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Some Wood Properties of 10-Year-Old *Eucalyptus Camaldulensis* Dehnh. in Three Diametric Classes

Algumas Propriedades da Madeira de Eucalyptus camaldulensis Dehnh. com 10 Anos de Idade em Três Classes Diamétricas

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Multipurpose forests are becoming more frequent, but research on wood is still needed to target it for adequate industrial consumption. However, such determination requires a knowledge of the seed provenance and planting characteristics. Accordingly, this work aimed to characterize the wood quality of 10-year-old *E. camaldulensis* in three diametric classes for potential use in paper and cellulose production, energy and sawn wood. We studied 10 trees of each diameter class (small, middle, and large) and employed the usual techniques for analyses of each property. *E. camaldulensis* wood is characterized by an increased percentage of heartwood and a decreased percentage of sapwood as tree diameter increases. Basic density was higher in the larger class; however, this was not directly reflected in better results in other physical properties. For example, volumetric shrinkage was higher in the middle class. Anatomical features-imposed limitations on the presence of fines, and fiber dimensions-imposed limitations on the quality indexes for paper and cellulose, which are important for the industrial use of wood. Wood waste from *Eucalyptus camaldulensis* could be exploited for bioenergy since its HHV values range from 16425 to 17056 kJ.kg^{-1}. In general, we suggest that trees in the studied spacing and edaphoclimatic conditions do have industrial utility, thus contributing to the forest-based market and reducing the exploitation of native species for this purpose. Based on its wood quality in different diameter classes, *E. camaldulensis* could benefit from the investment technological strategies to boost genetic gains and obtain better wood properties.

Keywords: Plant breeding; reforested wood; wood chemical properties; wood quality

1. Introduction

The characterization of technological wood properties allows wood to be assigned to the most suitable uses. Wood characterization should also be carried out considering internal variations, based on the determination of properties in different diameter classes, also allowing assignment to the best technological use, including the classification of sawn wood with similar properties and the homogenization of lots for their commercialization.[1] Wood is a heterogeneous and anisotropic material, and its characteristics vary in longitudinal and radial directions.[2] Wood quality parameters can be influenced, for example, in the basal proportion of trunk by root system and at top of trunk by branches.[3]

The structure of a planted or native forest presents wide differences which can be interpreted through the pattern distribution of diameter classes.[3] Thus, through the technological classification of wood by diameter classes, the ideal interval for cutting trees can be established. This will result in more efficient production and, at the same time, good wood quality.

The formation of forest stands with fast-growing species, such as *Eucalyptus* spp., is a strategy to increase wood supply and other forest products, while, at the same time, reducing the pressure on native forests.[4,5] The range of potential products that can be generated from *Eucalyptus* spp. wood is wide, including, for example, plywood panels, laminated wood, sawn wood, telephone and electric poles, construction anchors, poles, charcoal, cellulose and paper, and structural pieces of buildings with flexible parts.[6] The success in large cultivable areas of *Eucalyptus* spp. results from the ability of these species to grow satisfactorily in different edaphoclimatic conditions, existing in different regions of Brazil, and to present widespread use of its wood.[7,8]

In this study, we will investigate *Eucalyptus camaldulensis* Dehnh. wood, which has a wide occurrence in several natural areas[9]. reports that *E. camaldulensis* subsp. *obtusa* is widely distributed between 11ºS and 36ºS throughout Australia, except the states of Victoria and

Tasmania. *E. camaldulensis* subsp. *simulata* is a tropical species with more restricted distribution between 15ºS and 22ºS in the Australian state of Queensland. The results of provenance tests demonstrated that this species has a high rate of growth, excellent wood properties, tolerance to salinity and alkalinity, and tolerance to drought and frost.[10] Currently, the commercial use of *E. camaldulensis* is concentrated in the extraction of essential oils used in controlling microbiological agents, such as bacteria, fungi, parasites and viruses.[11] Essential oils are volatile by the presence of alcohols, ketones, aldehydes, monoterpenes, hydrocarbons and terpenoids in the oil-forming compounds.[12]

Because of these qualities, breeding programs for *E. camaldulensis* have been carried out in Australia, Brazil, China, India, Sri-Lanka, Thailand, the USA, Vietnam and Zimbabwe.[13] Pioneering work in implementing breeding strategies for *E. camaldulensis* in different countries was started by. [14-18] These studies also recommended starting with large base populations of seedling lots from natural stands complemented by locally selected material because of uncertainty about the origins of terrestrial breeds and the need to minimize depression from inbreeding. In addition, *E. camaldulensis* clones have been genetically transformed *in vitro* with success.[19] Primary and secondary diversity centers have vast genetic resources for *E. camaldulensis*. However, it is often impossible to trace seeds provenance used for plantations, so the extent of genetic variation available in various regions is uncertain. The wide genetic variability between and within provenances of *E. camaldulensis* has enabled considerable genetic advances for production, justifying its adoption in breeding programs.[13]

Research on wood is still needed before it can be targeted to appropriate industrial consumption. However, such determination requires a knowledge of seeds provenance and planting characteristics. Accordingly, this work aimed to characterize the wood quality of 10-year-old *E. camaldulensis* in three diametric classes for potential use in paper and cellulose production, energy and sawn wood.

2. Material and Methods

2.1. Location and sampling

The *E. camaldulensis* seed orchard used in this study was established using within family selection from a provenance and progeny test, which was established from open-pollinated seeds collected at two locations in Australia: Nott's Crossing and Katherine River.[20] The provenance and progeny test (PP) was planted in April, 1986, in the municipality of Selvíria, Mato Grosso do Sul State (20°20′S, 51°24′W, elevation 371m). The site is characterized as moderately flat with a climate classified as Aw, average annual temperature of 24.5°C, annual average humidity of 64.8 %, and average annual rainfall of 1,232 mm.[20] The local soil has been classified as oxisoil clay, moderate, hipi-distrophic, kaolinitic, ferric compressed, very deep, and moderately acidic.[21] In 2008, from free-pollinated seeds collected in a PP test reported by [20], other plantings were installed in the same place in an area of 3.18 hectares. The experimental design used in both tests was completely randomized blocks, spacing of 3.0 m x 1.8 m: a) 136 treatments (progenies), five plants per plot and four replications and b) 133 treatments (progenies), one plant per plot and 20 repetitions. At the age of ten (2018), 40% of trees were thinned within the treatments / experiments aiming at the formation of a seedlings seed orchards (SSO).[22] The sampling of the present study was from test b.

Based on the highest individual additive genetic value predicted for diameter at breast height (DBH), survival and shape form, using the genetic-statistical Selegen-REML/BLUP software[23] was followed to thin genetically inferior trees. Thirty trees were selected, 10 of each diametric class: large 12.03 (14.87) 17.70; middle 8.28 (9.81) 11.49; small 1.43 (4.94) 7.10 cm, minimum (mean) and maximum values, respectively. From smaller tree (1.43 cm), samples for density and volumetric shrinkage were smaller than those of the other trees.[22]

From each tree, we cut discs from the trunk base (10 cm thick), and from these, samples close to the bark were obtained to determine heartwood and sapwood percentage and grain orientation, basic density, volumetric shrinkage, anisotropy coefficient, performance, anatomical features, some quality indexes for paper and cellulose based on fiber features, and higher heating value.

2.2. Heartwood and sapwood percentage and grain orientation

Eucalyptus camaldulensis wood is characterized by having red to reddish-brown heartwood (after exposure to light and air), so the heartwood and sapwood percentages were initially evaluated by visual observation of disc surfaces (sanded with sandpaper) and analyzed, and relative area calculations were made with a ruler according to the equations below.

$$HA = \frac{\Pi x (D - 2xA)^2}{40000} \quad (1)$$

$$SA = G - HA \quad (2)$$

$$HA = 100 - SA \quad (3)$$

$$SA = \frac{SA}{G} \, x \, 100 \quad (4)$$

$$G = \frac{\Pi x \, D^2}{40000} \quad (5)$$

$$H/S = \frac{HA}{SA} \quad (6)$$

Where: HA = Heartwood area (m^2); D = Average disc diameter (cm); A = Sapwood thickness (cm); SA = Sapwood area (m^2); HA% = Heartwood area percentage;

SA% = Sapwood area percentage; G = Average sectional area (m^2); H/S = ratio of heartwood/sapwood.

2.3. Basic density

Basic density was determined by the ratio between dry mass and saturated volume. The specimens (3x2x2 cm) were immersed in water and were considered saturated when they presented constant mass during monitoring in the laboratory. Subsequently, the specimens were dried in an oven at 105 °C ± 2°C to obtain the dry mass. The saturation volume was obtained by the hydrostatic balance method. Wood basic density was calculated by the relationship between dry mass and saturated volume in accordance with the Brazilian[24] as follows:

$$BD = \frac{Dm}{Sv} \quad (7)$$

Where: BD = Basic density ($kg.m^{-3}$); Dm = Dry mass (kg); Sv = saturated volume (m^{-3}).

2.4. Volumetric shrinkage

Volumetric shrinkage was obtained from the same samples as those used for the basic density.[25] The samples were saturated in water, their dimensions measured with a caliper (accuracy = 0.001mm) taking three measurements per direction. Then the samples were oven-dried at 105 ± 3°C, followed by determination of the dry volume of each sample. Volumetric shrinkage (as a percentage) is the difference between initial saturated and oven-dried volume divided by initial volume. The anisotropic factor was determined by the relationship between tangential shrinkage and radial shrinkage.[26] Performance is given as a percentage as follows:

$$Performace = \left(\frac{Rv}{Tvx\,Vs}\right) x\ 100 \quad (8)$$

Where Rv = Radial variation; Tv = Tangential variation; Vs = Volumetric shrinkage.

2.5. Anatomical analyses

We cut small portions of wood from each sample for maceration using Franklin's method[27]. Wood fragments were stained with aqueous safranin and mounted temporarily in a solution of water and glycerin (1:1). Samples of 2 cm^3 were softened in boiling water and glycerin (4:1) for 1-2 hours. From these samples, transverse sections 25μm in thickness were obtained with a sliding microtome. Sections were bleached with sodium hypochlorite (60%), washed thoroughly in water, and stained with 1% safranin.[28] Measurements followed the recommendations of the IAWA Committee (1989).[29] Quantitative data are based on at least 25 measurements for each characteristic from each tree, thus fulfilling statistical requirements for the minimum number of measurements. All anatomical measurements were performed on a microscope (Olympus CX 31) equipped with a camera (Olympus Evolt E330) and a computer with image analyzer software (Image-Pro 6.3).

2.6. Anatomical ratios for pulp and paper

From values of length, diameter, lumen diameter, and fiber wall thickness, we calculated the following ratios for pulp and paper: Flexibility coefficient, Wall proportion, Runkel ratio, and Slenderness ratio.[30]

$$FC = \frac{d}{D} \quad (9)$$

$$WP = \frac{2w}{D} x\ 100 \quad (10)$$

$$RR = \frac{2w}{d} \quad (11)$$

$$SR = \frac{L}{D} \quad (12)$$

Where: Fiber length is L; fiber diameter is D, lumen diameter is d, and fiber wall thickness is w. We calculated the following ratios for pulp and paper: Flexibility coefficient (FC), Wall proportion (WP), Runkel ratio (RR), and Slenderness ratio (SR).[30]

2.7. Higher Heating Value (HHV)

The samples were fragmented into smaller pieces with a hammer and chisel and milled in a micro mill. Higher heating value was determined after thermal rectification with dry samples. To perform the analysis, the isoperibolic method was used with an IKA C200 calorimeter.[31]

2.8. Energy Density (ED)

Energy density was calculated as a function of the multiplication of the basic density by the superior calorific power according to the Equation 13.

$$ED = BD\ x\ HHV \quad (13)$$

Where: ED = Energy density; BD = Basic density; HHV= Heating Higher Value.

2.9. Data analyses

We initially undertook descriptive statistical analyses and used Box Plot graphics to detect outliers. Thus, values 1.5 times higher than the 3rd quartile and values 1.5 times lower than the 1st quartile were excluded from the analyses. Normality tests were performed to check the distribution of data, and when a normal distribution was not observed, data were square root-transformed. For radial variation, a parametric analysis of variance one-way analyses of variance (ANOVA) was performed. When a significant difference was observed, Tukey's test was used to identify pairs of significantly different means.

3. Results and Discussion

3.1. Growth characteristics

It is common in technological wood characterization to work with the average of technological properties of a given woody species, aiming at its characterization and even recommending its use. The industry, mainly cellulose and paper, takes additional precautions in the use of wood raw material. The anatomical, physical and energy properties among trees and in different diameter classes are always studied and considered when using this material for industrial processing.

For tree height and DBH, values increased from low to high diametric classes. Heartwood percentage increased, while sapwood percentage decreased. The ratio of heartwood to sapwood increased toward the large class. The same pattern of increase from small to large diametric class occurred for basic density. Volumetric shrinkage was higher in the middle class. Anisotropic factor did not vary among the three classes. Performance was higher in the large class and lower in the middle class. Vessel diameter and fiber length increased from small to large diametric classes. Vessel density was higher in the small class, but lower in the large class. Fiber diameter did not differ among classes. Fiber lumen decreased and, consequently, wall thickness increased towards the large class. Flexibility coefficient was higher in the small class, but lower in the large class. Other indexes, including wall fraction, Runkel ratio, and slenderness ratio, were higher in the large class and lower in the small class. HHV was higher in middle and large classes. Energy density increased from small to large class (Table 1).

The average height of 10-year-old *Eucalyptus camaldulensis* progenies is similar to values reported [32] with the same age (14.63 m) and lower than at 19-year-old (17.84 m),[33] so individuals have a good performance in growth. The mean diameter at breast height (DBH) of progenies agrees with results[32-34] *E. camaldulensis* progenies in two locations at 9-year-old (10.5 and 13.8 cm) reported mean values between 11.9 - 15.8 cm at 10-year-old in 13 provenances. These authors also explain that growth in diameter depends on water availability, temperature and genetics provenance.

3.2. Relationship Heartwood and sapwood

The ratio of heartwood to sapwood differed among the diameter classes (Table 1). The proportion of heartwood in the large class was greater than that in the small and middle classes, whereas the proportion of sapwood was greater in the small and middle classes. The use of treated wood, or cellulose production, will give preference to higher proportions of sapwood. Heartwood is less permeable than sapwood which would involve more difficulties in drying and absorbing preservatives, in addition to increasing the consumption of alkali, which would reduce the yield in cellulose since extractives content is also greater.[35]

Table 1. Comparison among wood properties of 10-year-old *Eucalyptus camaldulensis* in three diametric classes

	Small	Middle	Large
TH (m)	9.0c	15.2b	20.3a
DBH (cm)	49c	9.8b	14.8a
HW (%)	50c	69b	75a
SW (%)	50a	31b	25c
H/S	1.0c	2.3b	3.0a
BD (kg.m^{-3})	425c	504b	546a
VS (%)	23.2b	27.9a	23.5b
AF	1.4a	1.5a	1.5a
P	2.7ab	2.4b	2.9a
VD (µm)	77c	87b	98a
Vd (n°mm^{-2})	18a	13b	10c
FL (µm)	1575c	1701b	1844a
FD (µm)	14.8a	14.4a	14.1a
FL (µm)	8.4a	7.0b	5.7c
FWT (µm)	3.1c	3.7b	4.2a
FC	56.27a	47.40b	39.75c
WP (%)	43.72c	52.59b	60.24a
RR	0.83c	1.23b	1.73a
SR	110.08c	123.71b	135.37a
HHV (kJ.kg^{-1})	16425b	17153a	17056a
ED (kJ.m³)	7757c	10081b	11183a

TH = tree height; DBH = diameter at breast height; HW = heartwood percentage; SW = sapwood percentage; BD = basic density; VS = Volumetric shrinkage; AF = anisotropic factor; P = performance; VD = vessel diameter; Vd = vessel density; FL = fiber length; FD = fiber diameter; FL = fiber lumen diameter; FWT = fiber wall thickness; FC = flexibility coefficient; WP = wall fraction; RR = Runkel ratio; SR = slenderness ratio

In charcoal production, H/S ratio affects the initial stage of processing, which is characterized by wood drying. Wood from trees with large diameter would require more time to dry and enter into the combustion process. Considering only drying time,[36] report that lower H/S ratio would be adequate. This occurs because high heartwood content may make it difficult to dry the wood since heartwood is impermeable, mainly owing to vessel obstruction by tyloses, making it difficult to transport water from pith to bark.[37] Sapwood dries faster, while heartwood is moist and slow to remove. Under these conditions, gas vapor pressure increases inside the anatomical elements, and the cells may rupture, culminating in a more fragile and brittle coal.

Lower H/S ratio observed in small and middle classes are required for fines production since carbonization occurs from the surface to the interior of a wood piece, resulting in the release of gases originating during the process.[36] These gases must be released, and for this to happen, disruption may occur, mainly in parenchymal cells, which have thinner cell walls and are, therefore, less rigid. Thus, a high percentage of heartwood will result in a proportionately higher obstructive pathway and, consequently, higher content of fines. However, this means lower reactivity power of coal. The proportion of fines resulting from wood combustion is dependent on the initial carbonization temperature, percentage of obstructed vessels, initial wood humidity, and piece diameter.

The H/S ratio values in diameter classes were higher than those[38] who evaluated wood quality of 10-year-old *Eucalyptus camaldulensis* from an agrosilvopastoral plantation, varying from 1.7-2.0. However, it is known that values based on ratios are largely dependent on edaphoclimatic, topographic and spacing conditions.[39] Therefore, since the wood studied came from a managed system, we suggest a direct influence on technological wood properties.[38]

3.3. Quality of wood to produce paper and cellulose, energy and sawn wood

Wood basic density is a complex property resulting from the combination of several factors, e.g., fiber dimensions, particularly wall thickness, vessel diameter and vessel density, as well as H/S ratio.[40] We observed that the large diameter class had higher basic density owing to its high proportion of heartwood, longer fibers with thicker walls and smaller lumen, i.e., low proportion of liquids in the intracellular spaces. The opposite effect was observed in the small class where basic density is lower as a result of high vessel density and shorter fibers with thinner walls (Table 1).

Basic density values indicate that wood quality in small and middle diameter classes has desirable characteristics suitable for the paper and cellulose industry. Pulp and paper producers using products from *Eucalyptus* forests prefer wood density values between 400 to 500 $kg.m^{-3}$. Wood density less than 400 $kg.m^{-3}$ in the pulp and paper industry leads to reduced yield, greater consumption of reagents and a high content of tailings, while density at 550 $kg.m^{-3}$ presents greater difficulties in chopping logs, which leads to wear of the chopping knives.[41]

Volumetric shrinkage was higher in the middle diametric class. In general, *Eucalyptus* spp. have high volumetric shrinkage, especially those from fast-growing trees. Evaluating volumetric shrinkage from seven *Eucalyptus* clones, reported values of 15.9 to 27.2%, a range of variation that fits the classes of small and large diameter for *E. camaldulensis*.[42] However, although the middle class has higher volumetric shrinkage, it inevitably leads to a greater propensity for the occurrence of defects in the drying phase. Furthermore, because of sudden variations in hygroscopic equilibrium humidity, drying techniques must be adopted in every wood piece in order to homogenize wood moisture and subsequently avoid defects in the processing parts.

The anisotropic factor is the relationship between tangential and radial retractability. The ideal situation for wood use, however rarely found, would be one in which the tensions arising from anisotropy would cancel each other out in the direction from which retractability first manifested, with values closer to 1. The importance of this index involves the propensity of wood to crack and warp during dimensional changes caused by hygroscopic variation when the distance from the ideal unit (1) increases. *Eucalyptus* species are known to have high anisotropy because they are a fast- growing species. Thus, our results in three diameter classes show broader satisfaction for wood use at a younger age.

Wood classification criteria for the anisotropic factor: 1.2-1.5, excellent; 1.5-2.0, normal; and above 2.0, poor.[43] According to their scoring system, *E. camaldulensis* wood would be considered normal to excellent, based on dimension class. It would be very stable, would find it useful for building fine furniture, frames, shelves, tables and uses that allow small bends.[44,45]

Closely related to basic density, wood anatomical features define wood quality, allowing it to be classified for the desired uses, e.g., paper and energy.[46-49]

Paper and cellulose industry prefers to use *Eucalyptus* wood up to six years of age since the fibers can be collapsed and hydrated more easily than can be done in older woods.[50] Thus, the use of older trees should be avoided, as adult wood tends to have a higher extractives content and mineral salts, in addition to higher density, which will decrease water permeability, making treatment for paper production more difficult. However, in the absence of production control over different diameter classes, the chips are mixed, and the batches are homogenized, making it difficult to differentiate wood quality for this purpose. Therefore, proposed a classification still used today by paper and cellulose producers.[51] It is a five-point classification known as the Runkel Index, as follows: fibers classified in group I (up to 0.25) are considered excellent for paper, in group II (0.25-0.50), very good, in group III (0.5-1.0), good, in group IV (1.0-2.0), regular, and in group V (above 2.0), they should not be used for paper production based on the low degree of collapse. Based in classification system, in our study, the small class is considered good (0.83), and the middle and large classes are considered regular.[51]

For all diameter classes in our study, wall fraction above 40% is recommended.[51] In practice, producers admit that fibers will be more rigid and difficult to collapse when the wall fraction is higher than 40% and, thus, produce a looser mesh paper without much connection between fibers. As a result, the corresponding papers are more porous, bulky, rough and absorbent.[51] In our study, small class has a value closer to what is considered ideal by the paper and cellulose industry (43.72%). This can be attributed to the shorter fiber as it affects some properties, such as tear resistance and resistance to folds. However, short fibers favor paper production with a more homogeneous pore size distribution, benefiting ink absorption and, consequently, printing.[41]

Flexibility coefficient is related to the degree of collapse that fibers undergo during the papermaking process such that the higher the value, the greater the resistance to breakage and the lower the tensile strength. Thus, in refined short fiber pulps, more intersections and areas of connections available per unit of mass will be found.[52] This is true in the small and middle classes which have greater resistance to rupture and low tensile strength relative to the large diameter class reported values between 0.50-1.00, as observed in the small class, allow the fibers to be classified as flexible, which, when intertwined, tend to form highly resistant paper. Large diametric classes, according to the classification of[53], are considered to exhibit medium interlacing of fiber, requiring greater amounts of reagents to be used for greater brightness of the cellulose pulp and greater compaction and union of fibers. However,[54] mention that species with flexibility coefficient values up to 2.00, as observed in *E. camaldulensis*, are suitable for production of paper with high mechanical resistance and can be used for papers used in writing, printing and packaging.

We observed differences in slenderness ratio among diameter classes, but all were considered satisfactory for paper production. However, the lower this index, the greater the resistance. The large diameter class has a value of 135.37, the highest value observed for this ratio. This occurred because of the presence of high heartwood percentage, longer fibers with thicker walls and smaller lumen. Thicker-walled fibers present greater defibrillation during the refining process, decreasing tensile strength.[41]

A higher calorific value in wood with higher density can be expected, but in our samples, this commonly known pattern was not observed, as the large diametric class presents higher wood density, but HHV did not differ between the large and middle classes. However, energy density was proportional to basic density increase in three diameter classes, inferring that the higher the density, the greater the energy amount stored per cubic meter. Therefore, this characteristic is very important in choosing species for direct wood burning. In addition, the higher wood density results in greater densities and resistance of charcoal, as well as a greater quantity of hanged mass, reducing production costs and increasing productivity of coal units (UPCs) and in the blast furnaces.[55]

Densities between 400 and 560 kg.m^{-3}; thus, whole log in different diameter classes of *E. camaldulensis* can be used for energy production since all values are within the aforementioned range.[56] Emphasize that *Eucalyptus* spp. are widely used in Brazil for bioenergy purposes and that these values are largely dependent on edaphoclimatic conditions, spacing, as well as a combination of factors, such as fiber dimensions, heartwood and sapwood ratio.

A study was carried out in Brazil evaluating the energy quality of *E. benthamii*, *E. dunnii*, *E. grandis*, *E. saligna*, and *E. urograndis*, all widely improved and used in Brazil for energy use at age 7. The study shows HHV results of 18961 to 19501 kJ.kg^{-1},[57] greater than that of *E. camaldulensis*. Genetic variation for energy production, growth characteristics and wood quality of 23 hybrids of 8.5-year-old *Eucalyptus* in China.[58] They reported HHV from 10962 to15815 kJ.kg^{-1}, lower than that observed in our study, allowing us to infer that seeking strategies and investing in genetic improvement through hybridization of *E. camaldulensis* in Brazil can bring benefits in terms of improving energy potential and wood quality since wood adapts well to Brazilian edaphoclimatic characteristics.

Brazilian forestry market admits that HHV values ranging from 16500 to 18000 kJ.kg^{-1} [59] could indicate exploitation of waste for bioenergy, suggesting the potential of *E. camaldulensis* wood for this purpose, i.e., HHV ranges from 16425 to 17056 kJ.kg^{-1}. However, *E. camaldulensis* has the potential to be improved in order to achieve gains and boost energy production and subsequently reduce exploitation of native wood for energy production.

4. Conclusion

Eucalyptus camaldulensis wood at 10 years is characterized by an increase in percentage of heartwood and a decrease in sapwood as tree diameter increases. The basic density was higher in the larger class; however, this was not directly reflected in better results in other physical properties such as VS, which was higher in the middle diameter class. Anatomical features impose limitations on the presence of fines, and fiber dimensions impose limitations on the quality indexes for paper and cellulose, which are important for the industrial use of wood. HHV values ranging from 16500 to 18000 kJ.kg^{-1} could indicate exploitation of waste for bioenergy, suggesting the potential of *E. camaldulensis* wood for this purpose, i.e., HHV ranges from 16425 to 17056 kJ.kg^{-1}. In general, we suggest that trees in the studied spacing and edaphoclimatic conditions have the potential to serve the wood-producing industry, contribute to the forest-based market, and reduce the exploitation of native species for this purpose. Wood quality in different diameter classes shows that *E. camaldulensis* has potential for investment in the technology required to make improvements to boost genetic gains and obtain better wood properties.

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