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MACHINING OF JUVENILE WOOD OF *Tectona grandis* LINN. F. FROM DIFFERENT GENETIC MATERIALS AND PLANTING SPACINGS

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Resumo

Usinagem da madeira jovem de Tectona grandis Linn F. proveniente de diferentes materiais genéticos e espaçamentos de plantio. Usinagem da madeira jovem de *Tectona grandis* Linn f. proveniente de diferentes materiais genéticos e espaçamentos de plantio. Reflorestamentos com a espécie *Tectona grandis* Linn F., popularmente conhecida como teca, vem se destacando por questões relacionadas à sua produtividade e qualidade de sua madeira, No Brasil, devido a diversos fatores, como as condições edafoclimáticas, o período de exploração ocorre entre 20 e 25 anos. Até o final desse ciclo são realizados desbastes no povoamento, sendo esse material denominado como "teca jovem", comercializado com valores inferiores em relação à madeira adulta. A compreensão acerca de um material é fator essencial para viabilizar o seu uso da melhor forma possível. O objetivo geral desse estudo foi avaliar a usinabilidade da madeira de quatro materiais genéticos da espécie *Tectona grandis*, provenientes de dois espaçamentos de plantio, visando fornecimento de matéria-prima para a indústria madeireira. A matéria-prima utilizada no estudo foi obtida de indivíduos de teca com 12 anos de idade. Foram selecionados quatro materiais genéticos (clonais e seminais) em dois espaçamentos de plantio (4x4 e 4x3 m). Foi realizada a avaliação visual, mediante à norma específica, para o comportamento obtido nas operações de usinagem para o aplainamento, lixamento, furação para inserção de cavilha, dobradiça e espiga, além do teste de fendilhamento por inserção de pregos. Os resultados foram satisfatórios, sendo classificados, em sua maioria com desempenho de "excelente" a "bom", e em menor frequência como "regular", sugerindo que a matéria-prima, jovem, pode ser utilizada para diversos fins que requerem elevada qualidade superficial da madeira.
Palavras-chave: Teca, Qualidade da madeira, Processamento mecânico.

Abstract

Reforestation with the species *Tectona grandis* Linn. F., popularly known as teak, has been marred by issues related to its productivity and wood quality. In Brazil, due to several factors, including edaphoclimatic conditions, the exploitation period occurs between 20 and 25 years. Until the end of this cycle, thinning is carried out in the stand. This material is referred to as "young teak" and is sold at lower prices compared to adult wood. Understanding the material is an essential factor to enable its optimal use. The general objective of this study was to evaluate the wood machinability from four genetic materials of *Tectona grandis*, from two planting spacings, aiming to proffer raw material for the timber industry. The raw material used in this study was obtained from 12-year-old teak individuals. Four genetic materials (clonal and seminal) were selected in two plant spacings (4x4 and 4x3 m). A visual assessment was carried out, following specific standards, to evaluate the behavior in the machining operations for leveling, sanding, drilling for dowel, hinge, and tenon insertion, as well as the splitting test by nail insertions. The results were satisfactory, mostly classified as having "excellent" to "good" performance, and less frequently as "regular", implying that young teak wood can be used for copious purposes that require high surface quality.
Keywords: Teak, Wood Quality, Mechanical processing.

INTRODUCTION

Tectona grandis Linn f., timber and is cultivated in at least 70 countries worldwide. The quality of its wood draws noteworthy investments from the private sector in Africa, Asia, and Latin America. In many countries, teak production and trade have become the main component of the forestry sector (KOLLERT; WALOTEK, 2015).

The timber industry in Brazil currently relies heavily on wood from the genera Pinus and Eucalyptus for mechanical processing. However, as a sound investment alternative, teak reforestation has been gaining prominence due to its productivity and wood quality (FERNÁNDEZ-SÓLIS *et al.*, 2018; MATOS *et al.*, 2018; MOYA *et al.*, 2020). In addition, its wood demonstrates satisfactory performance during the drying process (BRAZ *et al.*, 2015). According to data from IBÁ (2023), in 2022 the country had 9.94 million hectares of reforested areas, of which teak plantations accounted for 76,000 hectares. Compared to the area planted with the species in 2010, this number represents an increase of approximately 16%.

In Brazil, due to various factors, the harvesting age for the species has been reduced to between 20 and 25 years to reach significant market value. Thinning operations are carried out in the stand until the end of this cycle (ZIECH *et al.*, 2016; CAMPOS; LEITE, 2017). This material is a market for what is termed "young teak," referring to wood obtained from smaller-diameter logs that are processed separately. This is a product with some characteristics similar to mature wood, but also with distinctions and particularities that make it suitable for specific applications, such as rustic furniture and decorative pieces (FIGUEIREDO *et al.*, 2005).

According to Bonduelle (2002), wood machining can be expressed through the 5M framework: i) Material – related to all the inherent properties of wood and their influences on the process; ii) Machine – related to the construction aspects of the machinery, involving fixtures, guides, and chip exhaust systems that aim to improve the machining operation; iii) Methodology – encompasses the entire description of the machining parameters to be used, as well as the selection of the most appropriate tools to optimize processing; iv) Manpower – considers the training of the operators responsible for machining tasks, who must know all previous items to be able to intervene if any deficiency is perceived in the process; v) Environment – it is considered that all processing stages should avoid environmental degradation, aiming for the satisfactory use of raw materials, reducing waste and noise.

The possibility of transforming the wood of a given species into various products, while also considering, among other factors, variations in genetic materials (VIEIRA *et al.*, 2018) and planting spacing, depends mainly on understanding its characteristics (MEDEIROS *et al.*, 2016) and how to work with them. Therefore, knowledge of its machinability is of utmost importance. Machinability aims to process the material using specific tools, seeking not only to cut the material but also to produce desired shapes and surfaces of satisfactory quality (BURGER; RICHTER, 1991).

The objective of this study was to evaluate the machinability of wood from four genetic materials of the species *Tectona grandis*, from two planting spacings, aiming to supply raw material for the timber industry.

MATERIAL AND METHODS

Material Collection Area

The plant material used was provided by the company Teak Resources Company (TRC), consisting of *Tectona grandis* trees from 12-year-old plantations located in the municipalities of Redenção and Santa Maria das Barreiras, both in the southeastern region of the state of Pará. The region is characterized by a tropical climate with a dry winter (Köppen classification 'Aw') (ALVARES *et al.*, 2013). The highest rainfall concentrations occur between December and March, while the lowest occur between June and August, with an average annual temperature of approximately 27.5°C (Banco de Dados Meteorológicos para Ensino e Pesquisa – BDMEP / INMET, 2024).

Sampling and Material Preparation

Four genetic materials of *Tectona grandis* were selected, comprising three clonal and one seed-origin material, planted at two different spacings (4x4 m and 4x3 m). Three trees were sampled from each genetic material and spacing combination, totaling 24 individuals (Table 1).

Table 1. Experimental outline according to the analyzed parameters (genetic material x spacing)
Tabela 1. Delineamento experimental em função dos parâmetros analisados (material genético x espaçamento)

Treatment	Provenance	Spacing (m)	Number of Trees
1	Clone 1	4 x 4	3
2	Clone 2	4 x 4	3
3	Clone 3	4 x 4	3
4	Seed	4 x 4	3
5	Clone 1	4 x 3	3

Treatment	Provenance	Spacing (m)	Number of Trees
6	Clone 2	4 x 3	3
7	Clone 3	4 x 3	3
8	Seed	4 x 3	3

For the preparation of the test specimens intended for the machining tests, the first log from each tree was designed, taken from a height of 60 cm above ground level (Figure 1). The logs were sawn into boards, and the resulting lumber was kiln-dried until it reached a moisture content of 10%. The sawing and drying processes were carried out at the sawmill of the Institute of Forests at the Federal Rural University of Rio de Janeiro (UFRRJ), involving members of the Wood Quality Research Center (Núcleo de Pesquisa em Qualidade da Madeira - NPQM) and the Wood Processing Laboratory (Laboratório de Processamento de Madeira - LPM)

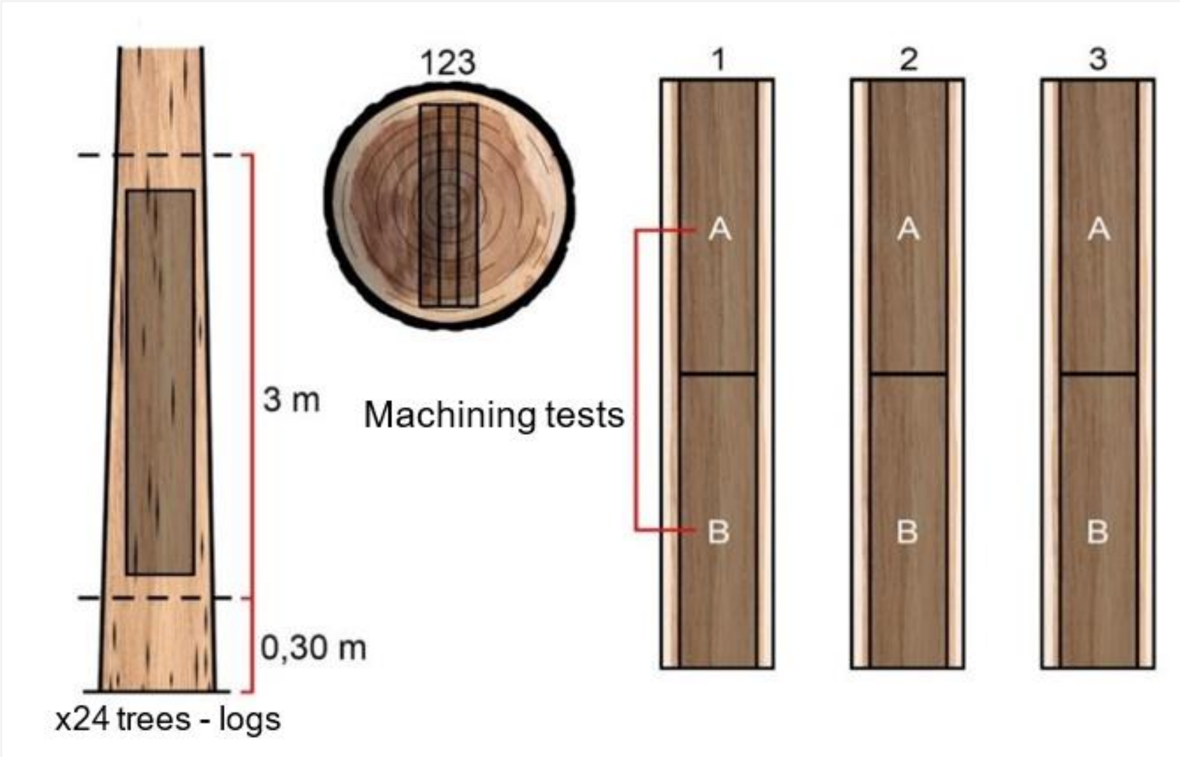

Figure 1. Location of test specimen removal for machining characterization.
Figura 1. Localização da retirada dos corpos de prova para caracterização da usinagem.

Machining Tests

The sawn wood was subjected to kiln drying until reaching a moisture content of 10%. The machining tests were held at the Wood Processing Laboratory (LPM/UFRRJ). Six test specimens were prepared from each log, resulting in 18 per treatment and 144 in total. The test specimens were manufactured with dimensions of 2.5 x 13.0 x 80.0 cm. Subsequently, along their longest dimension, the test specimens were cut into two parts: one measuring 55 cm, used for the leveling tests, and the other measuring 25 cm, intended for sanding, drilling (for dowel, hinge, and mortise and tenon fitting), and nail insertion. The quality of the machined surfaces was evaluated by three assessors, who assigned scores from 1 to 5 based on the absence or presence of defects and their intensity, as follows: 1 – "Excellent"; 2 – "Good"; 3 – "Fair"; 4 – "Poor"; 5 – "Very Poor". The tests and evaluations followed the methodology proposed by the ASTM D1666-22 (2022) standard, with adaptations in the type of machinery and the quantity and dimensions of the test specimens. Figure 2 shows the representation of the test specimen used in the machining tests. To prevent the influence of knife, drill bit, and sandpaper wear on the wood surface quality, they were replaced after every 48 test specimens.

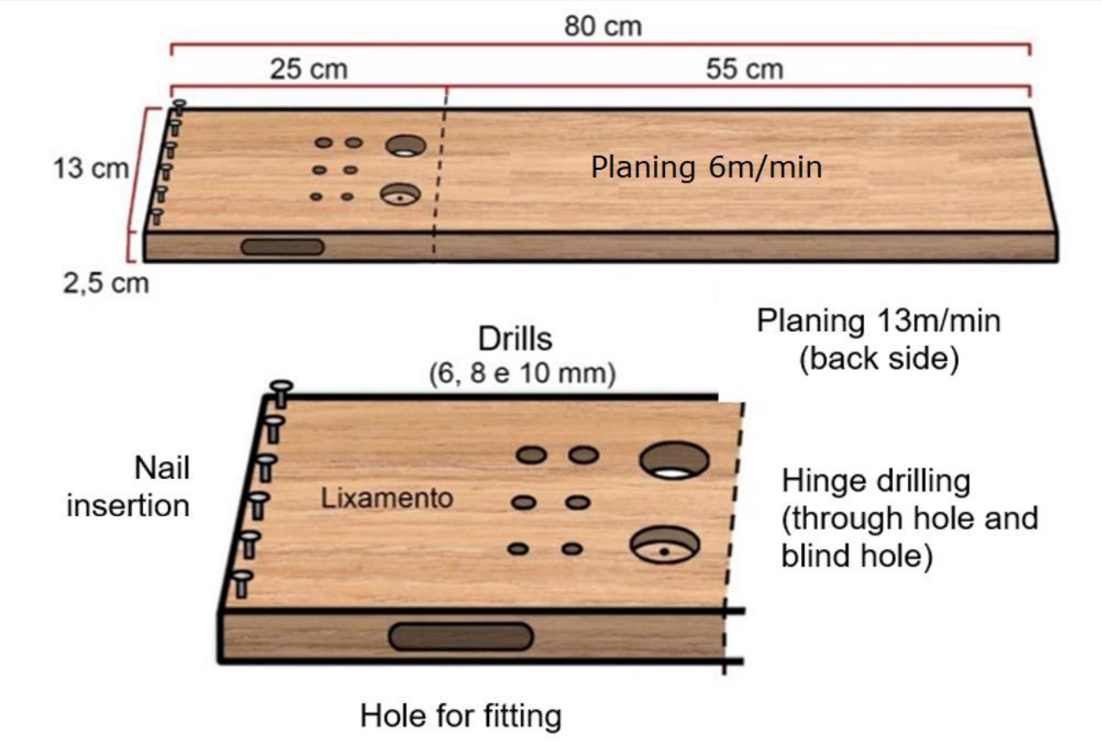

Figure 2. Sample representation for machining operations.
Figura 2. Representação do corpo de prova para as operações de usinagem

For the planing test, a Baldan DPC-4 jointer (planer) was wielded, equipped with 3 knives, a rotation speed of 4.500 RPM, a cutterhead diameter of 99 mm, and set for a cutting depth of 1.6 mm. An automatic feeder was also used to standardize the feed speeds. The chosen feed speeds were 6 m/min and 13 m/min. For this operation, each face of the test specimen was planned at the aforementioned speeds. leveling was also performed on half the width of the test specimen, both against and along the grain. The following defects were evaluated: fuzzy grain, torn grain, and chip marks (ASTM, 2022).

For the sanding test, a Possamai brand belt sander, model LXA-7200, was used, with 2.70 m between the drive wheel and the idler wheel, a belt speed of 1,400 m/min, a motor speed of 3.600 RPM, and equipped with 80-grit sandpaper. The sanding process was standardized for a period of 30 seconds. The following defects were evaluated: scratching and fuzzy grain (ASTM, 2022).

For the drilling tests for dowels and hinges, a vertical drill press with manual feed and a motor rotation speed of 3100 RPM was used. For this purpose, the drill was equipped with high-speed steel twist drill bits with the following respective sizes: 10 x 87 x 133 mm (diameter, bit length, and flute length); 8 x 75 x 117 mm (diameter, bit length, and flute length) and 6 x 57 x 93 mm (diameter, bit length, and flute length). Six through-holes were drilled in each specimen, two for each bit size. The holes were drilled with a minimum distance of 25 mm between them and also from the edges. The following defects were evaluated: tearouts and fuzziness. For the hinge drilling test, 25.4 x 152 mm spade bits were used, producing one through-hole and one blind hole (ASTM, 2022).

The mortise drilling test was performed on the lateral face of the piece. A Motomil brand horizontal drill press, model Fc-250, with manual feed and 1,275 RPM, equipped with a 10 x 87 x 133 mm (diameter, bit length, and flute length) twist drill bit was used. Successive holes were drilled in a line, and the bit was subsequently moved sideways through the holes, creating the mortise. The following defects were evaluated: crushing and fuzziness (ASTM, 2022).

The methodology described by the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA, 1997) was adopted. Nails were driven into the same specimens used for drilling, and sanding tests were performed, with 6 nails in each. 15 x 15 steel nails (34.5 mm long, 2.4 mm in diameter) were used, spaced 20 mm apart and 10 mm from the ends (Figure 9). The test specimens were evaluated for the presence or absence of cracks propagating from the nail location to the top of the test specimen, and the percentage of specimens with cracks was recorded.

Statistical Analysis

Descriptive statistical analyses (overall mean and coefficient of variation) of the scores assigned in all machining tests were carried out using Assistat software, version 7.7 (SILVA & AZEVEDO, 2016).

RESULTS

The results of the visual evaluation of the machined wood surfaces, conducted according to the ASTM D1666-22 (2022) standard and the previously described methodology, are presented below. The scores were assigned based on the intensity of each defect, ranging from 1 to 5, where 1 represents the best and 5 the worst performance.

Tables 2 and 3 show the mean visual evaluation for the planed teak surfaces at 6 and 13 m/min, respectively. Médias das notas, por defeito, referentes às operações de aplainamento a 6 m/min

Table 2. Average scores, by defect, referring to leveling operations at 6m/min
Tabela 2. Média das notas, por defeito, referentes às operações de aplainamento a 6 m/min

Treatment	leveling 6 m/min		
	Fuzzy Grain	Torn grain	Chip Mark
Clone 1 – 4x4	1.7 (29.27)	2.0 (34.08)	1.0 (06.22)
Clone 2 – 4x4	1.4 (36.97)	1.5 (28.31)	1.0 (00.00)
Clone 3 – 4x4	1.5 (31.47)	1.7 (40.12)	1.0 (05.29)
Seed – 4x4	1.3 (26.08)	1.3 (25.36)	1.0 (05.29)
Clone 1 – 4x3	1.6 (26.12)	1.8 (25.76)	1.1 (09.38)
Clone 2 – 4x3	1.4 (27.31)	1.7 (26.02)	1.0 (08.81)
Clone 3 – 4x3	1.6 (32.71)	1.8 (27.83)	1.1 (11.76)
Seed – 4x3	1.3 (22.00)	1.5 (23.63)	1.1 (15.27)
Overall average	1.5 (30.25)	1.7 (31.77)	1.0 (09.95)

Values in parentheses indicate the coefficient of variation (%)

Table 3. Average scores, by defect, referring to leveling operations at 13 m/min
Tabela 3.Médias das notas, por defeito, referentes às operações de aplainamento a 13 m/min

Treatment	leveling 13 m/min		
	Fuzzy Grain	Torn Grain	Chip Mark
Clone 1 – 4x4	2.0 (32.84)	3.0 (30.59)	1.2 (15.49)
Clone 2 – 4x4	1.9 (31.84)	2.6 (28.43)	1.1 (15.64)
Clone 3 – 4x4	1.7 (37.95)	2.4 (36.22)	1.0 (08.34)
Seed – 4x4	1.5 (22.52)	2.1 (31.32)	1.1 (11.50)
Clone 1 – 4x3	1.8 (29.61)	2.7 (27.42)	1.2 (14.56)
Clone 2 – 4x3	1.8 (30.85)	2.6 (28.71)	1.2 (14.68)
Clone 3 – 4x3	2.1 (25.69)	2.9 (22.37)	1.2 (19.12)
Seed – 4x3	1.4 (23.79)	2.4 (30.93)	1.4 (21.69)
Overall average	1.8 (32.24)	2.6 (30.82)	1.2 (18.06)

Values in parentheses indicate the coefficient of variation (%)

The sanding operations, for all treatments, received a score of 1, with all specimen surfaces rated as "Excellent". Therefore, no scratching or fuzzy grain defects were observed.

Table 4 presents the mean visual evaluation results for the drilling operations performed for dowel insertion of 6, 8, and 10 mm.

Table 4. Average scores, by defect, in dowel drilling operations
Tabela 4. Médias das notas, por defeito, referentes às operações de furação para cavilha

Treatment	Dowel drilling					
	6 mm		8 mm		10 mm	
	Torn Grain	Raised Grain	Torn Grain	Raised Grain	Torn Grain	Raised Grain
Clone 1 – 4x4	1.5 (39.61)	2.8 (39.07)	1.8 (46.67)	1.8 (34.30)	1.6 (40.89)	1.6 (44.60)
Clone 2 – 4x4	1.6 (36.19)	1.9 (46.79)	1.6 (47.07)	1.6 (39.58)	1.6 (36.33)	1.4 (35.20)
Clone 3 – 4x4	1.4 (42.63)	1.8 (36.96)	1.9 (57.76)	1.6 (32.91)	1.4 (45.09)	1.7 (38.85)
Seed – 4x4	1.4 (39.46)	1.9 (36.63)	1.4 (42.37)	1.5 (44.15)	1.3 (31.44)	1.4 (34.77)
Clone 1 – 4x3	1.2 (29.21)	1.6 (41.09)	1.8 (47.25)	1.4 (50.22)	1.1 (33.01)	1.1 (15.32)
Clone 2 – 4x3	1.2 (32.07)	1.7 (49.69)	1.5 (44.32)	1.5 (36.33)	1.1 (24.67)	1.2 (28.83)
Clone 3 – 4x3	1.4 (29.10)	1.5 (45.82)	1.6 (34.40)	1.3 (29.78)	1.2 (32.07)	1.2 (20.79)
Seed – 4x3	1.4 (40.12)	1.5 (34.55)	1.5 (41.14)	1.2 (25.46)	1.2 (42.61)	1.2 (29.40)
Overall average	1.4 (37.22)	1.8 (46.03)	1.6 (46.83)	1.5 (38.77)	1.3 (38.86)	1.3 (37.86)

Values in parentheses indicate the coefficient of variation (%)

Table 5 shows the average results of the visual assessment of the holes for hinge insertion, with through and non-through holes.

Table 5. Average scores, by defect, in overlay hinge drilling operations
Tabela 5. Médias das notas, por defeito, referentes às operações de furação para dobradiça

Average	Hinge drilling			
	Through hole		Blind hole	
Treatment	**Torn Grain**	**Raised Grain**	**Torn Grain**	**Raised Grain**
Clone 1 – 4x4	3.0 (28.94)	2.0 (28.44)	1.1 (17.70)	2.6 (29.78)
Clone 2 – 4x4	3.0 (34.67)	2.1 (26.39)	1.2 (32.55)	2.5 (32.16)
Clone 3 – 4x4	2.9 (30.13)	2.1 (31.09)	1.0 (11.47)	2.1 (25.04)
Seed – 4x4	2.6 (41.06)	2.1 (22.40)	1.1 (15.32)	2.3 (23.18)
Clone 1 – 4x3	2.9 (33.80)	2.1 (29.95)	1.1 (17.70)	2.6 (25.01)
Clone 2 – 4x3	2.4 (36.18)	2.2 (29.62)	1.0 (00.00)	2.1 (30.85)
Clone 3 – 4x3	2.2 (44.30)	1.8 (33.09)	1.1 (23.75)	2.4 (22.06)
Seed – 4x3	2.5 (32.18)	1.6 (31.11)	1.0 (00.00)	1.9 (30.01)
Overall average	2.7 (35.93)	2.0 (29.79)	1.1 (19.41)	2.3 (28.86)

Values in parentheses indicate the coefficient of variation (%)

As with sanding, the drilling operations for tenon fitting received a score of 1 (Excellent) for all treatments. Hence, there were no crushing defects and/or rough grain.

Table 6 shows the percentages referring to the number of splittings observed in teak wood resulting from nail drilling.

Table 6. Relative amount of nail perforations that cracked the samples
Tabela 6. Quantidade relativa de perfurações por prego que causaram rachaduras nos corpos de prova

Treatment	Nail-induced splitting (% of cracks)
Clone 1 – 4x4	25.0 (76.70)
Clone 2 – 4x4	13.0 (112.9)
Clone 3 – 4x4	22.8 (77.80)
Seed – 4x4	20.0 (79.00)
Clone 1 – 4x3	18.5 (60.90)
Clone 2 – 4x3	19.6 (93.02)
Clone 3 – 4x3	07.4 (138.5)
Seed – 4x3	02.8 (230.1)
Overall average	16.1 (100.2)

Values in parentheses indicate the coefficient of variation (%)

DISCUSSION

When leveling at 6 m/min, for the three types of defects evaluated: fuzzy grain, torn grain, and chip marks, all treatments were classified as “excellent” to “good.” For the fuzzy grain defect, the lowest score was for the seed material in the 4x3 spacing and the highest was for clone 1 in the 4x4 spacing. For torn grain, the lowest value observed was for the seed material in the 4x4 spacing and the highest for clone 1 in the 4x4 spacing, which reached the limit for classification as “good.” The chip marks defect occurred rarely, which was rated as ‘excellent’ to “very good.” The chance of such a defect occurring is greater in woods that contain resin, where the resin can adhere to chips on the edge of the planer blade, which, upon returning to the wood for a new cut, may cause small marks due to surface crushing. When leveling at 13 m/min, an increase in the intensity of wood defects was observed, especially for grain pull-out, now classified as “good” to “fair,” with minimum and maximum values of 2.1 and 3.0, respectively. This difference in behavior is explained by the fact that the feed rate of 13 m/min is more aggressive to the wood, since the material is displaced by the planer, and consequently by the knives, at a speed more than double that of the first situation (6 m/min). The fuzzy grain defect remained classified as “excellent” to “good”, with lower and higher average values of 1.4 and 2.0, respectively. The chip mark defect showed greater intensity in relation to the 6 m/min feed rate; however, it still maintained an evaluation ranging from “excellent” to “very good.”

Sanding was one of the two machining operations that showed the best results among the others. The woods from all treatments, for the defects of scratching and fuzzy grain, were evaluated as "excellent", indicating their absence. It is observed, by the null values of the coefficient of variation, that the scores assigned by all evaluators and for all specimens were equal. The sanding operation is employed after the use of the thickness planer or jointer, when the material subsequently needs to be reworked to achieve a surface of superior quality. The scratching defect occurs due to the use of poorly manufactured sandpaper, or when a solid particle adheres to the abrasive, causing grooves on the wood surface. Fuzzy grain, a defect that can occur during thicknessing or leveling, can be totally removed provided the wood is subjected to the sanding operation for an adequate time.

In the drilling operations for dowel insertion with twist drills of 6, 8, and 10 mm diameters, the results obtained for the defects of torn grain and raised grain received a classification from "excellent" to "good", except for the raised grain defect when using the 6 mm drill bit for clone 1 in the 4x4 spacing, which approached the "fair" classification. It was also observed that this defect decreased as the drill bit diameter increased, with overall averages of 1.8, 1.5, and 1.3 for the 6, 8, and 10 mm drill bits, respectively.

It was observed that the drilling operation for hinge insertion, in the case of the through-hole (the one that passed entirely through the specimen), generated scores classified as "good" to "fair" for the torn grain defect, whereas for the same defect in the blind hole, the classification was very close to "excellent". This can be explained by the fact that the flat drill bit "pushes" a portion of the material as it passes through the wood, thus increasing the occurrence of the defect. For both types of holes, the occurrence of the raised grain defect was similar, ranging from "excellent" to “fair”.

Along with the sanding operation, the drilling for tenon fitting showed the best results among all machining operations. The woods from all treatments, for the crushing and raised grain defects, were evaluated as "excellent". The null values of the coefficient of variation indicate that the scores assigned by all evaluators for all specimens were equal. The excellent performance was due to the drilling for tenon fitting being performed by means of several individual and successive holes, through which the twist drill subsequently passed, removing any raised grains that were present.

The seed material, in the 4x3 spacing, showed the lowest percentage of cracking during nail insertion, while the highest was observed in clone 1 in the 4x4 spacing. However, no relationship was observed between the number of cracks and any other treatment variable. High coefficients of variation were recorded in all treatments, indicating that the specimens within the same treatment exhibited large variations in the amount of splits.

CONCLUSIONS

- The wood pieces subjected to machining tests showed satisfactory results, with most of them being classified as ranging from "excellent" to "good," and less frequently as "fair”.
- Based on this study, young raw material is viable for copious purposes that require high surface quality when subjected to machining, provided that proper precautions are taken during the process.

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