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Selection of *Pinus Taeda* Progenies for Greater Income in Cellulose and Paper Production

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Abstract

Brazil is the second largest producer of pulp and eighth in paper production in the world, among the most used species, or *Pinus taeda* is a major highlight, especially in the production of pulp and kraft paper. *Pinus taeda* is a second most planted species in Brazil, especially in the colder regions of the country, where it has high rates of development, reaching a rate of over 30m^3 / ha / year. The objective of this research work was to characterize ten *Pinus taeda* progenies, based on the characteristics of the basic specific mass and the dimensions of its fibers, having as main focus the use of these trees in the pulp and paper production. The study analyzed 28 trees of ten different 18 year old *Pinus taeda* progenies. These trees were collected in the municipality of Otacilio Costa, state of Santa Catarina. The progenies were analyzed based on the following properties, specific mass, length, inner diameter, outer diameter and wall thickness of the fibers, aggregating as fiber measurements, also used correlations among them, flexibility coefficient, wall fraction, index weakening and Runkel index. The main results obtained in this work were that the progenies, although growing under conditions equal to development, present significant differences between the analyzed variables. Fiber length were the most prominent in fiber measurements, exceeding the values referenced by up to two times, the other measurements, wall fraction, internal and external diameter, if equivalent to the values surveyed. The relationships determined between the measurements of the raw fibers show great importance in the progeny selection process, as well as the Pearson correlations applied to the measured variables, observing the behavior of the basic specific mass, which alone does not provide reliability in this work. However, when analyzed together with the other data, it makes the selection process reliable. The selection of *Pinus taeda* progenies using the properties of tracheids is possible, combining the basic specific mass and increasing the confidence in selection. The progenies that stood out the most were 12, 21, 74 and 112, these were selected because they have greater balance among the analyzed variables, being the number 112 the best among them because it has the largest basic specific mass, added to the other characteristics, provides greater benefits in pulp and paper production.

Keywords: *Guru Tua*, character education

INTRODUCTION

Brazil is the world's second-largest producer of pulp and eighth in paper production. In 2016, Brazilian pulp production reached 18.8 million tons, an increase of 8,1% over the previous year. In the same period, exports reached 12.9 million tons, 11,9% higher than in 2015. Paper production rates were 10.3 million tons in 2016, and 20% of this amount was destined to exports (IBA, 2017).

Among the most prominent species in Brazil is *Pinus taeda*, native to the southern United States (USA), being the most economically important in this country (SOUSA et al., 2007). Introduced in Brazil, the species has adapted well in the cold regions of the country, especially in the southern states, where it is currently the most cultivated species, extending over an area of approximately 1.45 million hectares, where it is mainly used. as lumber, bioenergy and in the production of pulp and kraft paper.

Pinus taeda wood is essential for the expansion of the pulp and long fiber paper industry in Brazil. For this reason, it is important to study provenances that meet this growing demand for high-quality long fibers. Determining the quality of wood is always related to the use that will be given to trees. For the pulp and paper industry, higher quality wood is one that has higher levels of cellulose in its composition, longer fibers, high basic density, among others. Thus, the classification of wood quality can be defined as a set of characteristics of interest that aim the best use and the best use of wood for a given application (TRUGILHO et al., 2005). Characterization of properties such as basic density and tracheoid morphology is important in this process, as these wood characteristics directly affect the quality of pulp and paper produced.

The relationships between fiber dimensions are more important than the values of their isolated dimensions, resulting in indices that help in the classification of wood quality for pulp and paper. Among the main indices are the bending, flexibility coefficient, wall fraction and Runkel (MIRANDA; CASTELO, 2012). Thus, the measurement of fiber dimensions is an important indicator of the potential of wood for the manufacture of pulp and paper, as these characteristics influence the manufacturing process.

Runkel index and wall fraction are indices related to fiber stiffness and are directly related to the pulp and paper properties since the degree of fiber stiffness influences the mechanical properties of the paper. Flexibility coefficient and bending index, on the other hand, measure how flexible the fibers are and their interlacing capacity and are also important for pulp and paper manufacturing (MIRANDA; CASTELO, 2012).

The objective of this work was to characterize *Pinus taeda* wood of different progenies, considering its use in the pulp and long fiber paper industry.

2. MATERIAL AND METHODS

Twenty eight trees of ten different 18-year-old *Pinus taeda* progenies from a clonal seed orchard located in the municipality of Otacílio Costa, Santa Catarina State, were used for the study. The trees come from seedlings produced with seeds from the southern United States. Disc cross-sections were collected at heights of 0%, DBH, 25%, 50%, 75% and 100% of the commercial height of the trees. The collection at these times had the objective of sampling the whole tree, from the base to the top, of each disc, without bark, the samples were taken to characterize the tracheids and the basic density.

The characterization of the fibers was performed using diametrically opposed wedges of the sampled discs, which were transformed into sticks. The sticks were placed in test tubes and macerated in a hydrogen peroxide solution, according to the method described by Kraus and Arduin (1997) for the individualization of the anatomical elements.

The preparation of the blades used in the characterization of the fibers consisted of agitating the macerated material, to keep the fibers in suspension so that they are not agglomerated and for the total individualization of the fibers to occur. The fibers were stained with 1% aqueous safranin solution for 10 minutes. After mounting the slides, 30 readings of length (C), outside diameter (D), inside diameter (d) and wall thickness (e) were taken at each tree harvesting height. With the values obtained from the fiber dimensions, it is possible to calculate the average for each progeny sampled and the relationships between the fiber dimensions by means of the flexibility coefficient (CF = (d / D x 100), wall fraction (FP = (2e / D) x 100), bending index (IE = C / D) and Runkel index (IR = 2e / d). The characterization of the basic specific mass of the samples was performed using wedges obtained from the discs, which were identified and submerged in water until reaching the saturation point. By the water displacement method it was possible to measure the wedge volumes. The weight was obtained after the wedges were oven-dried, reaching 0% humidity. By the relationship between these two measurements it was possible to determine the specific mass of each sampled disc.

Statistical analyzes were performed using Statgraphics® software, version 16.1.11, Tukey's test (HSD) and Pearson's correlation coefficient, both with 95% confidence.

3. RESULTS

It is observed that the parameters related to *Pinus taeda* fibers presented significant differences between the progenies analyzed in the variables of length, external and internal diameter. The wall thickness did not show significant differences influenced by the progenies.

Table 1: Descriptive measures of the dimensions of the fibers *Pinus taeda*

Progeny	Length (mm)	External diameter (µm)	Internal diameter (µm)	Wall thickness (µm)
5	7,65 a (23,22)	90 a (21,19)	46 d (35,46)	45 a (38,40)
8	7,61 a (21,65)	90 a (20,54)	44 d (34,58)	45 a (35,11)
9	6,91 b (15,14)	86 bc (16,90)	56 b (32,75)	45 a (26,65)
12	6,90 b (16,57)	84 c (17,51)	49 c (31,48)	47 a (31,06)
20	7,07 b (13,22)	86 bc (15,26)	55 b (32,82)	47 a (28,30)
21	6,72 b (17,89)	84 c (17,88)	50 c (30,66)	47 a (30,22)
74	7,08 b (14,35)	84 c (15,33)	49 c (32,13)	47 a (31,32)
104	7,49 a 13,82)	89 ab (15,89)	59 a (36,11)	47 a (33,24)
108	7,72 a (21,69)	91 a (20,78)	45 d (36,01)	45 a (39,01)
112	6,93 b (15,62)	84 c (16,83)	49 c (31,61)	47 a (30,88)

Means followed by the same letter in the same column are statistically equal by the statistical test.

Regarding the fiber length, the average value obtained by the progenies of the present study was 7,21 mm, being higher in more than 100% of the values found by Vivian et al. (2015) in a 21-year-old *Pinus taeda* tree, which obtained an average value of 3,50 mm. Cit (2007) studying 16-year-old *Pinus taeda* trees found an average value of 2,98 mm. Castelo (2008) found an average value of 3,03 mm in 14, 16 and 18 year old *Pinus taeda* samples. However, Trianoski (2012) studying tropical Pinus species, obtained for *Pinus taeda*, with 18 years, the maximum value of 5,11 mm, a value closer to the samples studied in this work.

The external diameter of the fibers of the studied progenies ranged from 84 µm to 91 µm, being the smallest and the highest index obtained for progenies 12, 21, 74 and 112 and 108 respectively. For the internal diameter, mean values of 44 µm and 59 µm were measured, the smallest being obtained for progeny 8 and the largest for 104. The statistical test showed that in the external diameter, progenies 5, 8 and 108 showed statistical similarities. among themselves, the samples 12, 21, 74 and 112 presented the same mean values. Thus these progenies are also statistically equal to each other.

The average wall thickness values of *Pinus taeda* progenies studied ranged from 45 µm to 47 µm. In this variable, the statistical test revealed that all progenies are statistically similar to each other.

Table 2 presents the Pearson correlation indices for fiber length, outer and inner diameter, and wall thickness measurements.

Table 2: Pearson correlations os studied variables: length (L), external diameter (Ed), internal diameter (Id) and wall thickness (Wt)

Pearson correlations				
	L	**Ex**	**Id**	**Wt**
L	1	0,024	-0,126	0,212
Ex		1	0,735	0,223
Id			1	-0,498
Wt				1

Table 2 shows the Pearson product correlations between each pair of variables. These correlation coefficients range from -1 to +1 and measure the strength of the linear relationship between the variables.

Table 2 shows a positive and significant correlation between the inner diameter and outer diameter, with a correlation value of 0,735.

For the ten studied progenies, it was found that the increase in fiber length did not significantly influence the other variables, which can be confirmed by the low values of the correlation coefficients. The same fact occurred between the variables external diameter and wall fraction, with a correlation of 0,223.

Negative and significant correlation can also be observed between the wall fraction and the internal diameter, with a correlation value of -0,498. A negative but not significant correlation was observed between the variables length and internal diameter, evidenced by the low correlation value of -0,126.

Table 3 shows the average values obtained for the relationships between fiber dimensions, used for the classification of wood for pulp and paper production of the studied progenies.

Table 3: Relationships between measured fiber dimensions

Progeny	**CF[1] (%)**	**FP[2] (%)**	**IE[3]**	**IR[4]**
5	51,35 c (27,97)	96,86 a (29,78)	84,10 b (30,23)	2,25 a (6,74)
8	51,19 c (23,14)	96,34 a (25,35)	83,70 b 28,65)	2,19 a (10,24)
9	59,36 ab (21,97)	81,41 bc (32,01)	75,60 c (21,89)	1,54 b (5,72)
12	58,37 b (21,51)	83,26 b (30,15)	92,40 a 24,83)	1,60 b (5,48)
20	59,15 ab (20,82)	81,45 bc (30,04)	75,10 c (19,81)	1,56 b (6,89)
21	58,42 b (20,10)	83,01 b (29,51)	92,00 a (22,51)	1,58 b (7,54)
74	58,12 b (20,98)	83,78 b (30,11)	91,20 a (23,44)	1,59 b (6,38)
104	60,81 a (24,65)	78,38 c (38,24)	77,30 c (21,23)	1,53 b (6,68)
108	51,56 c (28,02)	96,51 a (28,09)	84,80 b (28,29)	2,20 a (9,74)
112	58,07 b (20,06)	83,35 b (29,86)	91,50 a (21,81)	1,61 b (8,01)

Means followed by the same letter in the same column are statistically equal by the statistical test. [1]Flexibility coeficiente; [2] Wall fraction; [3] Binding rate; [4]Runkel index.

Regarding the Flexibility Coefficient, it was found that the mean values ranged from 51.19% to 60.81%, with the extremes presented by progenies 8 and 104, respectively. The statistical test showed that there are statistical similarities between progenies 8, 5 and 108 in the lowest and highest progenies 104, 9 and 20.

The Fraction Wall of the studied progenies presented a range of variation of 78.38% and 96.86%, where the lowest average result was presented by progeny 104 and the largest fraction was obtained in progeny 5. Statistical analysis of the average results showed that statistical similarity between treatments 108, 5 and 8, with the highest rates, and between progenies 104, 20 and 9 with the lowest mean values.

For the Indexing Index variable, values from 75,10 to 92,40 were observed, where the lowest and highest results were obtained from progenies 20 and 12. The statistical test applied to the average values of the samples indicated that there were statistical similarities between the progenies 9, 20 and 104, with the lowest indices, between progenies 5, 8 and 108, with intermediate values and between progenies 12, 21, 74 and 112 with the highest average values.

The average values of the Runkel Index of *Pinus taeda* progenies ranged from 1,53 to 2,20, where the lowest and highest mean values were presented by 104 and 108 respectively. In this variable the statistical test showed similarities between progenies 104, 9, 12, 20, 21, 74 and 112 with the lowest indices and between samples 108, 5 and 8 with the largest.

Table 4 shows Pearson correlations between the established fiber ratios.

Table 4: Pearson correlations os studied variables: flexibility coeficiente (Fc), wall fraction (Wf), buckling index (Bi) and Runkel index (Ri)

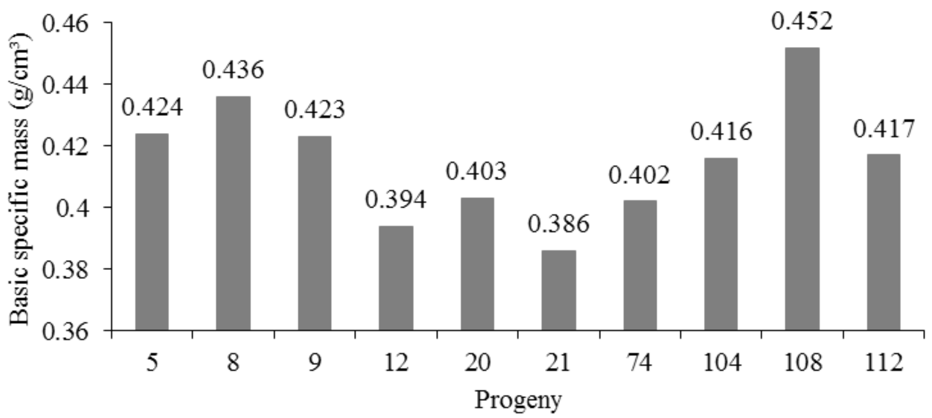
Pearson correlations				
	Fc	**Wf**	**Bi**	**Ri**
Fc	1	-1,00	-0,335	-0,917
Wf		1	0,335	0,917
Bi			1	0,291
Ri				1

Table 4 shows the correlation coefficients between the relationships established for *Pinus taeda* fibers, their values vary between -1 and +1 and measure the strength of the linear relationship between the variables.

Table 4 shows the occurrence of a positive and significant correlation between the wall fraction and the Runkel index. Negative and significant correlations are observed between the flexibility coefficient and the wall fraction and between the flexibility coefficient and the Runkel index.

For the progenies analyzed, it was verified that the indexing did not significantly influence the flexibility coefficient, the wall fraction and the Runkel index, which is confirmed by the low correlation indexes presented between these variables.

Graph 1 presents the average values obtained for the basic specific mass of progenies analyzed in this study.



Graph 1 - Average values of the basic specific mass per progeny

Table 5 describes the average values of the basic specific masses, together with the statistical test, and the respective coefficients of variation of the progenies analyzed.

Table 5 - Average values of basic specific mass obtained by progeny

Progeny	**5**	**8**	**9**	**12**	**20**	**21**	**74**	**104**	**108**	**112**
MEB (g/cm³)	0,424 ab	0,436 a	0,423 ab	0,394 bc	0,403 bc	0,386 c	0,402 bc	0,416 abc	0,452 a	0,417 abc
C.V (%)	10,86	12,92	11,6	10,31	8,2	8,26	13,5	12,23	7,79	23,92

Means followed by the same letter are statistically equal by the statistical test.
Values in parentheses refer to the coefficient of variation between samples.

For the basic specific mass variable, the mean values found ranged from 0,452 g / cm³ to 0,386 g / cm³, with the highest and lowest values corresponding to progenies 108 and 21. The statistical test applied to the obtained values showed that there were statistical similarities between In samples 108 and 8 only, progeny 21, besides the smallest value, was not statistically equal to any other progeny analyzed, by the statistical test it was possible to observe a similar behavior among several progenies, some of them being similar to those of higher index and of minor, progeny 104 and 112 behavior.

4. DISCUSSIONS

The measured length variable of the ten progenies studied in this study showed indices higher than those cited in the literature, exceeding the values cited by more than 100%. The other variables measured, internal and external diameter and the wall fraction, were adequate for the species. Pearson correlation showed a significant correlation only between inner diameter and outer diameter

The Flexibility Coefficient is related to the degree of breakdown that the fibers undergo during the papermaking process, the higher the value will be their tensile strength and the lower the tensile strength. binding available making the formed paper more resistant (NISGOSKI et al. 2012). In the study, the ones with the best indices were progenies 104, 20 and 9, with values close to 60%. This indicates, according to the classification of Foelkel and Barrichelo (1975) that they present partial collapse, with good contact surface and a good union between the cellular elements.

The Wall Fraction indicates fiber stiffness, interconnection, and their relationships to tear strength, tensile strength, and burst strength. Dinwoodie (1965) points to Fraction Wall as the main variable related to tear resistance, since the fibers form ribbons and have a greater number of bonds. The values obtained for all *Pinus taeda* progenies analyzed in this study were above those quoted by Foelkel and Barrichelo (1975) who report that fibers higher than 40% are less rigid, more flexible, with less interconnection difficulty and greater resistance to fiber traction and bursting, with progenies 5, 8 and 108 being the best for this index.

For the Buckling Index variable, which is related to the tear and tear resistance (MOGOLLÓN; AGUILERA, 2002) and that, as well as the flexibility coefficient, how flexible cellular elements are and their ability to intertwine (CASTELO, 2007). According to Baldi (2001), the preferable values are above 50 and indicate that the paper has good tear-related characteristics, and all progenies studied were at least 25% higher than the mentioned index, being the progenies 12, 21, 74 and 112 as with the best indices in this variable.

The Runkel Index, according to the indices established by Foelkel and Barrichelo (1975) for the evaluation of cellulosic pulp and paper, are less than 1 indices. Values close to or above this value indicate that the fibers are more rigid. However, since *Pinus taeda* wood is mainly intended for the manufacture of kraft paper, which needs a higher resistance capacity, the higher stiffness of the fibers can give the paper produced with the studied progenies a superior quality, however the progenies 5 , 8 and 108, because they have a much higher index than indicated can cause problems for the formation of the role, and the other progenies are preferable when analyzing this variable.

The research conducted with *Pinus taeda* refer that the relationships established from the fiber dimensions show that the progenies studied in this work are close to those determined by other authors, Vivian et al. (2015) obtained the following values for flexibility coefficient, wall fraction, buckling index and Runkel coefficient of 68, 32%, 86 and 0.46 respectively, thus demonstrating that the ten studied progenies are capable of providing quality raw material to pulp and kraf paper production industry. Especially progenies 12, 21, 74 and 112 which have the most balanced indices among all analyzed.

The basic specific mass of the progenies researched in this study are in agreement with the values cited by several authors who studied the *Pinus taeda* species, such as Delucis et al. (2018) studying the chemical and energetic properties of residues obtained values between 0,393 g / cm³ and 0,372 g / cm³ for their samples. Vivian et al. (2015), in a study on the quality of Pinus wood for the production of kraft pulp, obtained a specific mass of 0,435 g / cm³ for 21-year-old *P. taeda* trees. Trianoski et al. (2016) obtained basic specific mass for *P. taeda*, 18 years old, of 0,485 g / cm³. Progenies 8 and 108 are preferable because they have the highest indexes.

Jointly analyzing the fiber dimensions, the relationships established between them and the basic specific mass, the progenies 12, 21, 74 and 112 were the ones that presented the most balanced values between the studied progenies, despite the basic specific mass of the progenies 12 and 21. Being the smallest among them, the fiber quality of all four gives superior quality to these progenies.

5. CONCLUSIONS

- *Pinus taeda* progenies evaluated in this study showed significant variations in the studied properties, allowing the continuity of tests using the analyzed variables;
- For the measurements made on the fibers of the ten studied progenies there was significant correlation only between the variables inner diameter and outer diameter;
- Pearson correlation analysis applied to the relationships between fiber measurements indicated that there were significant correlations between the flexibility coefficient and the Runkel index and between the wall fraction and the Runkel index;
- The use of the buckling index, Runkel index, wall fraction and flexibility coefficient contributed significantly to the selection of *Pinus taeda* progenies;
- Using only basic specific mass values for wood classification in pulp and paper production does not provide sufficiently reliable data.
- Considering the variables analyzed together, related to the production of pulp and kraft paper, the most prominent progenies were 12, 21, 74 and 112, since they presented a greater balance between the analyzed variables.
- Among the progenies cited, progeny 112 is the most indicated, because besides the balancebetween the variables, it has a higher basic specific mass, which gives greater yield to this sample.

6. LIMITATIONS AND RECOMMENDATIONS

- Perform the determination of the yield obtained in the production of pulp and the quality of kraft paper produced with the studied progenies;
- Establish continuity in the studies of these progenies;
- Evaluate progeny behavior in other applications.

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ENDNOTES

'All the Authors Contributed Equally to this Work'.

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