Air-Drying Performance of Three Genotypes of Teak Wood

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The clonal materials of *Tectona grandis* L. f. in fast-growing plantations exhibit faster growth than the seminal materials. Therefore, it is necessary to investigate the differences in wood drying to ensure the quality and yield of the final product. This study evaluated the outdoor drying behavior of three genotypes of teak lumber. Two clonal genotypes (G1 and G2) and one of seminal origin (G3) were assessed. Boards measuring 30 × 150 × 1000 mm (thickness × width × length) were produced from the basal logs. The average moisture content (79.3, 64.9, and 60,1%), final moisture content (10.8, 9.8, and 11.6%), and mean drying rate (1.2, 0.97, and 0.85%.day^{-1}) were observed in the wood from genotypes G1, G2 and G3, respectively. The clonal material crooked and bowed below 5 mm.m^{-1}, which is considered the tolerance limit for both warpings. The seminal material had a greater incidence of splitting. The clonal genotypes G1 and G2 had similar qualities and presented higher drying rates, final moisture contents below 11% and a lower incidence of defects, especially splitting, compared to the naturally seeded material.

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INTRODUCTION

Teak (*Tectona grandis* Lf, Lamiaceae) is the most planted tropical hardwood species in the world (Takizawa *et al*. 2022). It has a planted area of approximately 6.83 million hectares, 80% of which are in Asia, 10% are in Africa, and 6% are in the Americas (Kollert and Kleine 2017). Its wood is highly valued in the world market because of its golden-brown color and high biological resistance (Takizawa *et al*. 2022). The same authors highlighted that the wood of this species from forest plantations is already established in the international market. The main uses are the manufacture of products with higher added value, such as furniture, flooring, moldings, decorative panels, windows, doors and household objects.

In Brazil, seminal teak plantations began in the late 1960s in the state of Mato Grosso, where climatic conditions are similar to those of their native habitat (Tsukamoto

Filho *et al*. 2003). The first clonal plantations were established in the 2000s (Takizawa *et al*. 2022). Clonal materials show greater increases in diameter, height and, consequently, volume than seminal material (Lemos *et al*. 2015; Thulasidas and Baillères 2017; Albues *et al*. 2023). Forestry companies have therefore invested in genetic improvement with the aim of reducing the production cycle and increasing volumetric productivity.

However, this material has cycles ranging from 15 to 30 years, logs 12 to 30 cm in diameter, and is abundant in juvenile wood (Moya *et al.* 2014). Thus, due to the rapid growth of clonal materials, there is a need for knowledge about the behavior (drying rate and defects) of this wood during drying compared to that of seminal material.

The adopted drying method determines the drying cycle, wood quality, final moisture content, and end use (Zen *et al.* 2019). Moreover, according to the aforementioned authors, air-drying can be an economical alternative for the timber industry due to the electric energy costs of artificial drying. However, air-drying is slower, and wood has a higher final moisture content, which restricts its use (Susin *et al.* 2014).

In this process, the final moisture content is dependent on the equilibrium moisture content (EMC) of the drying location, since the EMC depends on the temperature and the relative humidity of the region (Souza *et al.* 2016). These environmental factors vary daily and seasonally, where daily variations impact the wood surface, with the appearance of surface splitting and the oxidation of chemical elements. On the other hand, long-term variations impact dimensional stability, resulting in drying defects, such as warping and splitting (Cassiano *et al.* 2013).

Because of the importance of environmental conditions in terms of duration or air drying, choosing the best season to start the process is very important. However, industries are not always able to start air drying in a more suitable season due to the constant market demand for wood. Therefore, understanding the variability of wood and conducting drying effectively can minimize drying defects, improve wood quality, increase the yield of processed wood, and generate high-quality products (Zen *et al.* 2019).

The observation of the drying curve is a successful tool for evaluating and controlling air-drying in the region where the wood pile is located (Braz *et al.* 2015). Understanding the intricacies of a species' behavior during the drying phase enables enhanced monitoring and, consequently, process optimization. Hence, evaluating the air-drying characteristics of distinct teak genotypes is imperative due to potential variations throughout the drying regimen. Consequently, this study aimed to investigate the air-drying behavior of three *Tectona grandis* genotypes.

EXPERIMENTAL

Materials

The material evaluated was obtained from 15-year-old trees of *Tectona grandis* L.f. from a forest plantation in the municipality of Cáceres, Mato Grosso, Brazil, belonging to the Teak Resources Company (TRC). Three genotypes were selected: two clones (G1 and G2) and one seminal material (G3). The material was collected in April 2019, with six defect-free straight trees representing the average diameter of the stand per genotype. Table 1 presents the physical properties, the dendrometric variables, and the commercial yield of the sawn wood of the teak genotypes under evaluation (Albues *et al.* 2023).

The basal logs of the trees, which were one meter long, were split (May 2019) into tangential boards containing heartwood and sapwood, with nominal dimensions of 30 × 150 × 1000 mm (thickness, width and length). In this study, 23 boards were evaluated per genotype.

Table 1. Average Values and Standard Deviations of the Basic Density (ρ_{bas}), Tangential Shrinkage (S_t), Radial Shrinkage (S_r), Anisotropy Factor, Diameter at Breast Height (DBH), Commercial Height (CH) and Commercial Yield (CY) of Wood from the Three Genetic Materials of Teak (*Tectona grandis*)

Treatment	ρ_{bas} (kg.m^{-3})	S_t (%)	S_r (%)	Anisotropy Factor	DBH (m)	CH (m)	CY (%)
G1	510 a (0.02)	4.6 a (0.51)	2.3 a (0.42)	2.1 a (0.36)	0.3 a (6.66)	13.1 a (3.39)	60.7 a (11.69)
G2	520 a (0.02)	3.9 a (0.48)	1.8 a (0.25)	2.3 a (0.47)	0.4 a (6.74)	14.3 a (2.02)	53.5 a (16.39)
G3	540 a (0.04)	4.1 a (0.92)	2.2 a (0.29)	1.8 a (0.41)	0.3 a (6.18)	11.4 a (1.69)	44.1 a (22.82)
Average	520	4.2	2.1	2.1	0.3	12.9	52.8
Norms	ABNT NBR 11941 (2003)	ABNT NBR 7190 (1997)		= S_t/S_r	-	-	-

Legend: Means in columns followed by the same letter are not significantly different according to the Tukey test at the 5% level. (...) Standard deviation. Source: Albues *et al.* (2023).

Methods

The boards were randomly distributed in a drying pile with dimensions of 1000 mm width × 1000 mm length × 800 mm height, 15 cm from the floor in a covered shed. Therefore, there was no direct influence of sunlight or wind on the pieces. The spacing between the samples was approximately 20 mm. At each reading, the drying pile was rearranged; *i.e.*, what was at the top went to the bottom, and what was at the bottom went to the top.

Air-drying was performed at the Federal University of Mato Grosso, municipality of Cuiabá, which is located at 15° 35' 56" south latitude and 56° 06' 01" west longitude, Midwest Region of Brazil. The average altitude is 165 m above sea level (Bombled 2007). According to the *Köppen-Geier* climate classification, the climate is tropical with a dry season (Aw), a mean annual temperature of 23 °C, and annual rainfall ranging from 1,200 to 2,000 mm (Souza *et al.* 2013).

The environmental variables of this period, temperature (T), relative air humidity (RH) and precipitation, were obtained from the National Institute of Meteorology (INMET, 2019). The moisture content of the boards during the drying process was measured four times (1, 18, 43 and 57 days), corresponding to the 1st, 2nd, 3rd, and 4th readings, respectively, until the samples reached a final average moisture content of 11%.

For this purpose, a capacitive moisture meter (Sultech, model ST 7500) was used to monitor the moisture content of the wood in the central part of the piece in relation to its width and length. In addition, the moisture content of the boards was also monitored using the gravimetric method (Eq. 1), and all boards per genotype were periodically weighed until they reached constant weight to control drying.

$$GM = ((IMC - FMC)/FMC) * 100) \quad (1)$$

The drying rate of the teak wood (Eq. 2) was determined based on the wood moisture content over time. The drying rate of the teak wood was determined based on the data acquired from the wood's moisture content over time. The decision was made to use values as close as possible to those in the literature, where the fiber saturation point is approximately 30%. Thus, based on the number of readings taken with the wood in this study, the closest value was 37% moisture. Thus, the three drying phases are from green to 37%, from 37% to 11% and from green to 11%, as described in Eq. 2 and as recommended by Zen *et al.* (2019).

$$DR = ((IMC - FMC)/T) \tag{2}$$

where DR is the drying rate (%.day^{-1}), IMC is the initial moisture content (%), FMC is the final moisture content (%), and T is the time in days.

In each reading, all the boards were measured to determine the degree of crooking, bowing, and splitting NBR 14806(2002), adopting the classification by the worst face of the board. Using a ruler, the boards were measured for maximum deformation on a flat table.

Statistical Analyses

Histograms showing the behavior of the defects listed in the tables for each genotype throughout the air-drying process. Subsequently, Pearson's correlation test was performed for the variables genotype, wood moisture content, bowing, crooking and splitting.

After observing the correlation between the variables, a factorial multivariate analysis of variance (MANOVA) was performed, with the levels being the genotype and drying period, to identify whether they influence the defects resulting from drying. In this analysis, the *Pillai* test was used to determine whether there was a significant difference ($p<0.05$). After this analysis, if the analyzed factors were significant, a cluster analysis was performed to evaluate the possible groups to be formed.

In addition, an analysis of variance was carried out to evaluate the behavior of the different genetic materials at different drying rates. If significant, a Tukey multiple comparison test was carried out ($p<0.05$). Statistical analyses were performed using R software, version 3.6.1.

RESULTS AND DISCUSSION

Moisture Content and Drying Rate

The environmental conditions during air drying were an average temperature of 24.7 °C, with a minimum of 11.1 °C and maximum of 35.0 °C, while the average relative humidity was approximately 62%, with a minimum of 21% and a maximum of 94%. The average wind speed was 1.63 m/s, the average radiation was 556.5 kJ/m^2, and there was no precipitation during the drying process (INMET 2019). The environmental variables during the air-drying process of teak in the Midwest-BR (Cuiabá city) are described in Fig. 1.

The averages and coefficients of variation of the initial moisture content of the wood for genotypes G1, G2, and G3 were 79.3% (17.8%), 64.9% (13.2%) and 60.1% (14.7%), respectively. At the end of air-drying, after 57 days, the wood reached average final moisture contents of 10.5% (7.4%), 10.9% (20.3%), and 12.3% (31.2%), respectively.

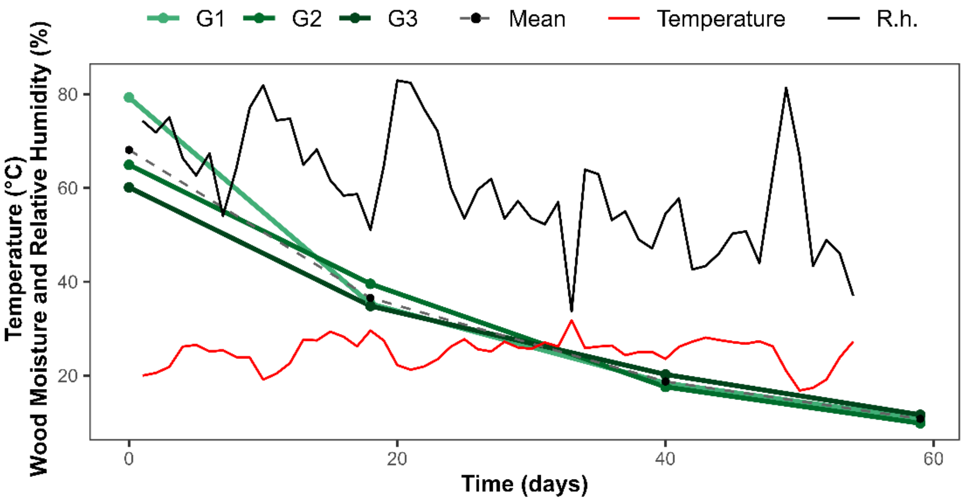

Fig. 1. Air-drying curve of different genotypes of *Tectona grandis* L. f. and environmental variables Subtitles: R.h.: relative humidity (%).

The initial wood moisture content of genotypes G2 and G3 was similar to that reported for teak wood in Costa Rica (Salas and Moya 2014). The difference in initial and final moisture contents between the clones and the seminal material in this study may be due to the high variability of teak wood permeability and, consequently, the pore distribution pattern and the variable distribution of tyloses along the trunk or the irregularities between heartwood and sapwood (Canal *et al*. 2020).

The final moisture content of the teak wood obtained in this study (Fig. 1) was similar to that reported in previous studies conducted in Brazil. After air-drying in Sinop-MT, *Tectona grandis* wood subjected to different types of splitting presented an average moisture content of 14.7% after 45 days of drying (Carmo *et al.* 2020). The average moisture content for the same species was 12% after 50 days of drying in the Southeast-BR (Braz *et al.* 2015), as well as for teak wood air-dried for 24 months in the Southeast region of Brazil (Batista *et al*. 2017)

The drying curve exhibited exponential behavior (Fig. 1), which is an expected result for any wood drying process, be it air-drying, a behavior observed by Liebl *et al.* (2017) and Zen *et al.* (2019), Carmo *et al.* (2020), Santos *et al.* (2022); Braz *et al.* (2015); solar drying, as described by Cremonez *et al.* (2020), Busatto *et al.* (2013) and Souza *et al.* (2015); and oven drying, as reported by Soares *et al.* (2016, 2019) and Maria *et al.* (2022). This behavior is mainly due to the lower energy requirement initially required for the removal of free water since it is found in cavities or intercellular spaces and does not exhibit chemical bonds with the wood, as occurs with the bound water (Soares *et al*. 2016).

The general drying rate was 1.0 %.day^{-1}. However, the mean drying rates for genotypes G1, G2, and G3 were 1.5 %.day^{-1}, 1.1 %.day^{-1}, and 0.97 %.day^{-1}, respectively. As expected, the highest drying rates occurred in the first drying weeks, and as the moisture content decreased, the drying rate decreased with time (Table 2). The higher the initial moisture content is, the greater the drying rate due to the greater amount of free water (França *et al.* 2019).

There were no significant differences ($p < 0.05$) among the three genetic materials for drying rate in the range of green wood moisture to stabilization (Table 2). Therefore, the average drying rate required to reach a moisture content of approximately 11% was 1.0%.day^{-1} (Fig. 1 and Table 2, respectively). This result was superior to that observed by

Carmo *et al.* (2020), who reported a drying rate of 0.37%.day^{-1} for teak wood in a period of 45 days in the Midwest-BR, which stabilized at 14.7%. Although the drying rate was lower than that found in the present study, the authors obtained a higher final wood moisture content.

Table 2. Drying Rates of Different *Tectona grandis* Genotypes as a Function of Wood Water Removal

Moisture Ranges	G1 (%.day^{-1})	G2 (%.day^{-1})	G3 (%.day^{-1})	Mean (%.day^{-1})
Green up to 37% *	2.6 a	1.5 b	1.5 b	1.9
37 up to 11%	0.7 a	0.88 a	0.58 a	0.71
Green up to 11%	1.2 a	0.97 a	0.85 a	1.0
Average for genotype	1.5	1.1	0.97	
where %.day^{-1} =drying rate, G1 = Clone 1; G2 = Clone 2; G3 = Seminal; *the rates are different for each genotype according to the Tukey test ($p<0.05$)				

In the wood moisture range of 37% to 11%, *i.e.*, in the removal of bound water (Table 2), the drying rate decreased by approximately 0.71% compared to the removal of free water, indicating that in this range, the removal of bound water is more difficult and slower, mainly because this water is impregnated in the cell wall. This result is lower than that reported by Braz *et al.* (2015) because although teak wood, in their study, exhibited a very typical drying behavior, there was a more accelerated loss of moisture, 25.5%, in the first five days. This can be explained by the conditions of relative air humidity and ambient temperature during drying, as well as factors intrinsic to the analyzed wood itself, such as anatomical characteristics.

As shown in Table 2, the average drying rate during the removal of free water was 1.8 times greater than that during the removal of bound water. This result was lower than that observed by Carmo *et al.* (2020), who reported that the drying rate during the removal of free water in teak wood was 3.7 times greater than that during the removal of bound water. Braz *et al.* (2015), during a 54-day period of air-drying with teak wood, reported that the average drying rate during the removal of free water was 18.2 times greater than that during the removal of bound water. Both studies yielded more favorable results than did the present study, which can be explained by the initial moisture content of the wood, which was lower in this study.

There were significant differences ($p < 0.05$) among the three genetic materials for the initial drying rate (green up to 37%) (Table 2). In particular, G1 had the highest value, while the values for the other genotypes were significantly equal. However, during the removal of bound water, *i.e.*, from 37% to 11%, the drying rates of the three materials were similar.

The G1 and G2 materials had initial moisture contents of 79.3% and 64.4%, respectively, while the initial moisture content of the seminal material was approximately 60%. However, the opposite trend was observed for the final moisture content of the wood, as the moisture content of the clonal materials was lower than 10.9%, while that of the seminal material was under 12%. This result is close to the equilibrium moisture content of wood found by Souza *et al.* (2016) in the Midwest-BR, with an average of 9.9% for the months of May, June, and July, where they presented average values of 11.2%, 10.1%, and 8.4%, respectively.

There was no rainfall during the experiment, and there was still variation in the amplitude of relative humidity, where some days presented 25% and others 40%. This result was higher than the amplitude of relative humidity observed by Souza *et al.* (2016), who reported an amplitude of 12.8% between May and June.

Table 3. Air-Drying Parameters of Wood in Different Regions

Species and Region	Rate drying (%)	Initial MC (%)	Final MC (%)	Days	Bow. (mm/m)	Crook. (mm/m)	Split. (%)	Authors
Teak (G1) Midwest-BR	1.2	79.3	10.8	57	4.0	4.3	24.3	This Study
Teak (G2) Midwest-BR	0.97	64.9	9.8	57	4.1	4.3	30.0	This Study
Teak (G3) Midwest-BR	0.85	60.1	11.6	57	4.5	3.8	48.7	This Study
Teak Midwest-BR	0.37	68.6	14.7	45	0	0	14.7	Carmo *et al.* 2020
Teak Southeast-BR	1.2	71.0	11.4	89	-	-	-	Braz *et al.* 2015
Teak (drying in a solar oven) South-BR	0.73	115.4	11.49	92	-	-	-	Loiola *et al.* 2015
Teak Costa Rica Dry weather	-	63.0	-	47	-	-	-	Salas & Moya 2014
Teak Costa Rica	-	-	14	-	3.8	4.2		Montero *et al.*, 2015
Bertholletia excelsa North-BR	0.01	63.9	15.1 (35 days)	100	0.04	-	-	Santos *et al.* 2022
Hovenia dulcis South-Br	3.7	107.5	15.4	25	1.6	3.0	14.8	Susin *et al.* 2014
Eucalyptus South-BR	0.58	54.7	14.1	116	1.9	2.1	-	Duarte *et al.* 2015

Subtitle: RD.= Rate Drying; IMC= Initial wood moisture content; FMC= Final wood moisture content; Bow. = Bowing; Crook. = Crooking and, Split. = Splitting.

The moisture content of teak after (natural) air-drying found in the present study was similar to that found by Loiola *et al.* (2015), who evaluated teak wood subjected to drying in a solar oven; however, the process lasted 92 days, and the maximum temperature was 55 °C.

Thus, field trials, even if they require more time, ensure factual results for the use of wood since during oven drying, the wood is not exposed to weathering (Souza *et al.* 2016). Thus, it is advisable that the wood be dried in the open air in places where the wood will be definitively used; otherwise, an acclimatization period is recommended before use (Braz *et al.* 2015). In different locations, the wood will exhibit different drying parameters due to the environmental variables of the location, as shown in Table 3.

Defects during Drying

At the 2nd reading, there was an increase in bowing of 61.3% (G1), 73.1% (G2), and 66.8% (G3) compared to the first reading, and the G2 clone had the highest incidence of this defect. The percentage of crooking increased by 77.5% (G1), 70.3% (G2) and 82.6% (G3). The defects with the highest incidence were split defects, which appeared immediately at the beginning of air-drying (Fig. 2).

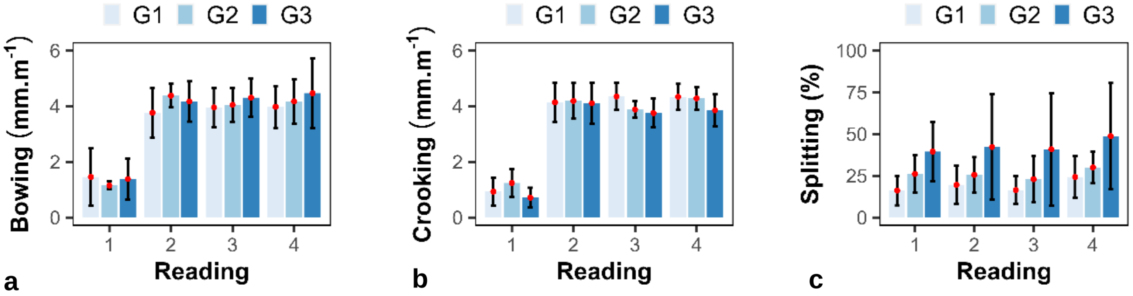

Fig. 2. Drying defects, **a**) bowing, **b**) crooking and **c**) splitting of wood of different *Tectona grandis* L. f. genotypes during air-drying

Unlike for the bowing and crooking defects, the splitting showed little variation between the green wood and the 37% wood moisture. However, there was a reduction in splitting in all genotypes when the wood presented moisture below the saturation point of the fibers (between readings 2 and 3). Again, there was an increase in these parameters between readings 3 and 4 (Fig. 3c). However, when considering the entire process, the splitting of genotypes 1, 2 and 3 exhibited variations of 66.6%, 87.0% and 81.0%, respectively.

The three genotypes exhibited different behaviors during the air-drying process because the clonal materials showed shorter intervals for defects than did the seminal material (G3), which shows that the clones are more homogeneous. The seminal genotype showed greater heterogeneity, which may affect the quality of the wood during the air-drying process, resulting in many different moisture contents and/or a prolonged drying period.

At the end of air-drying, for the bowing and crowing defects, the three genotypes presented values lower than 5 mm.m^{-1}, qualifying them as first class (IBDF, 1984). In addition, the anisotropy coefficients for the three genotypes were close to 2 (Table 1). Monteiro *et al.* (2015), when evaluating fast-growing teak from a tropical moist forest with a high-fertility site obtained results similar to those in this study, despite having a greater anisotropy factor. This factor is important for drying performance because the material will be less prone to defects (Souza *et al.* 2023).

In general, there was an increase in defects during the air-drying process. However, only the seminal genotype showed a reduction in crooking, and clonal genotype 2 showed reduced bowing. This result is similar to that of the study by Duarte *et al.* (2015), who analyzed the air-drying of *Eucalyptus* and reported the evolution of the intensity and percentage of crooking in the pieces after drying; however, for bowing, the opposite behavior was observed.

Crooking was the defect with the least representation during the drying process; however, in the seminal genotype, this aspect was highlighted. The clones in this study showed similar results to those of fast-growing teak in tropical rainforest regions of Costa Rica found by Montero *et al.* (2015) and air-dried fast-growing teak wood during dry weather found by Salas and Moya (2014). These authors stated, as in the present study, that there was a reduction in crooking throughout the drying process. In addition, Salas and Moya (2014) stated that the increase or decrease in bowing and buckling defects in green wood compared to dry wood can be explained by shrinkage within the board, which can vary between years and produce different degrees of shrinkage.

A low rate of crooking was observed in the study by Santos *et al.* (2022) when evaluating the air-drying of *Bertholletia excelsa* Humb. and Bonpl., Brazil nut (Table 3), and explained that this is due to the cutting predominantly in the tangential direction. Thus, to avoid this defect, tangential splitting is recommended, in addition to planing the pieces to reduce the percentage of crooking.

The wood's behavior regarding splitting varied throughout the drying process. It decreased when moisture neared the fiber saturation point but increased again as the wood reached equilibrium moisture content. This pattern of reduction and increase doesn't mean the splits disappear. Instead, there's a decrease in the severity of these defects—meaning the dimensions of the splits may soften as the wood, an anisotropic and heterogeneous material, adjusts during moisture release below the fiber saturation point. This may be related to the moisture gradients that occur during drying. When the center and the surface of the sawn wood have different moisture levels, contractions increase. However, when the gradient decreases, the microfibrils move closer together, and the splits partially close (Susin 2018). This behavior was also verified in the work of Lima *et al*. (2022) who evaluated the drying of sawn wood.

Splitting was the most common defect among the three teak wood genotypes. Because they presented values greater than 20%, they fell into the fifth class of ABNT NBR 14,806 (2002), which does not present a defect limit. The exposure of wood to environmental variables may have caused the evolution of splitting at the end of drying (Susin *et al*. 2018). According to ABNT NBR 7190 (1997), the standard condition for use in civil construction is an equilibrium humidity equal to 12%, which is obtained for environments with a relative humidity equal to or greater than 65%.

Santos *et al.* (2022) evaluated *Bertholletia excelsa via* air-drying and reported that the mean incidence of top and surface splitting was 5.5%. When evaluating the presence of splitting in the *Tectona grandis* lumber, Gómez and Moya-Roque (2008) observed that this splitting increased both in intensity (percentage of pieces with this defect) and in magnitude. In this study, there was a similar behavior, but with a greater frequency of splitting in the pieces derived from the seminal material. Such performance can reduce the total yield of the piece and cause greater expense to the forestry producer. However, this defect can be reduced by waterproofing the tops of the wooden pieces before the drying process.

According to the Pillai test, only the genotype had a significant effect on drying defect variables such as bowing, crooking and splitting during the air-drying process (Table 4).

Table 4. Behavior of Moisture Content, Bowing, Crooking and Splitting According to the Different Genotypes of *Tectona grandis* and Time in the Air Drying Process

Interaction	D.F.	Pillai Test	F approx.	Significance
Genotypes	2	1.16197	4.068	0.001*
Reading	3	0.07299	0.507	0.868^{ns}
Genotype: Reading	6	0.18871	0.732	0.775^{ns}
Residues	60			

where: D.F. = Degrees of freedom; F approx. = Approximate F statistic; * = Significant at the 5% level; ns = Not significant at the 5% level.

When analyzing the correlation between wood variables (genotype, moisture content and defects), a negative correlation was observed between wood moisture content and bowing and crooking defects (Fig. 3a and 3b). Thus, the lower the moisture content is, the greater the incidence of these defects. However, bowing and crooking are positively correlated, *i.e.*, the occurrence of one of these defects will lead to the presence of the other. With regard to splitting, this variable was the only variable that showed a correlation with the genotypes, albeit it was weak (Fig. 3a). For the grouping of the different *Tectona grandis* genotypes, the clonal genotypes (G1 and G2) were similar and diverged from the seminal genotype (G3) according to the cluster analysis (Fig. 3b).

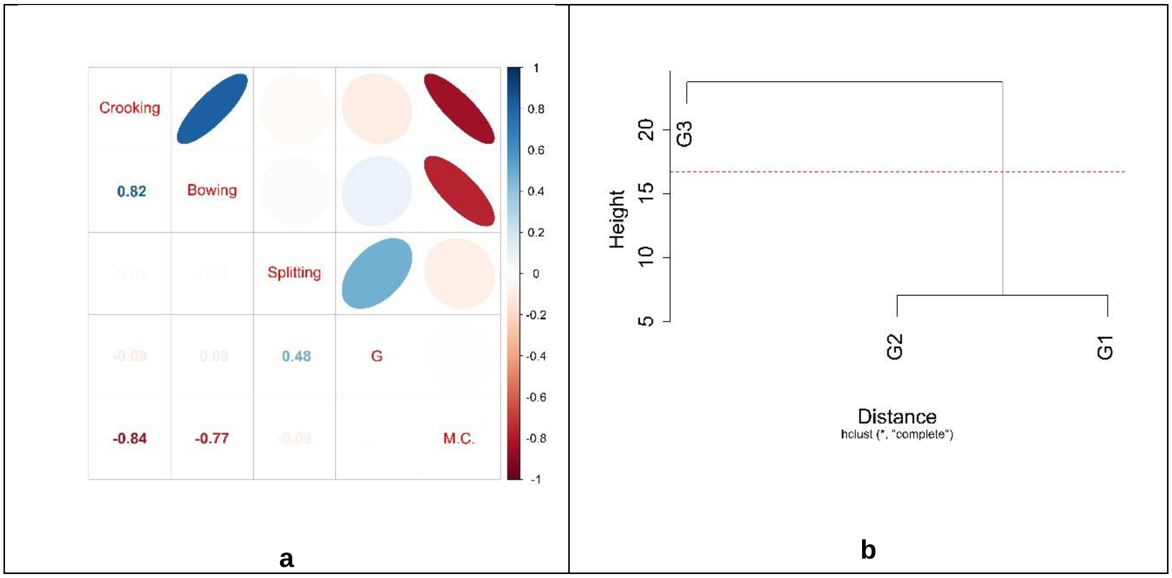

Fig. 3. **a**) Correlations between the variables of *Tectona grandis* wood subjected to air-drying; **b**) grouping of the three *Tectona grandis* genotypes according to *cluster* analysis; where Bow= Bowing, Crook= crooking, Split= splitting; G=Genotype and MC= Wood moisture content.

There was little correlation between the defects analyzed and the environmental variables (Fig. 3a). Thus, the appearance of defects is characteristic, above all, of genetic material as a function of drying time. This study by Santos *et al.* (2003) supported the findings reported in the present article because during the removal of bound water, the water evaporation line is restricted to the center of the board, and the drying rate is regulated exclusively by the quality of the material until moisture content equilibrium is finally reached. However, Salas and Moya (2014) stated that temperature was the main influencing variable in the different seasons, with the highest value recorded in the dry season, facilitating the drying process.

Despite the three genotypes having the same basic density (Table 1), they exhibited different drying rates (Table 2). This is affected by the density of the wood, where the higher the density is, the lower the permeability, and consequently, the natural or artificial drying will be slower (Braz *et al.* 2015). However, G1 presented the highest drying rate, while G3 presented the lowest. The basic density and drying rate showed a weak inverse correlation (-0.35) for the studied genotypes.

However, drying, bowing and crooking defects were strongly negatively correlated with moisture content (Fig. 3a); *i.e.*, the greater the loss of water in the wood was, the greater the number of warping defects. This is evident in Fig. 1, where readings 1 and 2 recorded the greatest moisture loss in the wood, close to the fiber saturation point, resulting in a significant evolution of warping for the three teak genotypes, as shown in Fig. 2. In contrast, in *Eucalyptus* ssp. woods, there was an average correlation with warping (França *et al.* 2019).

Santos *et al.* (2003) supported the findings reported in the present article because during the removal of bound water, the water evaporation line is restricted to the center of the board, and the drying rate is regulated exclusively by the quality of the material until moisture content equilibrium is finally reached. Thus, at the end of the air-drying process (57 days), the clonal materials (G1 and G2) showed better air-drying performance than the seminal material (G3) (Fig. 3b) and, consequently, a higher yield for the timber industry.

CONCLUSIONS

1. After the air-drying process, the final moisture content was greater in the naturally seeded material. For the drying rate, in the range from green moisture content to 37%, G1 showed the highest rate, while G2 and G3 showed the same behavior. However, the overall drying rate, which ranged from 11% to green wood, did not differ among the three materials.
2. Environmental factors had no significant correlation with the air-drying process of the three materials. However, the behavior of wood was found to be directly related to its qualities. The moisture content of the wood was strongly negatively correlated with crooking and bowing defects. Thus, the clonal genotypes are similar but differ from the seminal genotype. Therefore, there was a lower incidence of defects, especially splitting, in the clonal materials than in the seminal material.

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