DRYING OF PLANTATION-GROWN *TECTONA GRANDIS* WOOD WITH DAILY-CONTROLLED DRYING RATE SCHEDULES

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The study compared drying speed between schedules rather than reducing drying time, by employing high daily drying rate (DR_{daily}) for *Tectona grandis* wood. The moisture content (MC), drying defects (twists, bows, cups, crooks, checks and splits), drying tensions and colour changes were evaluated. Results showed that it was possible to dry wood in 88 hours by employing drying schedules with a high DR_{daily} with no significant variability in the final MC of the dried-lumber. Utilisation of such schedules increased the incidence and magnitude of twist, crook, bow and split defects, while decreased in cup and check defects. However, it was possible to obtain a lower incidence of drying defects by using an endless screw for daily adjustment of the lumber piles during drying. Drying tensions decreased with drying schedules with a high DR_{daily}, but slightly increased when endless screws were used. Finally, application of drying schedules with high DR_{daily} produced variation in the colour of the lumber, yielding more reddish (a*) and yellowish (b*) wood.

Keywords: Wood drying, index of quality, kiln drying, drying speed, high daily drying rate

INTRODUCTION

Wood drying is an important stage of the manufacturing process as it contributes towards dimensional stability and workability of lumber as well as wettability of the finish and adhesive, besides other wood properties. Drying performance varies for each species, thus different methods are employed for the drying of lumber. One of the most important is kiln drying, but investment and operation costs are high and it demands qualified labour and complex humidity control systems (Carlsson & Arfvidsson 2007, Oltean et al. 2007).

One advantage of kiln drying is that the drying rate can be controlled in short periods. The drying rate (loss of humidity within a time period) is a variable that can positively influence the drying time and quality of dried-lumber. This parameter is affected by characteristics such as properties inherent to the lumber, drying chamber and drying conditions, specifically temperature, relative humidity and air speed (Carlsson & Arfvidsson 2007, Denig et al. 2000, Tenorio et al. 2012).

The study and knowledge of drying rate (DR) can aid in decreasing drying time especially in species from temperate climate (Denig et al. 2000). However, research on drying rate of juvenile wood from tropical fast-grown plantations is limited to a few species. Recently, Tenorio et al. (2012) studied the effect of drying time and moisture content variations upon DR, measured daily in several tropical species, in order to improve the efficiency of drying time for the species studied.

On the other hand, *Tectona grandis* is the most important species for commercial reforestation in tropical climate (Moya et al. 2014). Nonetheless, Moya et al. (2013) determined that *T. grandis* is one of the species with the highest drying time and presence of drying defects when compared with other tropical species from plantations in Costa Rica. Previous studies found that *T. grandis* showed a drying time between 9 and 11 days, and drying defects increased when kiln drying was employed. The prolonged process of drying, together with high percentage of juvenile wood, appearance of drying defects and failure in achieving a uniform colour in dried lumber are set-backs when competing with other tropical woods (Moya et al. 2014, Salas & Moya 2014).

The objective of this study was to evaluate the final moisture content, drying defects (warp, split and check), drying tensions and colour in juvenile wood of *T. grandis* from fast-growing plantations, using three different drying schedules controlled by high daily drying rate (DR_{daily}), as a way to decrease the drying time. The use of endless screws on the lumber piles to maintain the pressed boards, to avoid formation of warps in wood, was also evaluated.

MATERIALS AND METHODS

Plantation characteristics and sawing pattern

Wood samples were taken from a second thinning of 11-year-old *T. grandis* plantation, with 3 m × 3 m spacing (1100 trees ha^{-1}). Stand density was 475 trees ha^{-1} at sampling time, with an average diameter at breast height (dbh) of 23 cm and a total height of 14 m. Sampled trees came from thinned trees. The grain pattern used was commonly implemented in Costa Rica for timber from forest plantations to produce 25-mm thick boards (Moya et al. 2013). A total of 1200 edged 25-mm thick boards were obtained.

Drying schedules

Three different drying schedules were tested. The first drying schedule (DS-standard) was recommended by Sydney et al. (1998) for *T. grandis*, named the 'H schedule'. Although the programme achieved good results in dried-lumber quality, the drying time reached by Moya et al. (2013) and Salas and Moya (2014) was greater for wood from fast-growing plantation trees and normal plantation trees, presenting good quality in relation to drying defects. In the second drying schedule (DS-2), the parameters of drying conditions (temperature and equilibrium moisture content) were modified by increasing DR_{daily}. To achieve this, three additional steps were added to DS-standard. The first additional step, added between the first and the second steps of DS-standard, reduced the equilibrium moisture content (EMC) difference. The second additional step, added between the second and third steps, reduced temperature and EMC difference between steps. The third additional step, added before the last step of the drying stage, reduced EMC (Table 1). The third schedule (DS-3) aimed at reducing drying time and it was similar to DS-2. For DS-3, the same stages of DS-2 were used, but higher dry bulb temperature was implemented at the end of drying where temperature was increased to 5 °C (Table 1).

The three drying schedules tested were performed in a conventional kiln with a 2-m^3 capacity, using an electrical power source to heat the resistance inside the chamber. The green

Table 1 Different drying schedules utilised for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood in kiln drying

Step	Drying schedule 1 DS-standard			Drying schedule 2 DS-2			Drying schedule 3 DS-3		
	DB (°C)	EMC (%)	MC (%)	DB (°C)	EMC (%)	MC (%)	DB (°C)	EMC (%)	MC(%)
Heating	55	-	60	55	-	-	55	-	-
	58	14	60	-	-	-	58	14.0	-
Drying	60	13.8	30	60	13.8	60	58	14.0	60
	60	10.0	25	60	12.5	50	60	12.5	50
	70	7.7	20	60	10.0	40	60	10.0	40
	70	6.4	20	65	8.5	35	65	8.5	35
	75	3.7	10	70	7.7	25	70	7.7	30
				75	6.4	25	75	6.4	25
				75	5.2	15	80	5.0	20
				75	3.7	12	80	3.7	12
Equalisation	75	11.0	-	75	11.0	12	80	11.0	12
Conditioning	75	11.5	-	75	11.5	-	80	11.5	-
Cooling	35	11.5	-	35	-	-	35	-	-

DB = dry bulb temperature, EMC = equilibrium moisture content, MC = moisture content lumber was stacked in packages of 10 boards wide and 30 pieces height, obtaining 300 pieces per drying charge. Cross-sectional pieces of 2.5 cm × 2.5 cm were used as stickers between the layers. Each drying schedule was performed in duplicate, therefore six different drying charges were completed.

Treatments for reduction of drying defects

Reduction of defects consisted in the placement of endless screws with plates that traversed the pile of wood from side to side (Figure 1a). Daily adjustments were made with the aid of nuts on the screw (Figure 1b) in order to maintain the pressed boards and to avoid formation of twists in the wood. Five treatments were applied, i.e. (1) DS-standard treatment without endless screws, (2) DS-2 treatment without endless screws, (3) DS-2 treatment with endless screws, (4) DS-3 treatment without endless screws and (5) DS-3 treatment with endless screws.

Control of moisture content (MC)

For MC control, six samples were obtained from the centre of six stacked representative boards for each drying method. These samples were placed at different heights at each side of the pile. Two samples were located at 25 cm from the ground, another two samples were located at 25 cm from the top and the last two samples were located at 50 cm from the other samples. The target MC was 12%.

Evaluation of drying defects

The defects were measured before and after drying and the parameters evaluated were warps (twists, crooks, bows and cups), splits, cracks and collapses. The methodology detailed in Salas and Moya (2014) and Tenorio et al. (2012) was used to evaluate the drying defects. The official Chilean standard, Nch993EO72, was used to determine the Index of Quality (IQ) which was computed for twists, crooks, cups, bows, checks and splits (Pérez et al. 2007). And its values and the means were detailed in Salas and Moya (2014) and Tenorio et al. (2012).

Determination of drying tensions

By the end of the drying process, six whole pieces of *T. grandis* were selected randomly for each one of the five treatments evaluated. Three transversal sections (two from the ends and one from the centre) were obtained from each one of these pieces. The transversal sections were used

Figure 1 Endless screw for daily adjustment during drying, (a) endless screw location in lumber stacked in piles and (b) nuts and washer

to determine the drying tensions immediately after the drying and another at 24 hours after drying, according to Korkut and Guller (2007). This method classifies drying tensions into three categories, namely, severe, moderate and slight.

Evaluation of colour

Colour was determined for 42 pieces, randomly chosen before drying, for each treatment, selecting only the heartwood within the area of measurement. After drying, colour was again measured in the same selected area. To obtain the values for laboratory standardised chromatological system, a spectrophotometer was employed. Colour change (ΔE^*) was determined by the luminosity (L^*), redness (a^*) and yellowness (b^*) values measured before and after drying, calculated according to ASTM D 2244 standard (2014).

Statistical Analysis

One-way ANOVA was applied to initial and final MC and wood colour parameters (L^*, a^* and b^*) measured during different drying schedules, to determine significant differences for each parameter. The Tukey's test was used to test the mean difference at a significance level of $p < 0.01$. The SAS 8.1 statistics program for Windows was used to carry out the analyses. For quality evaluation, each defect was analysed based on its percentage of incidence and the magnitude of severity before and after drying.

RESULTS

Drying time and drying rate

Drying time varied from 88 (DS-3 without endless screws) to 142 hours (DS-2 with endless screws) and drying time was reduced for DS-3 (Table 2). Although significant statistical differences were observed between the drying time of DS-standard and DS-2 (Table 2), the objective of decreasing the drying time was not accomplished in the latter schedule.

Moisture content

Before drying, teak lumber showed a variation in the initial moisture content (MC_i) from 86 to 115% in the different drying schedules, reporting a significant statistical difference (Table 2). Lumber from DS-2 showed MC_i values less than 100%, whereas for the rest of the lumber of other schedules, the MC_i was over 100%. However, low MC_i values did not determine a greater drying rate nor a lower drying time, as the highest drying rate and the lowest drying time at 2.09% hour^{-1} were obtained even with a MCi over 100%. The variation in MC_i did not influence the drying time, since the lower drying time presented MC_i values similar or superior to those values presented for lower drying time (Table 2). Final moisture content (MC_f) of the dried-lumber was close to 12% and no statistical differences appeared among the different batches (Table 2), therefore the application of drying schedules

Table 2 Initial and final moisture content, drying time and average drying rate data obtained from the different drying schedules utilised for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood

Drying schedule	Initial MC (%)	Final MC (%)	Drying time (hour)	Average drying rate (% hour^{-1})
DS-standard without endless screws	114.7 (14.30) a	11.7 (8.82) a	110	1.74
DS-2 without endless screws	85.9 (17.21) b	12.1 (6.45) a	122	1.19
DS-2 with endless screws	96.8 (19.26) c	12.4 (8.34) a	142	1.16
DS-3 without endless screws	101.1 (19.31) d	12.4 (8.48) a	88	2.09
DS-3 with endless screws	111.4 (16.95) a	13.0 (8.05) a	104	1.99

Different letters indicate statistical significances at 99%, the values in parentheses represent the coefficient of variation; MC = moisture content with the purpose of decreasing drying time again did not alter the MC_f of lumber. It is important to note that low coefficients of variation (8.05 to 8.82%) appeared in dried lumber from different drying schedules, contrary to the MC_i for which the coefficients of variation were slightly higher (14.30 to 19.31%) (Table 2).

Wood quality before drying

Before the drying process, lumber showed little to no incidence of twists, cups or checks (Figure 2a, 2d and 2e). Incidences of crooks, bows and splits was present in green lumber (Figure 2b, 2c and 2f). The incidences of twists, cups, checks and splits increased with the drying process (Figure 2a, 2f), whereas the incidences of crook and bow defects decreased (Figure 2b and 2c).

Wood quality after drying

The dried-lumber quality using IQ showed that DS-sandard twist was cataloged as 'excellent' and crook defects was classified as 'good'. Other drying defects of dried-lumber were catalouged as 'very good' quality (Table 3). DS-2 dried-lumber quality was similar to DS-standard, but lower in DS-3 for twist, cup, check and split (Table 3)

Twist defects

Incidence of twists in dried-lumber increased with controlled DR_{daily} (DS-2 and DS-3) aiming at decreasing drying time (Figure 2a), in comparison with DS-standard. The IQ_{after} value in dried-lumber from DS-2 and DS-3 is greater than DS-standard (Figure 3a). Moreover, it was

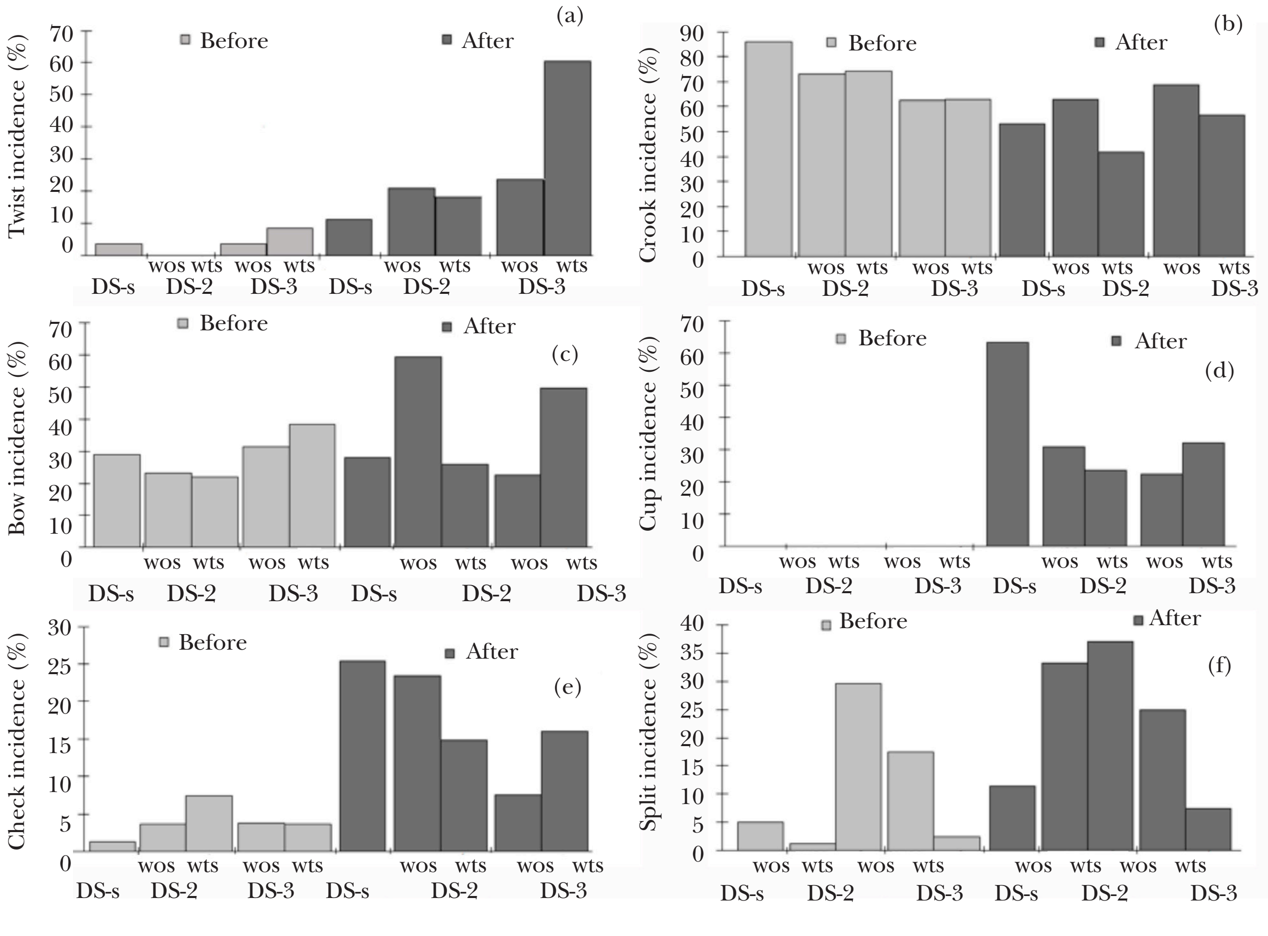

Figure 2 Different drying schedules utilised for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood, (a) percentage of incidences of twist, (b) crook, (c) bow, (d) cup, (e) check and (f) split defects obtained for; DS-s = drying schedule standard, DS-2 = drying schedule 2, DS-3 = drying schedule 3, wos = without endless screws, wts = with endless screws

Table 3 Classification of dried-lumber obtained for different drying schedules utilised for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood

Drying Schedule	Evaluation	Twist	Crook	Bow	Cup	Check	Split
	DS-standard	Excellent	Good	Very good	Very good	Very good	Very good
	DS-2 without endless screws	Very good	Good	Good	Very good	Good	Good
Classification	DS-2 with endless screws	Very good	Very good	Very good	Very good	Very good	Very good
	DS-3 without endless screws	Very good	Good	Good	Very good	Very good	Very good
	DS-3 with endless screws	Very good	Good	Very good	Very good	Very good	Very good

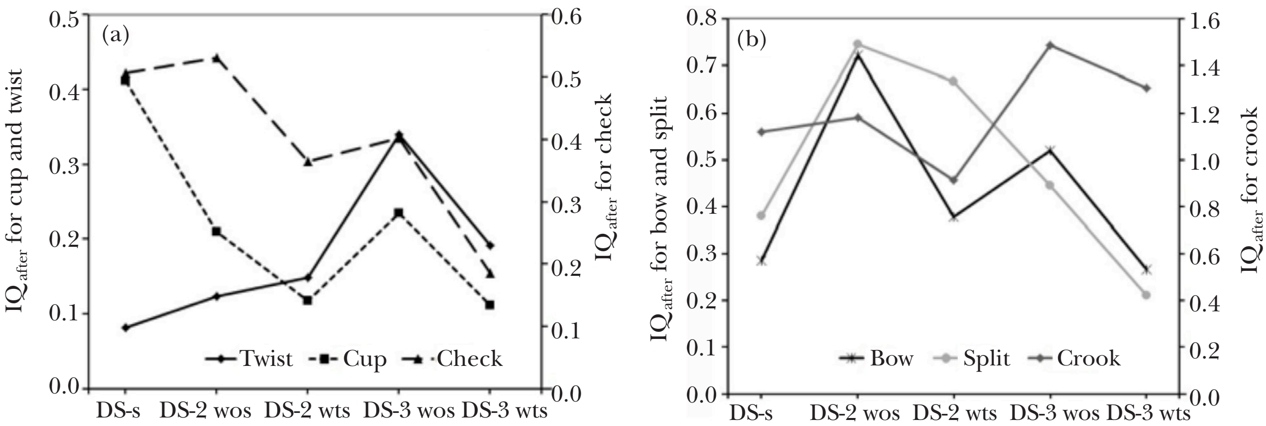

Figure 3 Index of quality before drying (IQ_{before}) for (a) cups, twists, checks and (b) bows, splits and crooks in dried-lumber from different drying schedules utilised for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood; DS-s = drying schedule standard, DS-2 = drying schedule 2, DS-3 = drying schedule 3, wos = without endless screws, wts = with endless screws

observed that, from the two schedules used to reduce drying time with controlled DR_{daily}, the incidence of twist defects was similar, with or without using endless screws to dwindle defects. The greatest incidence of defects was produced with greater DR_{daily} (DS-3 with endless screws) (Figure 3a). Regarding quality of lumber and usage of endless screws, in DS-2 and DS-3, the IQ_{before} value increased when screws were not employed (Figure 3a), hence the decrease in lumber quality due to twist defect.

Crook defects

When endless screws were not used on the pile, incidence of crooks in dried-lumber increased in the drying schedules with high DR_{daily}, used to reduce drying time (DS-2 and DS-3) in comparison with DS-standard. Meanwhile, when screws were used, incidence of thes defect decreased (Figure 2b). DS-2 showed lower IQ_{after} values than DS-3 (Figure 3b). In drying schedules with high DR_{daily}, for reduction of drying time (DS-2 and DS-3), the IQ_{after} value grew when endless screws were not used. However, use of screws to maintain the pile of lumber with the least possible movement, produced lower IQ_{after} values in dried-lumber (Figure 3b). The value was lower in DS-standard than in DS-2.

Bow defects

Incidence of bow defect was augmented by the use of schedules with a high DR_{daily} for reduction of drying time, in the case of DS-2 without screws. When using screws, the incidence was less in relation to DS-standard (Figure 2c). Dried-lumber from DS-3 without screws was lower than DS-standard. Meanwhile, use of endless screws increased the incidence in DS-2 and DS-3 with high DR_{daily} to reduce the drying time (Figure 2c). Lumber dried with DS-standard showed a

IQ_{before} value of 0.22, but this value increased with schedules of high DR_{daily} for reduction of the drying time (Figure 3b). Additionally, in DS-2 and DS-3, the IQ_{after} value for dried-lumber decreased when screws were employed. Nevertheless, in DS-2 the IQ_{after} values were inferior to DS-3 with screws (Figure 3).

Cup defects

For cup defects, the incidences decreased when schedules of high DR_{daily} were employed for reduction of drying time (Figure 3d). The use of screws to avoid defects was more effective in DS-2, whereas in DS-3 the incidence rose slightly (Figure 2c). In the evaluation for quality of dried-lumber, the IQ_{after} was lower in schedules aimed at decreasing drying time, with or without using screws, while for DS-2 and DS-3, the use of screws decreased the value (Figure 3a).

Presence of checks

Presence of checks in lumber before drying was low, but increased after drying (Figure 2e). The DS-standard produced the highest incidence of this defect. A drying schedule with a high DR_{daily}, to reduce drying time, decreased the incidence. The use of screws and plates on the pile to avoid defects was more effective in DS-2, as incidence decreased. The opposite occurred with DS-3 where it caused the incidence of defects to rise (Figure 2e). In the evaluation of quality, the IQ_{before} values were lower than 0.18, while for dried-lumber the IQ_{after} value increased, in addition to reducing the incidence of checks with the use of drying schedules with high DR_{daily} (Figure 3). In this way, an increase in quality was achieved. On the other hand, use of plate and screws system to avoid defects on the pile decreased the IQ_{after} value in both schedules with a high DR_{daily} (Figure 3b). In these two schedules, the drying of lumber with DS-3 yielded lower IQ_{after} values than those obtained through DS-2 (Figure 3a).

Presence of splits

Dried-lumber from schedules with high DR_{daily} showed increased incidence of splits, with the exception of lumber from DS-3 with endless screws, for which incidence was similar to that present in DS-standard (Figure 2f). When the endless screw system was employed to lessen the amount of defects, there was a slight increase in split incidence for DS-2, yet for DS-3 it decreased (Figure 2f). After drying, the value increased where no screws system was employed (Figure 3b). Evaluation of quality showed that schedules with high DR_{daily} for reduction of drying time (DR-2 and DR-3) and the use of screws decreased the IQ_{after} value (Figure 3b). Moreover, IQ_{after} values for dried-lumber were lower in the schedule with the greatest DR_{daily} (DS-3) in comparison with DS-2 (Figure 3b), which exhibited lower DR_{daily} value.

Drying tensions

Presence of drying tensions was reduced by employing drying schedules intended to decrease the drying time, with or without using a system of screws to avoid defects (Figure 4). When employing DS-standard, approximately 55–57% of the dried-lumber showed tensions catalogued as 'moderate' immediately after drying (Figure 4a) or at 24 hours after termination (Figure 4b). On the other hand, in lumber dried with high DR_{daily} to decrease drying time, the amount of lumber classified as 'low tension' increased for both periods evaluated (Figure 4). In DS-2 immediately after drying, a greater percentage of lumber classified as 'low tension' appeared in relation to lumber dried with DS-3 (Figure 4a). However, 24 hours after drying, the percentage of incidence was similar in both schedules (Figure 4b). The utilisation of endless screws produced a slight decrease in the percentage of lumber, classified as 'low tension', thus increasing the percentage of 'moderate tension' lumber in both drying schedules and drying periods (Figure 4).

Evaluation of colour

After drying, teak wood colour parameters of redness (a*) and yellowness (b*) increased significantly in relation to lumber before drying in DS-standard as well as in the different schedules employed to increase the DR_{daily} (DS-2 and DS-3) so as to reduce drying time (Table 4). The colour parameter of luminosity (L*) increased slightly in dried-lumber from DS-standard and DS-2 without endless screws, whilst in DS-2 with endless screws and DS-3, luminosity was not significantly altered (Table 4).

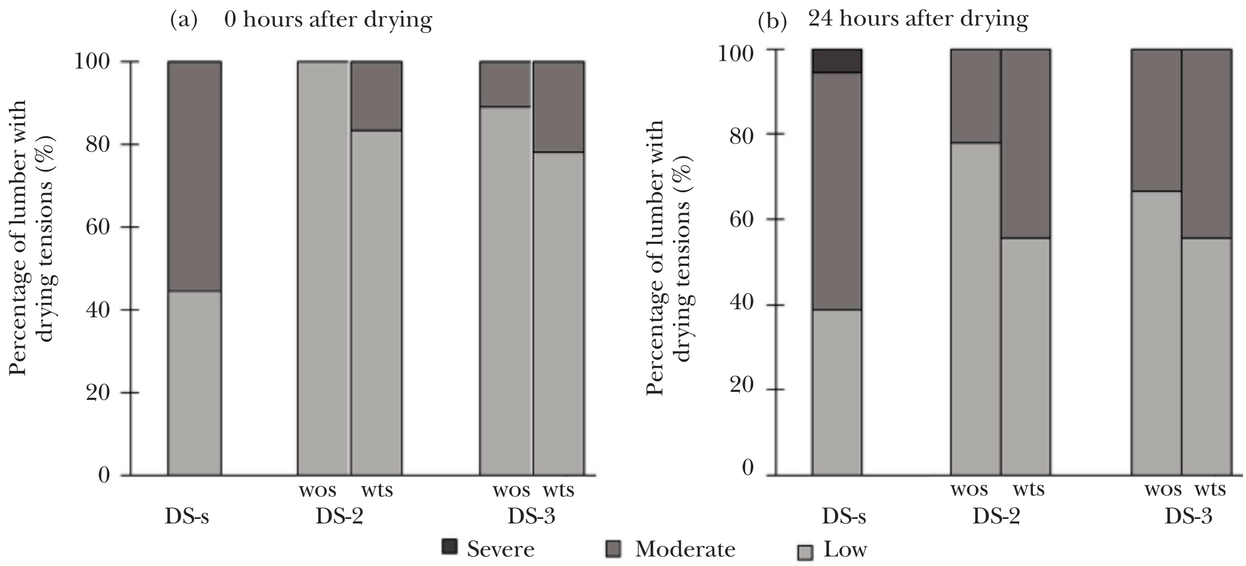

Figure 4 Drying tensions in dried-lumber at (a) 0 hours and (b) 24 hours after termination of drying for different drying schedules used for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood; DS-s = drying schedule standard, DS-2 = drying schedule 2, DS-3 = drying schedule 3, wos = without endless screws, wts = with endless screws

Table 4 L*, a* and b* colour parameters of *Tectona grandis* wood before and after drying with different drying schedules utilised for increasing daily drying rate and decreasing drying time of *Tectona grandis* wood

Drying schedule	Evaluation	L*	a*	b*	Average of ΔE*
DS-standard	before	61.5 (6.6) a	4.3 (28.4) a	23.3 (12.9) a	6.95 a
	after	64.3 (6.6) b	6.3 (16.5) b	26.22 (8.7) b	
DS-2 without endless screws	before	64.0 (6.2) a	4.6 (34.7) a	24.0 (10.7) a	10.58 c
	after	69.8 (8.7) b	8.0 (18.7) b	29.08 (9.2) b	
DS-2 with endless screws	before	63.3 (6.5) a	3.8 (37.5) a	23.8 (10.7) a	7.67 ab
	after	63.3 (8.4) a	8.5 (17.9) b	28.63 (9.3) b	
DS-3 without endless screws	before	61.5 (9.3) a	6.6 (26.5) a	26.1 (9.0) a	7.68 ab
	after	61.4 (8.6) a	8.8 (20.2) b	29.0 (8.4) b	
DS-3 with endless screws	before	60.0 (11.5) a	6.2 (36.7) a	23.1 (12.5) a	8.90 b
	After	57.7 (15.3) a	9.6 (18.1) b	26.1 (14.1) b	

DS = drying schedule; different letters indicate statistical significances at 99%; the values in parentheses represent the coefficient of variation; L* = luminosity, a* = redness, b* = yellowness, ΔE* = colour change

In the colour evaluation (ΔE*), a slight increase was found in lumber dried with high DR_{daily} drying schedules for reduction of drying time (Table 4). However, the change in colour parameter was not statistically significant in DS-2 with endless screws or DS-3 without endless screws. Meanwhile, colour change was statistically significant in the other two drying schedules implemented for reducing drying time (DS-2 without endless screws and DS-3 with endless screws) (Table 4).

DISCUSSION

Drying time is related to drying rate (Tenorio et al. 2012) which manifested in the present study, where a lower drying time was obtained when drying schedules of high DR were implemented in DS-2 and DS-3 (Table 2). Drying rates ranged from 1.16% to 2.09% hour^{-1}, in DS-2 with endless screws and DS-3 without endless screws respectively, and these values were greater than those reported for other tropical climate species in forest plantations (Moya et al. 2013).

Compared to drying rates reported by Salas and Moya (2014), which were lower than 1% hour^{-1}, the drying rate obtained for teak wood in this study was greater, between 1.19% and 2.09% hour^{-1}. The difference may be due to the age of the trees used. Salas and Moya (2014) worked with lumber from a 14-year-old plantation, while the wood used for this study was 11 years old. A higher content of heartwood is present at an older age and this type of wood shows less permeability for water displacement inside the wood (Ahmend & Chun 2011, Moya et al. 2014). For schedules with high DR_{daily}, the teak lumber was dried for 4 days, similar to *Pinus radiata* (Ananias et al. 2012), a species with the fastest kiln drying and highly commercialised worldwide.

Variation of MC_i values in *T. grandis* lumber before drying, 85% to 114.7%, and CV from 14.3% to 19.31%, were superior to those reported by Salas and Moya (2014), who indicated MC values ranging from 57% to 109% and CV from 5% up to 26%. Regarding MC_f, where schedules of high DR_{daily} were implemented for reduction drying time (DS-2 and DS-3), the value obtained was close to the targeted MC of 12%, while the CV for the value remained low (Table 2). This condition is an advantage, as the schedules do not alter uniformity of the MC_f of dried-lumber.

In this study, lumber was obtained from fast-growing trees, less than 11 years old, which presented a high percentage of juvenile wood as well as high levels of growth stress (Solórzano et al. 2012, Moya et al. 2014). Green lumber from *T. grandis* species exhibited some warps (crooks and bows), splits and checks (Figure 2a, 2f). The present study confirmed that cup defects did not generally appear in green lumber from forest plantations but increased after drying (Figure 2d) (Tenorio et al. 2012, Moya et al. 2013).

The increase of drying defects after kiln drying, especially of twist, cup, check and split defects (Figure 2a, 2f), could be related to the presence of juvenile wood, known to produce distortions in dried-lumber due to higher longitudinal shrinkage than normal wood (Zobel & Sprague 2012). However, drying stress that occur during lumber drying can also produce distortion (Straže et al. 2011).

The incidence and magnitude of defects found in dried-lumber were consistent with studies performed by Moya et al. (2013) and Salas and Moya (2014), who found that the incidence of twist, cup, check and split defects increased, while crook and bow defects decreased, similar results to those found in this study (Figure 2b and 2c). The use of higher temperature and lower equilibrium MC in drying programs used to decrease drying time (DS-3) decreased quality, as it increased the incidence of twist, crook, bow, check and split defects (Figure 2a–c, 2e–f, Figure 3a–b), with the exception of cup defect (Figure 2d). Increment occurred due to high temperature which caused greater moisture gradients that produced internal stress inside the lumber, leading to failure, as is the case with checks, splits or the tendency to warp (Olten et al. 2007).

Nonetheless, the use of loads at the upper part of the pile and maintaining it together to avoid movement had a positive influence on wood above fibre saturation point in combination with high temperatures, with the purpose of counteracting drying defects such as checks and splits, owed to high temperatures (Vansteenkiste et al. 1997). Improvement of drying quality by using endless screws on teak wood was not adequately reflected in the incidence of each defect since the behaviour was irregular; incidence increased for some defects and decreased for others (Figure 2b). However, the quality of drying was evident in the IQ_{after} value, as for most defects the value decreased, therefore an increase in quality of the dried-lumber was observed (Figure 3a–b). The forces to maintain the pressed pile, work in a direction tangential to growth rings, thereby reducing the development of internal checking. Besides, the force can be viewed as a counteracting force for stress developed during drying or as a restraining force to internal stress in wood that gives it a great tendency to accumulate drying defects.

Stress in lumber is caused by the differential gradient of MC, established between the interior and outermost layer of wood sample (Vansteenkiste et al. 1997). The outer layer of wood reaches fibre saturation point faster, thus generating stress between the interior and exterior (Passarini et al. 2015). In drying schedules with a high DR_{daily}, for reduction of drying time (DS-2 and DS-3), the percentage of dried-lumber with 'low drying tensions' was greater than the percentage obtained from DS-standard at both stress measurement points (Figure 4).

The use of endless screws for daily adjustment during drying produced a lower percentage of dried-lumber, catalogued as 'low drying tension', in relation to the lack of screws on the pile of lumber (Figure 4). The results, together with evaluation of defects, indicated that drying schedules with high DR_{daily}, implemented to decrease drying time, and endless screws placed on the pile for daily adjustment, lessened the incidence of warps, checks and splits (Figure 3). Colour parameters in green lumber as well as dried-lumber (Table 4) were similar to *T. grandis* wood from plantations in several locations of Costa Rica (Salas & Moya 2014). Drying schedules with high temperatures, to attain high DR_{daily}, increased parameters a* and b* (Table 4), which were related to darker coloration of wood, resulting in darker dried-lumber, with greater E*, than DS-standard. A darker tone in *T. grandis* lumber is closer to that of wood grown in natural conditions (Moya et al. 2014).

CONCLUSIONS

Lowest drying time (88 hours) was obtained in DS-3 without endless screws, while DS-2 treatment with endless screws rendered the longest drying time (142 hours). And MC_f varied a maximum of 2% in relation to the objective value established for the five treatments. Lumber quality, expressed as ratio of defects after drying, increased in terms of twist, bow, cup, check and splits whereas the percentage of crooks decreased. However, applying the IQ, it was determined that most of the drying schedules were considered 'excellent' or 'very good'. As for colour change from, no differences were found between DS-standard and DS-2 or DS-3, before and after treatment.

The best drying treatment for juvenile *T. grandis* lumber, taking as reference the drying rate, colour change, IQ for drying defects (very good and excellent) and drying stress (low to moderate), would be DS-3 without endless screws.

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