J Indian Acad Wood Sci (December 2023) 20(2):191–196
https://doi.org/10.1007/s13196-023-00318-x

ORIGINAL ARTICLE

Selection of eucalyptus hybrid clones planted in Brazil for growth and wood quality

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Received: 25 January 2023 / Accepted: 16 August 2023 / Published online: 13 September 2023

Abstract This study was conducted to assess clones of hybrids eucalyptus to quantify the genetic gain from growth and wood quality selection traits. The analysis assessed 29 clones of hybrids eucalyptus previously selected from a clonal test, and differing in growth. Wood quality was assessed by longitudinal residual stress (LRS), volume without bark (*V*wb), weighted basic density (ρ_{weigh}), log end splitting index (LSI), variance components estimation and genetic gains from the selection. The eucalyptus clones differed for wood quality. Selection for trait combination resulted in reduced genetic gain for LRS, with 11.7%, and LSI, with 36.5%, and increased genetic gain for *V*wb, with 2.2%, and for ρ_{weigh}, with 9.8%. Superior eucalyptus clones can be identified to contribute to genetic improvement programs for quality wood production.

Keywords Genetic improvement · Trait combination · Wood properties

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Introduction

Eucalyptus is important plant which has been planted worldwide. It consists of more than 700 species, and it is in the family of *Myrtaceae* (Pujiarti and Kasmudjo 2016). Eucalyptus improvement programs are viable for increasing wood production and quality, since this genus occupies approximately 5.7 million hectares of total tree planted area in Brazil (IBÁ—Indústria Brasileira de Árvores 2019). *Eucalyptus* species and their hybrids are widely planted in tropical, subtropical and temperate regions, due to their rapid growth, environmental adaptability and suitability for the production of cellulose and paper (Gomes et al. 2015). Castro et al. (2016) talk about the history of eucalyptus improvement in Brazil, highlighting that the selection of more productive genotypes has become a goal for this culture, reducing the planting area and the use of inputs. However, there are still limitations regarding its application, especially in civil construction and for sawmill wood, which requires defect-free wood. However, eucalyptus uses as a timber remain limited because of the appearance of cracks and/or splits due to the release of growth stresses during cutting, sawing and drying. In addition, eucalyptus exhibits high shrinkage and collapses (Amer et al. 2019).

The knowledge and the search for variability among forest species available for wood production, among the different forest segments (cellulose and paper, sawn wood, energy), and the relationship between their technological and dendrometric traits, are extremely relevant to improve and develop selection strategies that result in productivity gains. Genetic improvement programs are carried out for commercial eucalyptus (*Eucalyptus* spp.) forests in regions of intensive silviculture for these species. Experiments at the intersection of silviculture and genetics are exceptionally important, as they can represent an ideal experimental situation to examine, for example, how genetic gains interact with initial plant density (Isaac-Renton et al. 2020).

With this, genetic improvement is the most promising solution for the optimization of wood quality and the reduction of chronic defects. Knowing the conditions that cause defects arising from the rapid growth of this genus makes it possible to find solutions to minimize them, which, consequently, leads to more appropriate levels of income and employability. Splitting and warping are the main defects caused by the growth stress in eucalyptus trees (De Lima and Stape 2017). They result in low yield in the production of sawn wood, as they force the reduction of the dimensions of the pieces, mainly longitudinally. This growth stress is related to genetic traits and, therefore, improvement can provide a definitive solution to minimize its effects, even in unfavorable environmental conditions. Thus, one way to obtain an appropriate selection is through the characterization and identification of species, origins, progenies and clones, or individuals with silvicultural and technological traits that are suitable for a given purpose.

Research on genetic improvement aimed at reducing growth stress in eucalyptus clones and the selection of clones with lower levels of growth stress are scarce and should be developed to provide a lower rate of splitting at the ends, bending and arching (Carvalho et al. 2010). Considering these aspects, the goals of this study were to assess genetic variability among clones of eucalyptus hybrids through genetic gains from the selection for growth and wood quality.

Materials and methods

Study area and *Eucalyptus spp.* material

Test planting was carried out with 138 clones of interspecific and intraspecific hybrids of *Eucalyptus* spp. belonging to the company CMPC Celulose Riograndense, with 3.0 × 3.0 m spacing, in August 2003, in the city of Tapes-RS (Latitude: − 30.6742, Longitude: − 51.3966 30° 40′ 27″ South, 51° 23′ 48″ West). The experimental design was composed of randomized blocks, with ten repetitions of lines with six trees, totaling 8.280 trees. Initially, these clones were selected for growth, considering the diameter at breast height (DBH) and the total height (Th) of the trees. Based on these data, the 138 clones were classified into groups, with the aid of the k-means method, according to the study by Beltrame et al. (2012). Thus, 29 clones were selected to be used in this work.

Definition of the variables

To combine growth with wood quality, the clones were evaluated only though superior dendrometric characteristics. Eight trees for each clone of 8 years old were evaluated for measure longitudinal residual stress (LRS), volume without bark, weighted basic density, and log end splitting index (LSI), that are great technological importance for qualitative wood characterization.

The longitudinal residual stress (LRS) was determined in standing and living trees. Initially, the bark of the trees was removed at breast height in order to open a window in the trunk, where two pins spaced 45 mm apart were inserted in the direction of the grain for fixing the extensometer, which was equipped with a digital clock. Then, with a hand drill, a 20-mm diameter hole was drilled in the median position between the pins. The rupture of the wood tissues resulting from this perforation causes the release of deformations inside the tree, which is an indirect measure of growth stress, registered by the device's clock.

To obtain the volume without bark (*V*wb), the trees were felled and scaled using the Smalian method, in which the volume of each section was calculated according to the length and basal areas obtained at the ends of the sections, following FINGER (2006).

To determine basic density (ρb), disks were removed at positions 0.10 m (base), 1.30 m (DBH), at 25, 50, 75 and 100% of commercial height, with a 10-cm diameter limit. First, the disks were labeled and stored in plastic bags to prevent moisture loss until they were transported to the Forest Products Laboratory of the Federal University of Santa Maria. The disks were cut into two symmetrically opposite wedges and submerged in a tank with water until they reached constant weight. The volume was measured by immersion method in water on a hydrostatic balance, described by VITAL (1984), and dry weight was obtained after drying in an oven at 103 °C. From the saturated volume and oven dry mass, basic density was determined using Eq. 1.

$$\rho_b = \frac{M_S}{V_U} \quad (1)$$

where ρ_b = Basic density (g/cm^3); M_S = Mass dried in oven at 103 °C (g); V_U = Saturated volume (cm^3).

After obtaining basic density in each trunk position, the weighted basic density (ρ_{b_weigh}) was determined in function of the volume of each tree section, according VITAL (1984), in Eq. 2.

$$\rho_{b\_pond} = \frac{\left[\left(\frac{\rho_{b\_0\%}+\rho_{b\_dap}}{2}\right) * V_1 + \left(\frac{\rho_{b\_dap}+\rho_{b\_25\%}}{2}\right) * V_2 + \cdots + \left(\frac{\rho_{b\_i}+\rho_{b\_i+1}}{2}\right) * V_j\right]}{V_{10^{s/c}}} \quad (2)$$

where ρ_{b_weigh}. = weighted basic density mass in function of tree volume, in g/cm^3; $\rho_{b"I"}$ = basic density at position "*i*," in g/cm^3; v_1, v_2, …, v_j = volume without bark corresponding to two successive positions, in m^3; V_{10} *w/b* = commercial tree volume without bark, in m^3.

Two trees from each clone were felled for the assessment of log top splitting indices (LSI). They were sectioned and labeled in four logs according to the DBH positions (1.30 m), at 25, 50, 75 and 100% of the commercial height, with a 10-cm trunk diameter limit for that height. After that, the ends of the logs were protected with plastic bags, in order to minimize dehydration and, consequently, the effects of open-air drying for splitting.

The logs protected by plastic bags remained in the same place for a period of 5 days (120 h), without being moved at all, according to the methodology proposed by (Purnell and Lundquist 1986). At the end of this period, the plastic bags were removed from the ends and the end-splitting present in the logs was measured. With the aid of a digital caliper, the measurement evaluated the length of the splits in the cross section (pith-bark), and the maximum opening at the thick and thin ends of the logs. The methodology described by LIMA (2000) was used to calculate the end-splitting indices, which consists of the direct measurement of each log end split, without attributing weights (Eq. 3).

$$\mathrm{LSI} = 200 * \left(\frac{\sum_{i=1}^{n} a_i c_i}{\pi D^2}\right) \quad (3)$$

where LSI = log end splitting index, in %; a_i = maximum opening of the *i*-th split (*i* = 1, 2, …, *n*), in cm; C_i = length of the *i*-th split (pith-bark), in cm; *D* = average cutting section diameter, in cm.

Statistical analyses and selection gains (SG)

The data were submitted to analysis of variance following a completely randomized design. The treatment averages were compared using the Scott-Knott test at 5% error probability, with the eucalyptus clones ranked for each of the studied traits. The best clones were the ones with the highest values for *V*wb and ρ_{b_weigh} (Value 1), and the lowest values for LRS and LSI, and the clones with the best combination of superior traits were identified based on the rank-sum method proposed by Mulamba and Mock (1978). Thus, the selection of clones was based on the best combination of superior traits and, therefore, equivalent to indirect selection. Based on this sum, 10 eucalyptus clones were selected for later prediction of gains from the selection (Eq. 4):

$$\mathrm{SG} = \left(\frac{\mathrm{TCA}}{\mathrm{OCA}}\right) * 100 \quad (4)$$

where SG = selection gains (%), TCA = ten clone average, OCA = original average for the 29 clones.

Results and discussion

The analysis of variance showed that the clones differ ($p \leq 0.05$) for all traits evaluated (Table 1). The variability between clones makes it possible to use the selection to identify clones that combine growth with wood quality, that is, identifying the clones with the best combination of growth and wood quality traits, and quantifying the genetic gain.

The sum of ranks was used to identify the clones with the best combination of traits. For the sum, group "a" was considered as 1, "b" as 2, "c" as 3, and so on. Thus, the lower the sum of ranks, the more favorable is the combination of growth and quality traits. The weighted basic density variable was the one that most contributed to the sum of ranks, since the best group was composed of only two clones, the second best by three clones, the third best by four clones, and the fourth best by five clones. A great number of clones was ranked in the two best groups of the other traits assessed, with 28 clones for volume without bark, 22 for longitudinal residual stress, and 25 clones for the log end splitting index.

The differences between clones were compared using the Scott-Knott test, at a level of 5% probability of error.

Table 1 Summary of the analysis of variance for volume without bark (*V*wb), longitudinal residual stress (LRS), weighted basic density (ρ_{weigh}), and log end splitting index (LSI) of eucalyptus hybrid clones

FV	DF	*V*wb (m^3)	LRS (mm)	ρ_{weigh} (g/cm^3)	LSI (%)
Clones	28	0.0680*	0.0056*	0.0045*	0.1840*
Error	29	0.0176	0.0013	0.0001	0.0137
eCV		18.38	23.80	2.73	25.49

where *DF* degree of freedom; *eCV* experimental coefficient of variation; *Significant by the F test at 1% probability; **significant by the *F* test at 5% probability; *NS* not significant

The eucalyptus clones were separated into three groups for volume without bark, four groups for longitudinal residual stress, seven groups for weighted basic density, and four groups for log end splitting index (Table 2).

This fact made it difficult to identify clones with a balanced combination of traits, and none of the studied clones had a sum of ranks equal to 4, that is, none was ranked in the best group of each of the traits studied. The best rank sums (6) include a clone (clone 34) with the seventh value of weighted basic density, and another clone (clone 23) with the 26th value of volume without bark and 16th value of residual longitudinal stress. Therefore, the sum of ranks showed that the clones assessed here did not present a balanced combination for the studied traits, which would be very important for eucalyptus clones to serve the different sectors of the timber industry.

The sum of ranks up to eight did not change the combination of favorable traits considering the groups of clones, as it includes two clones of the group of the weighted basic density. In this scenario, ten clones of eucalyptus hybrids with the best combination of growth and wood quality traits were selected. These clones presented the combination of the lowest values for longitudinal residual stress and log end splitting index, and the highest values of volume without bark and weighted basic density, which are considered the most relevant traits for wood quality, both for sawmills and for cellulose. In this case, it is necessary to select clones based on several traits,

Table 2 Average values for volume without bark (*V*wb), residual longitudinal stress (LRS), weighted basic density (ρ_{weigh}), log end splitting index (LSI), and sum of the ranks for 29 clones of eucalyptus hybrids

Clones	*V*wb (m^3)	LRS (mm)	P_{weigh} (g/cm^3)	LSI (%)	Sum of ranks
34	0.789 a*	0.120 a	0.463 c	0.243 a	6**
23	0.550 b	0.140 b	0.522 a	0.380 a	6
1	0.599 b	0.198 c	0.535 a	0.220 a	7
22	0.918 a	0.145 b	0.494 b	0.604 b	7
24	0.634 b	0.137 b	0.494 b	0.521 a	7
8	0.743 b	0.103a	0.471 c	0.143 a	7
31	0.945 a	0.103 a	0.437 d	0.228 a	7
64	0.615 b	0.149 b	0.449 c	0.249 a	8
54	0.963 a	0.110 a	0.405 e	0.176 a	8
68	0.622 b	0.095 a	0.425 d	0.154 a	8
7	0.419 b	0.180 c	0.496 b	0.606 b	9
25	0.712 b	0.164 c	0.463 c	0.485 a	9
33	0.684 b	0.144 b	0.439 d	0.224 a	9
3	0.927 a	0.127 a	0.406 e	0.637 b	9
13	0.665 b	0.123 a	0.414 e	0.293 a	9
35	0.824 a	0.119 a	0.385 f	0.298 a	9
16	0.319 c	0.100 a	0.431 d	0.166 a	9
26	1.111 a	0.121 a	0.368 g	0.306 a	10
12	0.953 a	0.113 a	0.363 g	0.243 a	10
53	0.723 b	0.113 a	0.396 f	0.340 a	10
72	0.571 b	0.094 a	0.395 f	0.395 a	10
73	0.974 a	0.231 c	0.426 d	0.937 c	11
21	0.668 b	0.147 b	0.398 f	0.402 a	11
14	0.454 b	0.147 b	0.410 e	0.793 b	11
9	0.597 b	0.127 a	0.377 g	0.279 a	11
11	0.861 a	0.202 c	0.361 g	0.725 b	13
29	0.746 b	0.161 b	0.398 f	0.923 c	13
10	0.633 b	0.221 c	0.415 e	1.151 d	14
27	0.710 b	0.316 d	0.380 g	1.230 d	17
Média	0.722	0.147	0.428	0.460	–

*Averages not followed by the same letter in the column differ by the Scott-Knott test at 5% probability

**For the sum of ranks, value 1 was assigned to the letter a, 2 to the letter b and so on to obtain the total sum of ranks

Table 3 Original clone average (OCA), selected clone average (SCA), genetic (SG) and percentage (SG%) indirect selection gain for volume without bark (*V*wb), longitudinal residual stress (LRS), weighted basic density (ρ_{weigh}), and log end splitting index (LSI) in clones of eucalyptus hybrids

Variables	*V*wb (m^3)	LRS (mm)	ρ_{weigh} (g/cm^3)	LSI (%)
OCA	0.722	0.147	0.428	0.460
SCA	0.738	0.130	0.470	0.292
SG	0.016	− 0.017	0.042	– 0.168
SG%	2.2	− 11.7*	9.8	– 36.5*

*Negative values represent favorable genetic gains for the variables longitudinal residual stress (LRS) and log end splitting index (LSI), because the lower these values, the better the quality of the wood

in order to better infer about their relative superiority, especially with regard to density (Weng et al. 2014).

The selection of the ten clones with the lowest sum of ranks corresponded to a genetic selection gain that reduced residual longitudinal stress by 11.7% and the log end-splitting index by 36.5%, and increased by 2.2% the volume without bark and the weighted basic density by 9.8% (Table 3). The selection of the ten clones of eucalyptus hybrids with the best combination for growth and wood quality resulted in a lesser genetic selection gain than that obtained by Rosado et al. (2009) for the volume of *Eucalyptus urophylla* wood, which was approximately 30%. The selection of eucalyptus clones for longitudinal residual stress resulted in a genetic gain of 28.2% (Trugilho et al. 2007), and in three different eucalyptus clonal areas, genetic selection gains of 36.05, 41.52% and 38.19% were reached (De Pádua et al. 2004). The selection of two superior eucalyptus clones for weighted basic density resulted in a genetic gain of 6.98% (Botrel et al. 2007).

One way to maximize the selection gain is to use the selection indices, as they allow the selection to occur simultaneously for several traits of interest, with the possibility of assigning different weights to each trait of interest (Spinelli et al. 2010). Clones 34 and 23 had the most balanced combination of the traits under assessment, which resulted in the lowest sum of ranks (6). For this reason, they can be considered clones with the potential to yield solid wood products. The result indicates that simultaneous selection of traits can result in genetic gains, favoring the production chain linked to wood inputs.

Considering this, selections that aim to elect clones with lower values of residual longitudinal stress and log end splitting index can ensure the future supply of quality wood for the timber sector. These two characters are directly correlated and prove to be limiting in the use of logs for sawn wood. However, according to Li and Dong (2017), there are limitations in genetic selection, so it is necessary to find a point of balance, depending on the end use of the material.

For logs for paper and cellulose production, for example, volume without bark and the weighted basic density are more relevant, because weighted basic density presents a good index in the yield of industrial processes and the assessment of wood quality (Setúbal et al. 2004). In this case, clones 8, 34, 1, 24, 22 and 23 are considered suitable for the production of cellulose, as they present adequate values of these traits for use in cellulose and paper production. With this, the present study is relevant to clones selection with wood quality for pulp and paper industry, especially in Brazil, since the country occupies the second place in the ranking for cellulose pulp production (Rossato et al. 2018). According to these authors, the pulp sector is directly influenced by the variables studied herein, especially the production and quality of wood.

The results of this study confirm that it is possible to select eucalyptus clones for the production of better-quality wood, thus reducing the main defects caused by stress (Rodrigues et al. 2008). According to Hamilton et al. (2010), growth stress hinders some uses of sawn wood, such as use in civil construction (manufacture of floors, walls, wooden beams, pillars, etc.). Therefore, the genetic gains obtained in this study indicate that the previous selection for growth and wood quality traits, in this case at the age of eight, is an important selection strategy for the identification of superior clones in eucalyptus improvement programs, and to obtain better quality wood for the timber sector. Thus, the selected clones must follow an assessment and selection process to identify the ones that most effectively serve the timber industry. Thus, genetic selection becomes an important tool to alleviate these problems.

Conclusion

Clones of eucalyptus hybrids vary for the traits of longitudinal residual stress (LRS), volume without bark, weighted basic density, and log end splitting index (LSI), which allows the selection of clones with more potential for growth and that produce better quality wood, with a satisfactory genetic selection gain. Selection for trait combination resulted in reduced genetic gain for LRS, with 11.7%, and LSI, with 36.5%, and increased genetic gain for *V*wb, with 2.2%, and for ρweigh, with 9.8%. Considering density as the most common parameter in the timber industry, clones with higher density do not necessarily have higher LRS, as expected, and it is always necessary to use this tool for selection. The assessment of these traits in eucalyptus improvement programs allows the selection of clones to serve the timber industry, both for sawmills and for paper and cellulose production.

Acknowledgements To the National Council for Scientific and Technological Development (CNPq) for granting scholarships, to the company CMPC—Celulose Riograndense, for loaning equipment and for the infrastructure provided during this work, and to the Engineering Center (UFPel) for enabling the translation of this article.

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