For maintain the relaxation of residual growth stress was used endless screw in during drying process of both species, which had shown appropriated performance for reducing drying defects ($Dyring_{with\text{-}screw}$). The endless screws consisted in the placement of endless screws with plates that traversed the pile of wood from side to side (Fig. 1a) in three different positions: extremes and middle of length pile. They were two twice adjusted with the aid of the nuts on the screw in order to maintain the boards pressed and thus avoid formation of twists in the wood, according to proposed by Denig et al. (2000). As a complement and comparison, a treatment without endless screw was tested ($Drying_{without\text{-}screw}$). The treatments used on the logs and during drying to increase wood quality are detailed in Fig. 1b.

Tab. 1: Drying schedule utilized in lumber from steaming and heating treatment log for D. panamensis and H. alchorneoides.

Species	**Stage**	**DBT** (°C)	**WBT** (°C)	**EMC** (%)	**RH** (%)	**MC** (%)
Dipteryx panamensis	Heating	37	-	-	-	-
	Drying	40	37	15.8	82	Green
		44	38	11.5	68	40
		46	38	9.7	60	30
		48	38	8.4	53	20
		50	38	7.4	47	15
	Equalization	50	42	10	62	-
	Conditioning	50	46	14	79	-
Hieronyma	Heating	40	-	-	-	-

alchorneoides		40	37	14.8	82	Green
	Drying	40	35	12.5	72	40
		45	37	9.7	60	30
		50	40	7.9	55	25
		55	42	6.2	47	20
		55	37	5.0	33	15
	Equalization	55	47	10	64	-
	Conditioning	55	51	15	81	-

Note: DBT - dry bulb temperature, WBT - wet bulb temperature, EMC - equilibrium moisture content, RH - relative humidity and MC - moisture content.

(b)

Log treatment	Dry treatment
Heating ($Log_{heating}$)	With screw ($Drying_{with\text{-}screw}$)
	Without screw ($Drying_{without\text{-}screw}$)
Steaming ($Log_{steaming}$)	With screw ($Drying_{with\text{-}screw}$)
	Without screw ($Drying_{without\text{-}screw}$)
Un-treated ($Log_{un\text{-}treated}$)	With screw ($Drying_{with\text{-}screw}$)
	Without screw ($Drying_{without\text{-}screw}$)

Fig. 1: a) Endless screw location in lumber stacked in piles for adjustment during drying (Berrocal et al. 2017), and b) treatments applied to sawn timber of D. panamensis and H. alchorneoides

Moisture control

Moisture content (MC) was monitored using control or kiln samples and was determined before and after drying. MC before drying, named initial MC (IMC), a cross section of 2.5 cm thick to 20 cm of the end was extracted from kiln samples (Simpson 1991) and was determined according to ASTM-4442-07 standard (ASTM 2007). After kiln samples were placed at different heights in the package in drying chamber according to log and drying treatment. Kiln samples were weighed two twice per day for MC and to establish the change in the schedule (steps) applied (Tab. 1) and MC decreasing during drying process. For final MC (FMC), again, a variation cross section of 2.5 cm thick was extracted from each board after drying. The average values for IMC and FMC for theses six samples were used to determine the average drying rate for each charge, which means moisture loss in percentage determined by Eq. 1:

$$Average\ drying\ rate\ (\%/hr) = (IMC\text{-}FMC)/Total\ drying\ time\ (hours) \qquad (1)$$

where: IMC - initial moisture content in percentage and FMC - final moisture content (%)

Wood color change

Wood color was measured before and after the drying process in the same point in a longitudinal surface. Measures were taken in both heartwood and sapwood. Color was measured using a HunterLab Mini Scan XE Plus spectrophotometer. The CIEL*a*b* system was used to measure the reflectance spectra (from 400 to 700 nm), with an 11 mm opening.

Color change (ΔE*)ΔE* was determined by the values L*, a* and b* before and after drying and calculated according to the formula laid down in the standard ASTM D 2244 (ASTM 2005).

Evaluation of drying defects

The defects measured were warp (twist, crook, bow and cup), splits and checks and were determined before and after drying. The methodology detailed in Salas and Moya (2014) and Tenorio et al. (2012), were used to evaluate all the drying defects. The Index of quality after drying (IQ_{after}) was determined. The official Chilean standard Nch993EO72 was used to determine IQ_{after}, which was computed for twist, crook, cup, bow, check and split according to Eq. 2 (Tenorio et al. 2016). The values close to 0 in this index means lower presence of defects and values close to 5 higher presences of defects. This standard sets limit quality values for the different parameters (Tab. 2). For splits and checks the classification was done according to American Softwood Lumber Standard PS20-05 (NIST-National Institute of Standards and Technology 2005) which establishes four different categories (Tab. 2). Finally, dried-lumber index quality was classified using Kauman and Mittak (1966) methodology (Tab. 2).

$$QI_{after} = \frac{(Na \cdot 0 + Nb \cdot 0.5 + Nc \cdot 2.0 + 2.5 \cdot Nd)}{Total\ boards\ dried} \qquad (2)$$

where: QI_{after} - quality index after drying; *Na* - number of pieces without any presence of warp; *Nb* - number of pieces with a slight presence of warp; *Nc* - number of pieces with a moderate presence of warp; *Nd* - number of pieces with a severe presence of warp.

Tab. 2: Limits values for classification of drying defects and classification of drying quality according to drying defects utilized in the D. panamensis and H. alchorneoides dried-lumber (Kauman and Mittak 1966).

Drying defects	Limits of quality	Drying quality	Limits of dried-lumber quality index
Cup	not present: 0 mm, slight: 1-3 mm, moderate: 3-5 mm severe: > to 5 mm	Excellent	0.0
Bow	not present: 0 mm, slight: 1-3 mm, moderate: 3-6 mm severe: > to 6 mm	Very good	0.1-0.5
Crook	not present: 0 mm, slight: 1-2 mm, moderate: 2-3 mm severe: > to 3 mm	Good	0.51-1.0
Twist	not present: 0 mm, slight: 1-5 mm, moderate: 5-8 mm severe: > to 8 mm	Satisfactory	1.1-1.5
Checks	not present: 0 mm, slight: 1-10 mm, moderate: 10-25 mm, severe: > to 25 mm	Regular Defective	1.51-2.0 2.1-3.0
Splits	not present: 0 mm, slight: 1-25 mm, moderate: 25-42 mm, severe: > to 42 mm	Poor Very poor	3.1-5.0 > 5.0

RESULTS

Initial and final moisture content, drying time and drying rate.

IMC ranged from 28% to 43%, the FMC ranged from 9% to 11%, the drying time was 168 hours for all treatments and the drying rate ranged from 0.13 to 0.20%/hr in *D. panamensis* lumber (Tab. 3). For *H. alchorneoides* lumber, IMC ranged from 64% to 128%, FMC 7.0% to 8.2%, drying time for all six treatments was 164 hours and drying rates were lowest in lumber from $Log_{Heating}$ (about 0.35 %/hour), while the highest value in $Log_{Steaming}$ with 0.73 %/hour (Tab. 3).

Tab. 3: Drying variables for D. panamensis and H. alchorneoides lumber with and without endless screw use during drying process.

Species	Log treatment	Screw use in drying	IMC (%)	FMC (%)	Drying time (hours)	Drying rate (%/hours)
D. panamensis	$Log_{heating}$	$Drying_{with-screw}$	29.98	7.01	168	0.14
		$Drying_{without-screw}$	38.05	7.20	168	0.18
	$Log_{steaming}$	$Drying_{with-screw}$	41.99	8.27	168	0.20
		$Drying_{without-screw}$	28.07	7.05	168	0.13
	$Log_{un-treated}$	$Drying_{with-screw}$	35.80	9.01	168	0.16
		$Drying_{without-screw}$	42.74	11.27	168	0.19
H. alchorneoides	$Log_{heating}$	$Drying_{with-screw}$	64.08	7.88	164	0.35
		$Drying_{without-screw}$	66.36	7.00	164	0.36
	$Log_{steaming}$	$Drying_{with-screw}$	127.85	8.20	164	0.73
		$Drying_{without-screw}$	74.85	8.17	164	0.41
	$Log_{un-treated}$	$Drying_{with-screw}$	107.91	7.24	164	0.61
		$Drying_{without-screw}$	90.84	7.78	164	0.51

Note: IMC - initial moisture content, FMC - final moisture content.

Variation of moisture content and drying rate in relation drying time

The variation of MC with time of *D. panamensis* and *H. alchorneoides* lumber showed a homogeneous behavior of decreasing MC with time in all treatments (Fig. 3). It was observed that were no differences in the behavior of MC variation between $Drying_{with-screw}$ and $Drying_{without-screw}$ (Fig. 3a,b). The variation of drying rate showed homogeneous behavior time in all treatment of *D. panamensis* (Fig. 3c), there was more differences in the lumber from $Log_{Steaming}$ and $Drying_{without-screw}$ in *H. alchorneoides* lumber, which presented a higher value of drying rate during the first two days (Fig. 3d), due to its high IMC (Tab. 3).

Drying defects

The quality classification of dried-lumber considering IQ_{after} cup of *D. panamensis* showed that lumber was classified as excellent in the different treatments (Tab. 4). The use of endless screw increased IQ_{after} of bow in lumber from $Log_{heating}$ and $Log_{un-treated}$, thus there was a decreasing the quality in $Drying_{with-screw}$. IQ_{after} of crook increased in $Drying_{with-screw}$ in lumber from $Log_{heating}$. The IQ_{after} of twist increased in lumber from three different log treatments. For IQ_{after} of checks, only dried-lumber from $Log_{un-treated}$ increased, while IQ_{after} of split increased in lumber from $Log_{heating}$ and $Log_{steaming}$ (Tab. 4).

For the *H. alchorneoides* lumber, the IQ_{after} of bow increased only in lumber from $Log_{heating}$ and $Log_{steaming}$, but IQ_{after} of crook did not increase lumber-dried quality (Tab. 4). For twist and check, the IQ_{after} increased in lumber from $Log_{steaming}$ and $Log_{un-treated}$ in $Drying_{with-screw}$ (Tab. 4). In the case of cup defects, the IQ_{after} increased the quality of the lumber when steaming treatment is applicated during drying. For split defects, the use of endless screw decreased wood quality in all log treatment (Tab. 4).

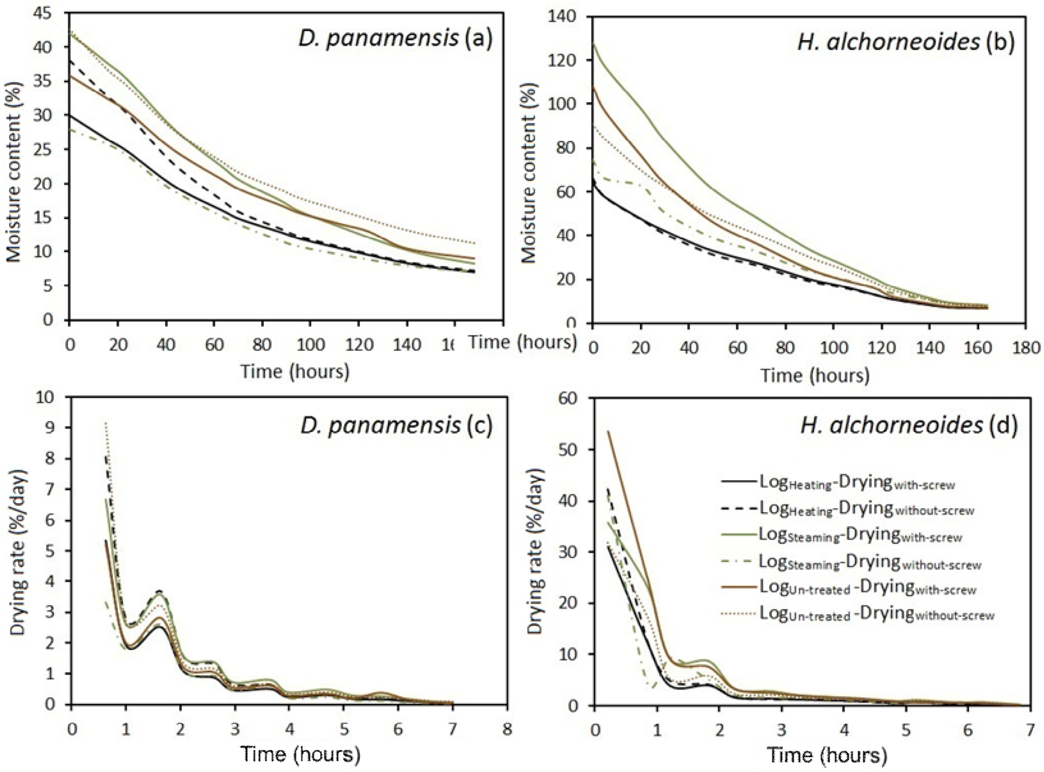

Fig. 3: Variation of moisture content and drying rate in relation to time for D. panamensis (a and c) and H. alchorneoides (b and d) lumber with endless screw use.

Tab. 4: Quality index after drying (IQ_{after}) and classification of dried-lumber obtained for log treatment and used or not of endless screw for increasing lumber quality of D. panamensis and H. alchorneoides.

Species	Log treatment	Screw use in drying	Cup	Bow	Crook	Twist	Check	Split
D. panamensis	$Log_{heating}$	$Drying_{with-screw}$	0.00 (Excellent)	1.39 (Satisfactory)	1.32 (Satisfactory)	0.03 (Excellent)	1.87 (Regular)	1.82 (Regular)
		$Drying_{without-screw}$	0.00 (Excellent)	2.05 (Regular)	1.71 (Regular)	0.74 (Good)	0.79 (Good)	2.24 (Defective)
	$Log_{steaming}$	$Drying_{with-screw}$	0.00 (Excellent)	2.18 (Defective)	2.25 (Defective)	0.41 (Very good)	1.11 (Satisfactory)	1.68 (Regular)
		$Drying_{without-screw}$	0.00 (Excellent)	1.57 (Regular)	2.11 (Defective)	1.14 (Satisfactory)	1.07 (Good)	2.32 (Defective)
	$Log_{un-treated}$	$Drying_{with-screw}$	0.00 (Excellent)	1.59 (Regular)	1.93 (Regular)	0.02 (Excellent)	1.02 (Good)	0.57 (Good)
		$Drying_{without-screw}$	0.00 (Excellent)	2.29 (Defective)	1.84 (Regular)	0.58 (Good)	1.58 (Regular)	1.05 (Good)
H. alchorneoides	$Log_{heating}$	$Drying_{with-screw}$	0.33 (Very good)	1.88 (Regular)	2.50 (Defective)	0.83 (Good)	1.77 (Regular)	1.90 (Regular)
		$Drying_{without-screw}$	0.25 (Very good)	2.22 (Defective)	2.28 (Defective)	1.06 (Good)	1.72 (Regular)	1.50 (Satisfactory)
	$Log_{steaming}$	$Drying_{with-screw}$	0.50 (Very good)	1.96 (Regular)	2.48 (Defective)	0.63 (Good)	1.20 (Satisfactory)	1.69 (Regular)
		$Drying_{without-screw}$	0.57 (Good)	2.27 (Defective)	2.33 (Defective)	1.17 (Satisfactory)	1.50 (Satisfactory)	1.17 (Satisfactory)
	$Log_{un-treated}$	$Drying_{with-screw}$	0.17 (Very good)	2.17 (Defective)	2.50 (Defective)	0.31 (Very good)	0.83 (Good)	1.55 (Regular)
		$Drying_{without-screw}$	0.36 (Very good)	2.14 (Defective)	2.32 (Defective)	0.89 (Good)	1.18 (Satisfactory)	1.21 (Satisfactory)

Color change

Color change (ΔE^*) was similar between in dried-lumber of heartwood and of sapwood in the 3 log treatments of *D. panamensis* (Tab. 5). In addition, it was observed that the ΔE^*, both of sapwood and heartwood, was higher in the lumber from $Log_{heating}$ and $Log_{steaming}$ than the lumber from de $Log_{un-treated}$ (Tab. 5). For *H. alchorneoides*, lumber from $Log_{heating}$ and $Log_{steaming}$, the ΔE^* was lower in heartwood than sapwood in both de $Drying_{with-screw}$ and $Drying_{without-screw}$. But contrary result was presented in lumber from $Log_{un-treated}$, where heartwood presented the highest ΔE^* value compared to sapwood (Tab. 5). Likewise, no effect of endless screw during drying was observed in ΔE^* value in all treatments (Tab. 5). An important aspect to note is that ΔE^* of two species studied was categorized as very evident, this because the ΔE^* values are in the range of 6 to 2 (Cui et al. 2004).

Tab. 5: Color change in D. panamensis and H. alchorneoides lumber from different log treatments and with / without steam application during drying.

Species	**Log treatment**	**Endless screw used**	**Color change ∆E***	
			Sapwood	Heartwood
D. panamensis	$Log_{heating}$	$Drying_{with\text{-}screw}$	11.8	10.9
		$Drying_{without\text{-}screw}$	10.8	11.3
	$Log_{steaming}$	$Drying_{with\text{-}screw}$	10.4	10.0
		$Drying_{without\text{-}screw}$	10.5	10.7
	$Log_{un\text{-}treated}$	$Drying_{with\text{-}screw}$	8.6	7.8
		$Drying_{without\text{-}screw}$	7.8	8.8
H. alchorneoides	$Log_{heating}$	$Drying_{with\text{-}screw}$	13.3	9.2
		$Drying_{without\text{-}screw}$	16.5	8.8
	$Log_{steaming}$	$Drying_{with\text{-}screw}$	15.8	14.0
		$Drying_{without\text{-}screw}$	17.9	13.1
	$Log_{un\text{-}treated}$	$Drying_{with\text{-}screw}$	9.8	12.8
		$Drying_{without\text{-}screw}$	9.8	12.9

DISCUSSION

Although the IMC was not related with endless screw use during drying, the influence of the log treatment (heating or steaming) on this parameter was observed. IMC of lumber of $Log_{steaming}$ and $Log_{heating}$ treatments were lower than $Log_{un\text{-}tretaed}$ (Tab. 3). This decreasing of IMC in lumber is attributed to the fact that during the application of steaming or temperature, there is an expansion of the water inside the wood, resulting in the wood coming out at the ends and also because when the wood cools down, there is a greater loss of moisture due to evaporation of this moisture (Zhang and Cai 2008).

In relation to the average drying rate, no effect of the use of screws during drying ($Drying_{with\text{-}screw}$ treatment) was observed (Tab. 3). Berrocal et al. (2017) agreed those results in *Tectona grandis* wood, who found that drying rate was not affected the use of screws during drying.

The variation of the MC and drying rate with time of the *D. panamensis* and *H. alchorneoides* lumber in all treatments showed a homogeneous decreasing of MC with time (Figs. 3a-c). This situation is to be expected, since the use of endless screw has the objective of keeping the boards fixed within the pile (Denig et al. 2000, Berrocal et al. 2017). Therefore, the drying rate and MC will not be affected over time, as occurred in the two species studied (Figs. 3a-c).

The presence of warps, split and check before drying of these two species (Tab. 4) is attributed to the fact that the trees used come from fast-growth trees condition with a high percentage of juvenile wood (Zobel and Sprague 1998) and high levels of growth stresses (Gril et al. 2017). Stemming and heating treatment applied as pre-treatments before sawing logs aims to relax the residual longitudinal stress of the wood and increase its permeability (Gril et al. 2017). In addition, with the increase in permeability, moisture gradients decrease and thus there is improving the quality of the wood in relation to the presence of warps, check and split (Lenth and Kamke 2001, Gril et al. 2017, Rodrigues et al. 2018). However, in the case of the two species studied, the effect was not congruent with the different types of drying defects present in dried-lumber (Tabs. 4).

$Log_{steaming}$ and $Log_{heating}$ treatment were not presented effects in the incidence or magnitude of warping, splitting or checking, although a slight reduction in the incidence of these quality parameters was observed in $Log_{steaming}$ (Tabs. 4). This difference was attributed to the fact that steam treatment creates better conditions for the relaxation of the different polymers in the wood (Kong et al. 2017, Moya et al. 2021). Among them, the higher temperature reached with the $Log_{steaming}$ in the internal part of the log or sawn timber than with the $Log_{heating}$. High temperature reached in $Log_{steaming}$ treatment is probably making the entire cross section of the log reach the glass transition temperature of the wood, allowing greater relaxation (Kong et al. 2017) and as well, the steaming reduces the crystalline zones of cellulose, therefore the amorphous zones increase (Kong et al. 2017).

Endless screw has objective to reduce check and split defects due to the application of temperature during drying and variations in the moisture content in the cross-section of a piece of wood during drying (Berrocal et al. 2017). The use of this system (Fig. 1b) allows the wood pile to be held in place to prevent movement and to have a positive influence when applied to wood above the FSP in combination with high temperatures (Vansteenkiste et al. 1997). In this case, the improvement of wood quality using endless screw to maintain wood quality was irregular and each defect behaves differently; the values obtained for incidence and magnitude of the defect increased or decreased according to the defect (Tab. 4). However, the effect of the use of the endless screw was reflected in the value of IQ_{after}, this value decreased, therefore, there was an increase in the quality of dried-lumber (Tab. 4). The reduction of these defects by endless screws used is due to the fact that this forces for maintaining pile working in the direction of the tangent of the growth rings could reduce the development of internal checking. Besides, this force can be viewed as a counteracting force for stresses developed during drying or as a restraining force to internal stresses in the wood that give it a great tendency to accumulate drying defects (Denig et al. 2000).

Likewise, the use of endless screws for daily adjustment during drying produced a lower percentage of dried-lumber classified as "low drying stress", in relation to the lack of screws in the wood pile (Tab. 4). This result, together with good pretreatment before sawing (heat or steam treatment) reduced the incidence of warping, checking and cracking (Tabs. 4).

In relation to color change (ΔE^*), the sapwood and heartwood show different behaviors of both *D. panamensis* and *H. alchornoides* wood (Tab. 5). Heartwood has a higher amount of extractives than sapwood (Hillis 1987), which produce a chemical change when temperature is applied (Tolvaj et al. 2012, Berrocal et al. 2016). During steaming, the polyphenolic compounds in the heartwood that give it its dark color can migrate into the sapwood and darken it (Tolvaj et al. 2012), as was evident in heartwood of both *D. panamensis* and *H. alchornoides* of present study. The highest color change was obtained when log received steaming before sawing. Tolvaj et al. (Tolvaj et al. 2012) based on studies of *Robinia pseudoacacia* indicated that the color changes are attributed to the fact that parameter L* decreased and the parameters a* and b* increased with temperature and steaming.

Endless screw use during drying does not change the chemical structure of the wood and the chemical composition of wood (Tolvaj et al. 2012, Berrocal et al. 2016), then no effects on the change in color or ∆E* was not evidenced (Tab. 5). Therefore, the changes observed in the color of lumber whose drying process included endless screw treatment are related to the pretreatments ($Log_{steaming}$ and $Log_{heating}$) of the logs prior to sawing.

CONCLUSIONS

The use of endless screw during drying, being a treatment that does not change the chemical structure of the wood but are external supports to maintain the shape of the board, has no effect on color change, drying time or drying rate, but its main benefits are related to the improvement of the magnitude, incidence and quality category of cup, check and split defects. In addition, this decreasing of defects is favored again when the use of endless screw in the wood piles was accompanied with a pre-treatment of the logs such as steaming and heating before sawing.

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RÓGER MOYA*, CAROLINA TENORIO
ESCUELA DE INGENIERÍA FORESTAL
INSTITUTO TECNOLOGICO DE COSTA RICA
P.O.BOX: 159-7050 CARTAGO
COSTA RICA
*Corresponding author: rmoya@itcr.ac.cr