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# COLORED AREA, GROWTH-RING WIDTH, AND LATEWOOD PERCENTAGE IN HYBRID PINE $F_1$ INTA-PINDO

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**Resumo**

*Área colorida, largura dos anéis de crescimento e porcentagem de lenho tardio no pinho híbrido $F_1$ INTA-PINDO*. As características dos anéis anuais são indicadores do crescimento e qualidade da madeira. Aos 11 anos de idade, foram tomadas uma amostra de 90 arvores de pinho híbrido $F_1$ de *Pinus elliottii x Pinus caribaea var. hondurensis* de 2 localidades, compostas por 15 famílias e 3 posições no ranking de crescimento genético. As rodelas foram tomadas a 0,10 m; 1,30 m e 4,45 m de altura do fuste, avaliou-se a porcentagem da área colorida na região central da tora, largura e área dos anéis de crescimento e proporção de lenho tardio. Os dados foram analisados com modelos lineares mistos. Foram encontradas diferenças estatisticamente significativas entre as famílias para as variáveis analisadas, com exceção do percentual de lenho tardio. A família 02 apresentou maior crescimento e área livre de coloração. As famílias 01 e 03 apresentaram maior porcentagem de área colorida. A porcentagem de área colorida aumentou com a altura da árvore. A largura do anel de crescimento diminuiu com a altura da árvore e foi maior para as famílias 01, 02, 03, 04, 05 e 07. A porcentagem de lenho tardio aumentou da medula para a casca e da base da árvore para a copa. Conclui-se que as famílias da posição superior do ranking genético de crescimento apresentaram maior valor médio de largura e área de anéis de crescimento e a mesma proporção de lenho tardio em relação às famílias de menor crescimento, sendo essas características desejadas para obtenção madeira de qualidade para usos estruturais.
*Palavras-chave:* Qualidade da madeira, duraminização da madeira, características do lenho, ranking genético de crescimento

**Abstract**

The characteristics of the annual growth rings are indicators of the growth and quality of the wood. At 11 years of age, 90 $F_1$ hybrid pine trees of *Pinus elliottii* x *Pinus caribaea* var. *hondurensis* were sampled from two sites. The sample consisted of 15 families and 3 positions in the genetic growth ranking. Disks were taken at 0.10 m, 1.30 m, and 4.45 m, colored area (%) in the central zone of the log, ring width, growth-ring area, and proportion of latewood were evaluated. The data were analyzed with mixed linear models. Statistically significant differences were found between families for the studied variables, except for latewood percentage. Family 02 showed higher growth and a low proportion of pink core. Families 01 and 03 had a higher percentage of colored area. The percentage of colored area increased with tree height. The ring width decreased with tree height and was higher for families 01, 02, 03, 04, 05, and 07. The latewood percentage increased from the pith to the bark and from the tree base to the crown. To conclude, top-growth families exhibited higher mean ring width and ring area than lower-growth families but the same proportion of latewood. These are desirable characteristics for obtaining wood quality for structural uses.
*Keywords:* Wood quality, heartwood, wood characteristics, genetic ranking growth.

## INTRODUCTION

In Argentina, the species most widely used in forest plantations are *Pinus taeda* L., *Pinus elliottii* var. *elliottii* Engelm (PEE), and, to a lesser extent, the hybrid *Pinus elliottii* var. *elliottii* × *Pinus caribaea* var. *hondurensis* and *Pinus caribaea* var. *hondurensis* (Senecl) Barrett and Golfari (PCH). The first plantations of hybrid pine material have shown high growth potential and stem straightness (CAPPA *et al*., 2013). For this reason, in 2004, INTA and the company PINDO S.A. started a program for the production of $F_1$ hybrids, aimed at obtaining seed material from the controlled pollination of pure species between PEE and PCH (hereinafter, $F_1$ INTA-PINDO). The creation of this new $F_1$ hybrid involves conducting studies on the growth and quality of its wood for different uses. The wood of the *Pinus* genus is currently used in the pulp and paper industry, as well as in fine carpentry, furniture in general, door and window frames, and structural uses. Physical-mechanical properties such as high density, latewood proportion, and heartwood percentage are highly valued in wood for structural uses. Such properties are attractive for this type of use since they are indicators of the rigidity and resistance of the wood (BURDON and MOORE, 2018), and heartwood provides greater natural durability because it contains extractives (WIEDENHOEFT *et al*., 2005).

In addition, in coniferous wood, growth-ring width, latewood/earlywood proportions, and heartwood quantity and constitution influence the permeability of the wood (ZIMMER *et al.*, 2014). Extractives impregnate the cell wall and give heartwood its colored appearance, reducing the swelling and contraction phenomena, as well as the penetration of liquids (BARAÚNA *et al.*, 2014). The permeability of wood to liquids influences the treatment with preservatives, drying, chemical pulping, gluing, finishing, and durability (ZIMMER *et al*., 2014; AHMED *et al*., 2012). The best-known extractives in the *Pinus* genus are called "resins". Resins are natural compounds whose function is to repair wounds and act as a biochemical defense against pests. Resin content decreases from the pith to the bark and is observed in the wood as a semisolid exudate that contains terpene compounds, such as the pinene group, which gives it a distinctive odor (BAILLERES *et al*., 2019). Extractives affect the density of the wood and, in turn, they are used for calculating wood rigidity, when the modulus of elasticity is estimated from data collected with ultrasound techniques (BAILLERES *et al*., 2019). On the other hand, the pink coloration, which occurs in the central area of the log, is a characteristic that often negatively affects wood for appearance uses (BURDON and MOREE, 2018).

Another characteristic of interest in the quality of wood for solid products is the variation in the growth rings from the pith to the bark. The radial uniformity of the ring width exerts a great influence on the technological properties. Ring width may vary according to the duration of the vegetative period, temperature, humidity, luminosity, and silvicultural management (PANSHIN and DE ZEEUW, 1980). Annual growth rings are composed of earlywood and latewood. The proportion of each type of wood within the growth ring and the number of rings per inch are important characteristics in determining the quality of wood for structural purposes (HASELEIN *et al*., 2000). In conifers, latewood density is three times greater than earlywood density (DEUCOX *et al*., 2004). Similarly, the Southern Pine Inspection Bureau standard for visual classification of wood for structural uses (SPIB, 1994) considers that resinous pine wood is dense when it has at least six growth rings per inch and at least one-third (1/3) latewood or four growth rings per inch and at least 50% latewood (HASELEIN *et al*., 2000). According to Zhang *et al*. (2021) and González *et al*. (2018), the greater the ring width, the lower the density and resistance of the wood (PANSHIN and DE ZEEUW, 1980). However, other authors found a positive (DIACONU *et al*., 2016; MARTIARENA *et al*., 2014) or null (KIMBERLEY *et al*., 2015) correlation.

The first studies on the characteristics associated with the wood quality of the hybrid $F_1$ INTA-PINDO have recently begun. They include the anatomical, physical, and mechanical properties of the wood. This study evaluates such wood characteristics as the colored area (%), growth-ring width and area, and latewood percentage in a sample of 90 hybrid pine $F_1$ INTA-PINDO trees belonging to 15 families selected from two trials.

## MATERIALS AND METHODS

### Description of trials

The genetic material used in this study was obtained from two trials of *Pinus elliottii* var. *elliottii* × *Pinus caribaea* var. *hondurensis* (hybrid pine $F_1$ INTA-PINDO). The first trial, containing 37 families, was located at 26° 33' S latitude and 54° 40' W longitude (site 1), while the second trial, containing 66 families, was located at 26° 09' S latitude and 54° 26' W longitude (site 2). Before trial establishment, site 1 had been a native forest, and site 2 a third-rotation pine plantation. The plantation design was complete blocks, with treatments distributed randomly in linear plots composed of five full siblings. The climate in the study region is characterized by a mean annual rainfall of 1864.5 mm, with mean temperatures of 26.4 ºC in the warmest month (January) and 14.9 ºC in the coldest month (July), and maximum extreme values of 40.6 ºC and a minimum of -6 ºC (SILVA *et al*., 2019).

### Tree selection

The trees were selected in two stages. First, the genetic growth ranking in the seventh year was used to select 15 families, five from the top ranking position (R1), five from the middle ranking position (R2), and five from the bottom ranking position (R3) (Table 1). Secondly, the diameter at breast height (DBH) and total height were measured in all trees in both trials at 11 years of age. Finally, based on the study by Pérez López (2005), 90 trees were sampled, three trees for each of the 15 families in each site (three specimens x 15 families x 2 sites = 90 trees), covering the entire DBH variability (minimum, mean, and maximum).

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Table 1 - Genetic growth ranking in the seventh year for the 15 families selected from both sites
Tabela 1 - Ranking genético de crescimento no sétimo ano de idade das 15 famílias selecionadas em ambos os locais

| Code | Families | DBH (cm) | H (m) | Ranking Position | Growth |
|---|---|---|---|---|---|
| 01 | F19 | 30.91 | 25.00 | | |
| 02 | F51 | 30.45 | 22.64 | | |
| 03 | F20 | 30.97 | 23.19 | R1 | top |
| 04 | F28 | 31.51 | 24.28 | | |
| 05 | F29 | 31.11 | 23.83 | | |
| 06 | F49 | 29.10 | 21.65 | | |
| 07 | F4 | 31.06 | 24.33 | | |
| 08 | F5 | 26.01 | 22.51 | R2 | middle |
| 09 | F13 | 27.08 | 20.23 | | |
| 10 | F33 | 24.19 | 20.08 | | |
| 11 | F11 | 25.15 | 21.00 | | |
| 12 | F23 | 24.64 | 21.02 | | |
| 13 | F59 | 27.30 | 22.70 | R3 | bottom |
| 14 | F6 | 23.87 | 19.53 | | |
| 15 | F35 | 23.45 | 20.10 | | |

DBH = mean diameter at breast height for families and H = mean total height for families at 11 years of age.

**Sampling**

Three disks were taken from each felled tree, at 0.10 m, 1.30 m, and 4.45 m of stem height (three disks x 90 trees = 270 disks). Each disk was coded with the tree number and the stem height from which it was obtained. The samples were oven-dried at 70 °C for 72 hours to prevent the development of fungi. Then, the central part of one of the faces was sanded to facilitate the identification of growth rings and false rings. The colored area was delimited visually on each disk through the color difference. The diameter with and without bark and the diameter of the central colored area of each disk were measured with a ruler on two orthogonal axes. In both cases, the two diameter measurements were mean (JOHANSSON and HJELM, 2013). The mean diameter of the colored zone made it possible to determine the colored area of the central zone of each disk (Figure 1). The colored area (%) was obtained by the percentage relationship between the area of the colored region and the total disk area, that is, the relation between the area of the colored zone and the total area multiplied by 100.

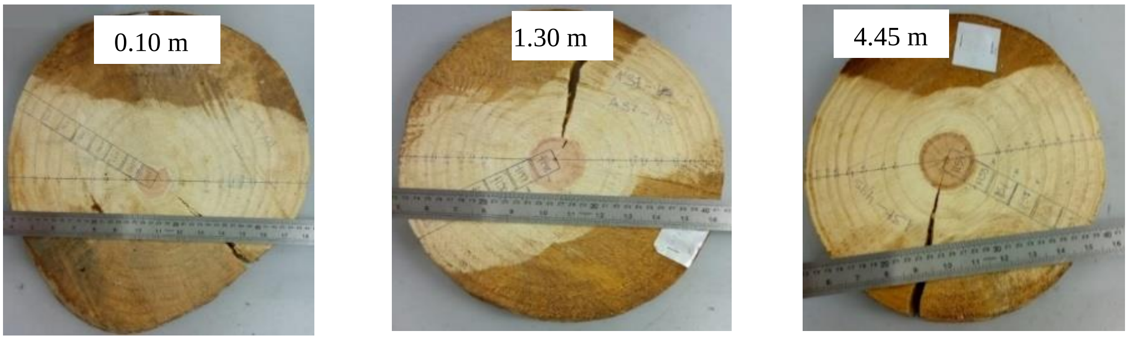



Figure 1 - Samples obtained at stem heights of 0.10 m, 1.30 m, and 4.45 m.
Figura 1 - Amostras obtidas nas alturas de fuste de 0,10 m, 1,30 m e 4,45 m.

Earlywood, latewood, and growth rings were visually delimited at each age by the color difference. To estimate the area of the earlywood and latewood of each growth ring for the 270 disks, the diameters were previously measured with a metal ruler at the beginning and end of earlywood and the end of each growth ring from years 1 to 11. The diameter of the latewood was calculated as the difference between the total diameter of the ring and the diameter of the earlywood. The measurement of the most peripheral rings of the suppressed trees required the use of a 10X magnifying glass. Then, for each age, the areas of the complete ring and the earlywood were calculated. The values of latewood areas for each age were obtained from the difference between the complete ring data and the earlywood area. In addition, the total area of each ring was determined from the difference between the values of two successive rings and the accumulated area of the disk at each age. Finally, the proportion of latewood was calculated related to the total area of the cross-section without bark at different heights.

**Data Analysis**

For the different statistical analyses, the Infostat® software (DI RIENZO *et al*., 2020) was used, with a confidence level of 95%. The data were analyzed with mixed linear models (MLM) (DI RIENZO *et al*., 2017). The mixed linear model used can be expressed according to equation 1. The models were selected according to the lowest values of the Akaike (AIC) and Bayesian Schwarz (BIC) parameters.

$$Y_i = X_i ß_i + Z_i b_i + e_i \ (1)$$

where $Y_i$ is the vector of responses (data); $X_i$ and $Z_i$ are known design matrices; $\beta$ is a vector of fixed effects and $b_i$ is a vector of random effects; finally, $e_i$ (error) is an unobservable random vector.

For the analysis of the response variables related to coloration, block, and tree were considered random effects whereas sites, families, stem height, and families × stem height were considered fixed effects. For width, area, and latewood percentage of rings, the fixed effect age was also incorporated. Non-significant variables were excluded from the analysis. For those variables that resulted in significant statistical differences, Fischer's LSD test was used for the comparison of pairs of means.

Multivariate analyses were also performed. The variables colored area (%) and growth-ring width were used to group families with a similar colored area (%) and similar growth, through the "*clusters*" technique. The hierarchical clustering method was used (taking into account the weighted means) and the Euclidean Distance was employed as a measure of similarity.

## RESULTS

**Summary measures of the studied variables**

Table 2 shows the descriptive statistics of the data set analyzed: diameter at breast height, total tree height, mean coloration, growth rings, and latewood percentage (the stem heights considered being 0.10 m, 1.30 m, and 4.45 m). The range for the DBH data was 23.08 cm and for height 12.50 m, with a lower coefficient of variation for height (11.75%).

The mean DBH without bark of the 90 specimens evaluated was 24.34 cm, varying between 14.47 and 37.33 cm. The minimum, mean, and maximum diameters of the colored central zone reached values of 0.00 cm, 3.05 cm, and 7.65 cm, respectively. The colored area (%) reached a mean value of 2.05%. However, some disks did not exhibit a colored region, resulting in a wide variation in the data for this characteristic. The mean ring width was 1.16 cm, ranging from 0.70 cm to 1.75 cm. The percentage of minimum, mean, and maximum latewood registered was 5.22%, 8.94%, and 16.85%, respectively. It did not reach one-third (1/3) of latewood to be considered suitable for structural uses (HASELEIN *et al*., 2000).

Table 2 - Descriptive statistics for the studied variables corresponding to 90 $F_1$ INTA-PINDO hybrid pine trees.
Tabela 2 - Estatísticas descritivas das variáveis estudadas correspondentes a 90 árvores de pinho híbrido $F_1$ INTA-PINDO.

| Variable | Mean | Min. | Max. | C.V. |
|---|---|---|---|---|
| Diameter at breast height (cm) | 27.46 | 17.03 | 40.11 | 20.60 |
| Total height (m) | 22.26 | 16.50 | 29.00 | 11.75 |
| Diameter at breast height without bark (cm) | 24.34 | 14.47 | 37.33 | 22.91 |
| Diameter of the central colored area (cm) | 3.05 | 0.00 | 7.65 | 61.36 |
| Colored area (%) (%) | 2.05 | 0.00 | 8.56 | 83.05 |
| Ring width (cm) | 1.16 | 0.70 | 1.75 | 21.07 |
| Increase in ring area ($cm^2$) | 46.95 | 16.25 | 102.85 | 43.48 |
| Percentage of latewood area | 8.94 | 5.22 | 16.85 | 21.21 |

Min.= minimum. Max.= maximum. C.V.= coefficient of variation.

**Color analysis**

Significant differences were detected between families (p-value≤0.05) for the mean colored area of the central zone of the log. No family exceeded the 5% mean of colored area (Figure 2a), with families 01 and 03 displaying the highest means of 3.96% and 4.82%, respectively. Both families have the same female parent, but different fathers. Regarding the longitudinal variation in the colored area (%), coloration increased with the position of the disk on the stem. Statistically significant differences (p-value≤0.05) were observed between the

0.10 m height and the other heights, 1.30 m and 4.45 m (Figure 2b). In contrast, the sites had no significant effect (p-value>0.05) on this variable (Figure 2c). There was no interaction between families and stem height (p-value>0.05), indicating that regardless of the family analyzed, the percentage of the mean colored area increased with tree height. A mean of 1.28%, 2.35%, and 2.42% colored area was observed at 0.10 m, 1.30 m, and 4.45 heights, respectively.

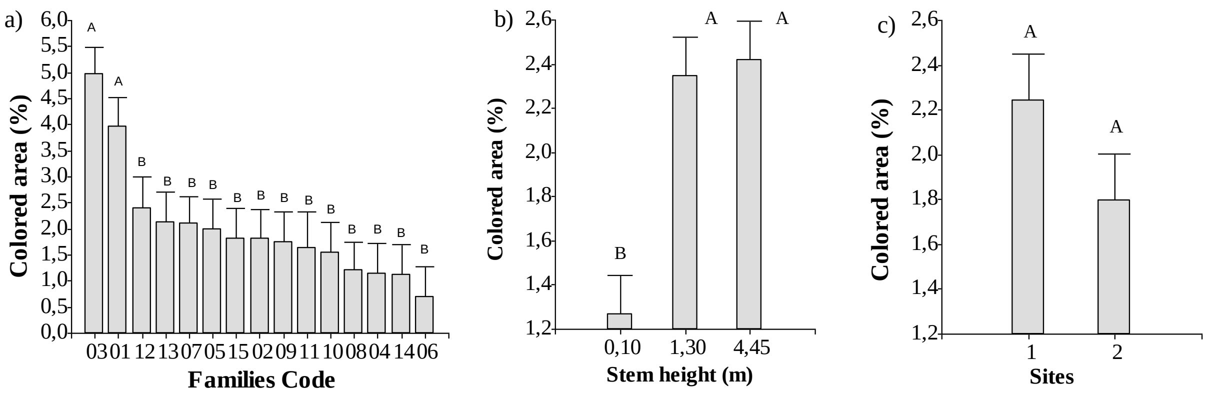
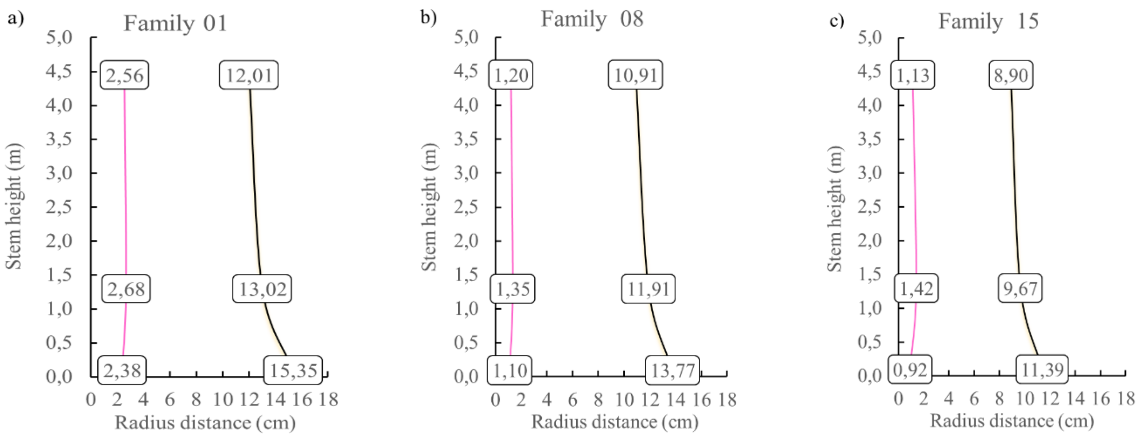



Figure 2 - Colored area (%) a) by families. b) by stem height and c) by sites.
Figura 2 - Porcentagem da área colorida discriminada a) por famílias, b) por altura do fuste e c) por sítios.

Figure 3 shows the mean growth and colored central zone for three of the 15 families evaluated, one from each position of the genetic growth ranking (R1, R2, and R3). The family exhibiting the greatest growth (01, R1) had greater coloration (> radius), with mean values of colored radius of 2.38 cm, 2.68 cm, and 2.56 cm at heights 0.10 m, 1.30 m, and 4.45 m, respectively (Figure 3a). In contrast, the family showing the lowest growth (15, R3), in general, showed the lowest mean values of colored radius (between 0.92 cm and 1.42 cm) (Figure 3c). Finally, the family exhibiting intermediate growth (08, R2) showed intermediate coloration values for the different stem heights studied (Figure 3b). The variation in the pink coloration close to the pith was not uniform with height and did not follow a cylindrical pattern within the 4.45 m of the evaluated stem (Figure 3a. 3b and 3c).




Note: Pink line indicates the colored radius. Black line: total radius of the disk.

Figure 3 - Radial growth and coloration profiles for the 0.10 m. 1.30 m, and 4.45 m of stem heights for the three evaluated families. a) Family 01. b) Family 08. c) Family 15.
Figura 3 - Perfis de coloração e crescimento radial para alturas do fuste 0,10 m, 1,30 m e 4,45 m para 3 famílias avaliadas. a) Família 01, b) Família 08, c) Família 15.

**Growth- annual ring width**

The mean ring width showed statistically significant differences between families (p-value≤0.05) but not for the site (p-value>0.05). Family 02 displayed the greatest mean ring width (1.35 cm), followed by families 01, 03, 04, 05, and 07, with values between 1.27 and 1.29 cm, grouping all the families belonging to position 1 in the genetic growth ranking (R1) and a family in R2. The materials with the smallest ring width were families 14 and 15, with 0.95 cm (Figure 4a). Regarding stem height, statistically significant differences were found in the mean ring width between the different heights (value-p≤0.05), which was higher in the base disk (1.24 cm) and decreased at 1.30 m and 4.45 m of stem heights (Figure 4b).

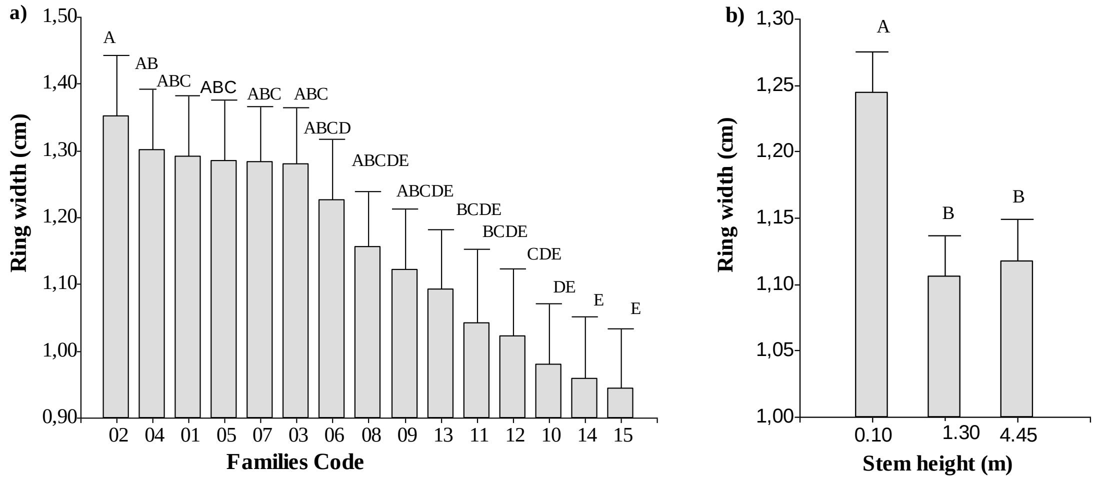



Figure 4 - Mean ring width a) by families and b) by stem height.
Figura 4 - Largura média do anel a) por família e b) por altura do fuste.

**Growth annual rings area**

Statistically significant differences were found for the growth-ring area between families, stem heights, and for the interaction between these factors (p-value≤0.05). The family with the highest mean values in ring area was 02 (366 cm$^2$), followed by families 03, 04, 05, 06, and 07 (with values between 317 cm$^2$ and 340 cm$^2$), coinciding with the values for positions 1 and 2 in the genetic growth ranking. The lowest ring area values were recorded for families 14 (182 cm$^2$) and 15 (189 cm$^2$) belonging to position 3 in the genetic growth ranking (Figure 5a). For stem heights, the mean values of the growth-ring area were 345 cm$^2$, 258 cm$^2$, and 219 cm$^2$ for 0.10 m, 1.30 m, and 4.45 m heights, respectively (Figure 5b). Regarding the interaction between families and stem height, the highest mean value of the growth-ring area occurred at 0.10 m stem height for families 02, 03, 04, 05, 06, and 07 (418 cm$^2$), and the lowest values for families 10, 14, and 15 (149 cm$^2$) for 4.45 m height.

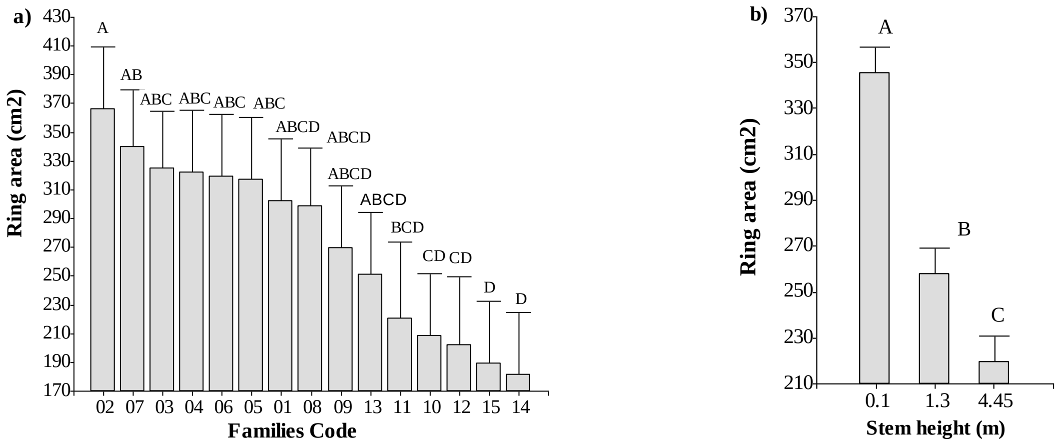



Figure 5 - Mean ring area a) by families and b) by stem height.
Figura 5 - Área média do anel a) por família e b) por altura do fuste.

No statistically significant differences were found between families in the percentage of latewood (p-value = 0.62) or the interaction between families and stem height (p-value = 0.18), but statistically significant differences were identified for stem height (p-value = 0.001), with higher mean values at 4.45 m height than at 0.10 m and 1.30 m, which were statistically equal to each other. The mean values recorded were 8.74%, 8.62%, and 9.49% for 0.10 m, 1.30 m, and 4.45 m of stem height, respectively. It was found that at 11 years of age, the hybrid pine $F_1$ INTA-PINDO is composed mostly of earlywood, which could have unfavorable effects on the mechanical property values of the wood from the basal logs, according to (HASELEIN *et al*., 2000).

**Analysis of wood by age**

The mean increase in growth-ring width for the analyzed stem heights was statistically higher in the first and second years, with a mean of 2.12 cm. From that age, growth was found to decrease linearly until the eighth and ninth years, thus yielding a mean value of 0.56 cm for the 8 and 9 years of age and 0.28 cm for 11 years of

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Revista Floresta

age. A greater variability in the growth-ring width was observed between families in the first year when values from 1.48 cm to 2.77 cm were recorded. Ring width decreased with age, reaching mean values between 0.15 cm and 0.62 cm at 11 years.

Figure 6a shows the increase in ring width with age for one family from each position of the genetic ranking (i.e., R1, R2, and R3), revealing that they maintained their behavior through the ages. In addition, Figure 6b shows that up to 2 years of age, all families developed similarly and then the increase in ring area decreased. The family located in the R3 ranking was the one that presented a more marked decrease in the increase in the growth ring area, while the family positioned in R1 was the one slowing its growth the least. For all families, the greatest increase in ring area occurred in the 5th year, reaching values of 80 $cm^2$, 69 $cm^2$, and 47 $cm^2$ for positions R1, R2, and R3, respectively. The difference in the increase in growth-ring area for the R1 families, relative to R3, was maintained until 11 years of age, which is the oldest evaluated age.

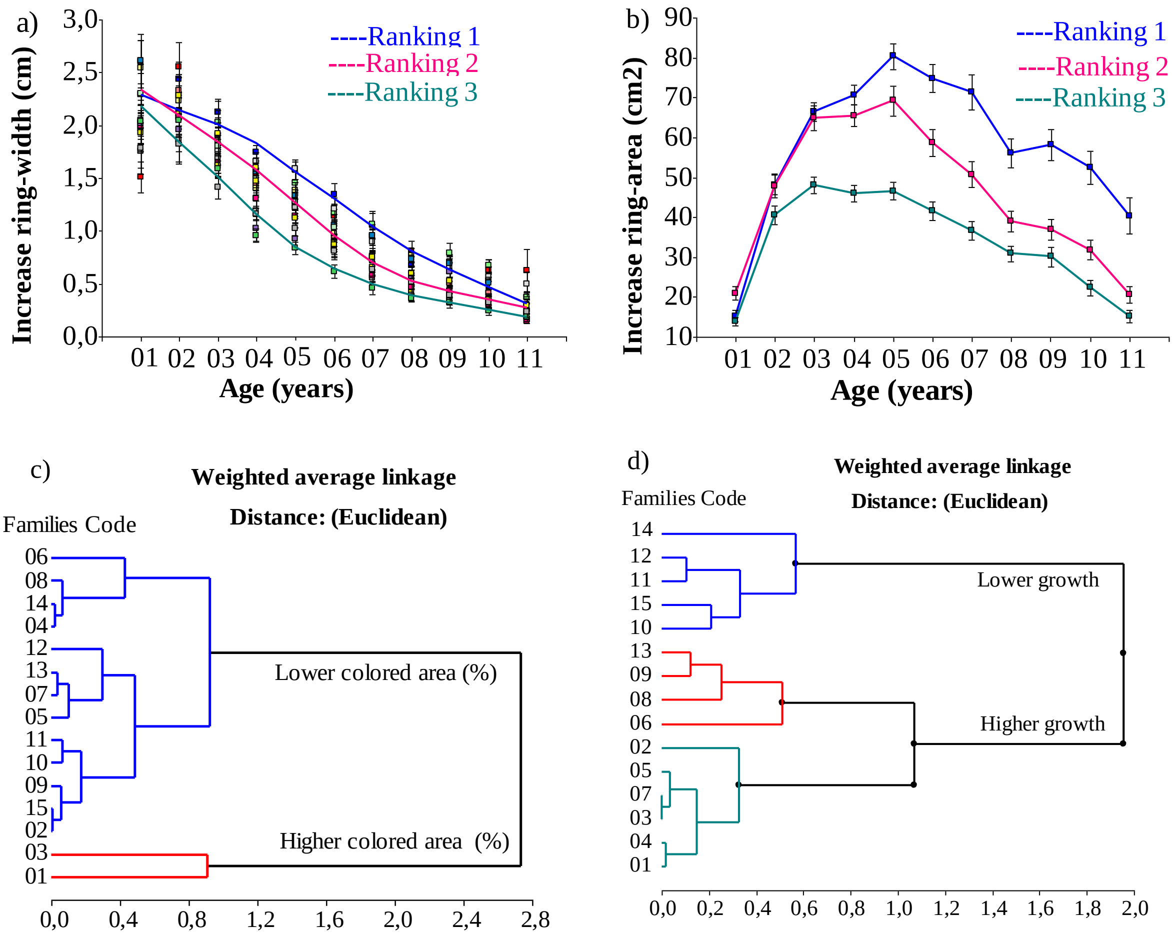


Figure 6: a) Mean annual increase variation for growth ring-width for representative families of the three positions in the genetic ranking. b) Mean annual increase for the ring-growth area for the three ranking positions. c) Grouping of families by colored area (%). d) Grouping of families by growth.

Figura 6: a) Variação do aumento médio anual da largura dos anéis de crescimento para famílias representativas das 3 posições do ranking genético. b) Aumento médio anual da área dos anéis de crescimento para as 3 posições do ranking. c) Agrupamento de famílias semelhantes por % de área colorida. d) Agrupamento de famílias semelhantes pelo crescimento.

Cluster analysis grouped families 01 and 03 for displaying a higher colored area (%) (Figure c) and families 01, 02, 03, 04, 05, and 07 for having greater mean growth-ring widths (Figure 6d). Five of these families belonged to R1 and one family belonged to R2. The cophenetic correlation was 0.84 for the colored area (%) and 0.80 for the increase in ring widt

## DISCUSSION

The pink coloration close to the pith is considered an undesirable characteristic for the wood industry because it negatively affects the visual aspect of wood for appearance uses (BURDON and MOREE, 2018). Furthermore, in the colored region, the permeability of the wood is altered and, therefore, for solid products that require treatment with preservatives, the pink coloration is not a coveted feature. The pink region also influences the drying process, chemical pulping, gluing, and surface finishing of the wood (ZIMMER *et al*., 2014; BARAÚNA *et al*., 2014; AHMED *et al*., 2012). In turn, the presence of extractives increases the density and the modulus of elasticity of the wood in compression processes, in which the wood becomes more brittle, and hence unsuitable for structural uses (BAILLERES *et al*., 2019). However, the colored region with the presence of resins gives the wood a distinctive smell and can act as a biochemical defense against pests, thus improving the natural durability of the wood (BAILLERES *et al*., 2019). For these reasons, it would be appropriate to suggest a more detailed study on families 01 and 03, which exhibited excellent growth and stood out for presenting a higher mean value of colored area, to recommend it for the most appropriate use.

Regarding wood for solid products, the materials whose propagation could be recommended are those with the highest growth in diameter (02, 04, 05, and 07 in positions 1 and 2 in the genetic ranking) and the lowest value in diameter of the colored area (%). No bibliographic references were found for axial color variation, so we believe there is a knowledge gap in this topic for the hybrid PEE x PCH pine tree. The information presented in this work on the colored area (%) at different heights in trees of $F_1$ INTA-PINDO hybrid pine families sets precedents for future research. New studies should incorporate silvicultural aspects that may be influencing this characteristic of the wood. The results obtained showed an increase in coloration with stem height. This could have a negative significant impact, in particular, on the performance of sawlog free of coloration for structural uses in the top logs of the tree. Therefore, we propose evaluating the profile of the colored area up to the minimum usable diameter by taking a greater number of disks from different heights of the tree and at a shorter distance since the colored area did not show a cylindrical pattern up to the evaluated height.

The growth-ring width decreased with tree height and age and was more marked after the fifth year, in agreement with the results obtained for *Pinus oocarpa* by Hara *et al*. (2018). These authors verified that ring width decreased significantly from the pith to the bark and from the base to the crown. Furthermore, the cumulative percentage of latewood increased with the number of rings from the pith to the bark. However, the increase in latewood width decreased with the number of rings from the pith to the bark. For the same taxon, Gonçalez *et al*. (2018) worked on three groups of ring widths: group 1: lateral wood with increases in ring width (0–0.7 cm); group 2: intermediate wood (0.7–1.20 cm); group 3: internal wood (1.2–2 cm). These authors found that the peripheral wood exhibited narrower growth rings with a greater proportion of latewood and higher values of density, acoustic velocity, and modulus of elasticity concerning internal wood, thus confirming the relationship between physical-mechanical properties and ring width. They also found a stronger correlation for lateral wood than for internal wood. Latewood is formed late in the vegetative period when there is a decrease in the physiological activity of the trees. Their tracheids display greater wall thickness and density. Due to these characteristics, this type of log influences the physical and mechanical properties of the wood. For this reason, it is of interest not only in terms of the absolute value but also in terms of the proportion of latewood in the ring/tree. Deucox *et al*. (2004) stated that, in conifers, the density of latewood is three times higher than in earlywood, the latter being an indicator of the structural properties. In this study, no statistically significant differences were found in the percentage of latewood (p-value>0.05) between the families, and therefore, somewhat homogeneous mechanical properties could be expected between them.

The area increase was greater in the fifth growth ring. Gonçalez *et al.* (2018) obtained similar results for the same taxon. They determined greater and practically constant growth for the first four years of age and then a decrease in growth. However, this behavior may vary depending on the silvicultural management applied.

The families that experienced greater growth in diameter also had a greater colored area in the central zone of the log. Variability was confirmed between families and the different stem heights studied in the hybrid $F_1$ INTA-PINDO pine at 11 years of age. Families 01 and 03 showed a higher colored area (%) in the central zone of the log. Therefore, in principle, propitiating their use as structural wood would not be recommended without more detailed studies of these families. In contrast, family 02 displayed greater growth, as shown by the ring width, as well as a higher increase in growth-ring area and a greater area free of coloration. These attributes indicate that it could be recommended for propagation as a high-quality family for solid wood products, due to its great growth and its lower colored area (%).

The six fastest-growing families share two mothers (18 and 20) and two fathers (104 and 115). The highest proportion of ring area occurred in the fifth year. The largest mean ring width was recorded for family 02, followed by families 01, 03, 04, 05, and 07. However, the choice of families for future propagation will depend on the production goal. If the colored area is seen as an undesirable characteristic for the industry, the propagation of families 01 and 03 should be avoided unless new studies provide more information about them. In addition, ring width decreased with age and tree height, as opposed to what happened with the colored central section of the stem.

Regarding the proportion of latewood, all families exhibited the same behavior. This would allow us to infer that the different genetic materials evaluated have similar mechanical behavior. The percentage of latewood rose from the pith to the bark and from the base of the tree to the crown.

## CONCLUSIONS

- Families in position 1 in the genetic growth ranking showed greater ring width at year 1 and maintained their superiority over time. Due to their adequate growth and log characteristics, their reproduction could be recommended for the production of wood for structural uses. In contrast, the families that ranked third in genetic growth experienced low growth and therefore, no resources should be spent on their multiplication.
- Family 02 (F51) stood out for displaying a high growth rate over the years and low values of colored area (%).
- Families 01 (F19) and 03 (F20) should not be orientated for solid and appearance uses due to their higher colored area (%). More detailed studies on coloring should be carried out, and perhaps these families could be recommended for low-demand uses due to their weakened resistance to external stresses or loads, but with favorable characteristics in terms of durability given that the resin protects the wood from the attack of biological agents.

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