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Anatomical characterization of black wattle wood for the pulp and paper production

Rodrigo Coldebella[1] Bruna Mohr Giesbrecht[1] Cristiane Pedrazzi[1] Paulo Fernando dos Santos Machado[1] Henrique Weber Dalla Costa[1*] Magnos Alan Vivian[2] Luciano Denardi[1] Claudia Marcia Gomes[1,3]

[1]Programa de Pós-graduação em Engenharia Florestal, Departamento de Ciências Florestais, Universidade Federal de Santa Maria (UFSM), 97105-900, Santa Maria, RS, Brasil. E-mail: hwdallacosta@gmail.com. *Corresponding author.
[2]Departamento de Agricultura, Biodiversidade e Florestas, Universidade Federal de Santa Catarina (UFSC), Curitibanos, SC, Brasil.
[3]Centro de Ciências Agrárias, Ambientais e Biológicas, Universidade Federal do Recôncavo da Bahia (UFRB), Cruz das Almas, BA, Brasil.

ABSTRACT: The growing worldwide demand in the pulp market has fostered research that evaluates alternative fiber sources with specific characteristics that attend the needs of the consumer market, with a view to add value to the final product and reduce production costs. *Acacia mearnsii* De Wild wood is a by-product of the extraction of tannin from the trunk bark, used for firewood, charcoal and pellets. However, its wood is still poorly studied, especially its anatomical characteristics, which can provide important information about its industrial potential. This study evaluated the anatomical characteristics of *Acacia mearnsii* wood for the production of pulp and paper. Ten trees at approximately seven years old were cut down, five from the seed production area (SPA) and five from the clonal population area (CPA). From each tree, one trunk disc was sectioned at the diameter at breast height (DBH), resulting in 10 (ten) wood samples. From each disc, a sapwood specimen was made oriented in the tangential longitudinal, radial longitudinal and transversal planes, for later obtaining the anatomical cuts and the macerates. The anatomical description of the wood followed the recommendations of the International Association of Wood Anatomists-IAWA. From the dimensions of the fibers, their quality evaluation ratios for the production of pulp and paper were calculated. Results obtained from the anatomical characterization allowed to conclude that the *Acacia mearnsii* woods from SPA and CPA are indicated as a source of raw material for the pulp and paper production.
Key words: *Acacia mearnsii*, wood anatomy, fiber morphology.

Caracterização anatômica do lenho de acácia-negra para produção de celulose e papel

RESUMO: A crescente demanda mundial do mercado de polpa celulósica tem fomentado pesquisas que avaliem fontes de fibras alternativas com características específicas que atendam às necessidades do mercado consumidor, visando agregar valor ao produto final e reduzir os custos de produção. No estado do Rio Grande do Sul, Brasil, o lenho de *Acacia mearnsii* De Wild é considerado um subproduto da extração de tanino da casca do tronco, utilizada como lenha, carvão e pellets. No entanto, ainda é pouco estudado, em especial suas características anatômicas, as quais podem fornecer informações importantes sobre suas potencialidades industriais. O presente estudo teve como objetivo avaliar as características anatômicas do lenho de *Acacia mearnsii* para a produção de celulose e papel. Foram coletadas dez árvores com aproximadamente sete anos de idade, sendo cinco provenientes da área de produção de sementes (APS) e cinco da área de povoamento clonal (APC). De cada árvore, foi seccionado um disco do tronco na altura do DAP, resultando em dez amostras de lenho. De cada disco, foi confeccionado um corpo de prova do alburno, orientado nos planos longitudinal tangencial, longitudinal radial e transversal, para posterior obtenção dos cortes anatômicos e dos macerados. A descrição anatômica do lenho seguiu as recomendações da Associação Internacional de Anatomistas da Madeira-IAWA. A partir das dimensões das fibras, foram calculados os seus índices de avaliação da qualidade para a produção de celulose e papel. Os resultados obtidos da caracterização anatômica permitiram concluir que os lenhos de *Acacia mearnsii* provenientes de APS e APC são indicados como matérias-primas para a produção de celulose e papel.
Palavras-chave: *Acacia mearnsii*, anatomia do lenho, morfologia da fibra.

INTRODUCTION

The growing worldwide demand in the pulp market has fostered research that evaluates alternative fiber sources with specific characteristics that meet the needs of the consumer market, aiming to add value to the final product and reduce production costs. According to the Brazilian Tree Industry statistical report (IBÁ, 2021), in 2020, Brazil was the world's largest exporter of bleached hardwood pulp and the second largest global producer, adding the short and long fiber segments, with 20.95 million tons.

Several sources of fibrous materials have been studied in recent years aiming to replace wood, the current and main source of fibers in the pulp and paper industries (KAUR et al., 2017; LIU et al., 2018; SHARMA et al., 2020a). Despite this, wood remains the main raw material used in pulping processes, because it is obtained from planted forests, which are extremely abundant sources of fibers and which have advanced technologies in the improvement of species, in the cultivation techniques and also, in adaptations to industrial processes, resulting in excellent quality pulps.

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According to the IBÁ statistical report (2019), in 2018 the country had a planted area of 161.9 thousand ha of *Acacia* spp., mainly in the Rio Grande do Sul State.

The species *Acacia mearnsii* De Wild (Fabaceae), as known as black wattle, is native from Australia, used mainly for the extraction of tannin from the trunk bark, while wood is considered a by-product, destined for products with little added value, such as firewood, charcoal and pellets, being exported in the form of chips to Asian countries, which are destined mainly for pulp industries (AGEFLOR, 2020).

Thus, *Acacia mearnsii* wood is a viable fiber source from an industrial point of view, with technological potential to be commercially explored (CHAN et al., 2015).

Acacia mearnsii wood, due to its basic density of approximately 0.544 g/cm^3 and low lignin content, can produce pulps with high yield and easy bleachability, being indicated for the production of tissue paper, partly, because it presents anatomical elements with lower mechanical strength when compared to *Eucalyptus* genus woods (GIESBRECHT et al., 2022; SANTOS et al., 2005).

Although, pulp can be manufactured with different fibers, aiming to the production of papers with very different physical and mechanical properties, *Acacia mearnsii* wood is little used for this purpose in Brazil.

The use of *Acacia mearnsii*, a widely cultivated species in the Rio Grande do Sul State, together with the possibility of obtaining pulp with quality and specific characteristics that meet the consumer market, will awaken the interest of national industries that export *Acacia mearnsii* and that use other sources of fiber as raw material for the pulp and paper production, adding value to the plantations of this species.

Thus, this studyevaluate the anatomical characteristics of *Acacia mearnsii* wood from seed production area (SPA) and from the clonal population area (CPA) for potential application in pulp and paper production.

MATERIALS AND METHODS

The present study evaluated wood samples of *Acacia mearnsii* De Wild (Fabaceae) from commercial plantations in Cristal, State of Rio Grande do Sul, Brazil, at the coordinates 30° 59’ 24” S and 52° 2’ 17” W. Ten representative trees at approximately seven years old were studied, five from the seed production area (SPA). and five from the clonal population area (CPA). The trees were randomly selected from the plantations, observing their vigor and health status (absence of apparent diseases), according to D5536-94 standard, of the American Society for Testing and Materials (ASTM, 2010).

From each tree, one trunk disc was sectioned at diameter at breast height (DBH), resulting in 10 (ten) wood samples. From each disc, a sapwood specimen was made oriented in the tangential longitudinal, radial longitudinal and transverse planes, for later obtaining the anatomical cuts and the macerates (Figure 1).

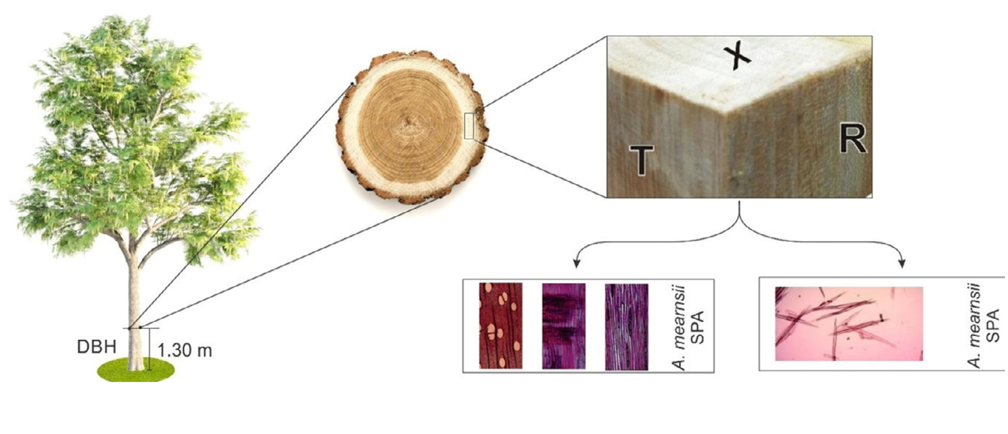

Figure 1 - Experimental scheme for microscopic anatomical characterization of *Acacia mearnsii* woods.

The preparation of the anatomical cuts slides followed the standard technique described by BURGER & RICHTER (1991), with the specimen boiling in water (15 hours), sectioned in a sliding microtome (thickness of 20 µm), stained with safranine and astra-blue, dehydration in increasing alcoholic series (50%, 70%, 90%, absolute alcohol), diaphanization using xylol and mounting of permanent slides with “Entellan”. Dissociation of woody tissue was performed by the nitric-acetic acid maceration method (FREUND, 1970). The other steps for mounting of macerated permanent slides followed the standard technique described by BURGER & RICHTER (1991).

After making anatomical cuts and macerates slides, observations were performed under an optical microscope for description and measurements of morphological parameters, following the recommendations of the International Association of Wood Anatomists-IAWA (WHEELER et al., 1989). The determination of the percentage of different tissues that make up the wood followed the methodology proposed by MARCHIORI (1980). From the measurement of the lumen diameter, width, length and wall thickness of the fibers, fiber quality evaluation ratios for the production of pulp and paper were calculated from the equations 1, 2, 3, 4 (FOELKEL & BARRICHELO, 1975):

$$Runkel\ ratio = \frac{2 \times wall\ thickness\ (\mu m)}{lumen\ diameter\ (\mu m)} \quad (1)$$

$$Flexibility\ ratio\ (\%) = \frac{lumen\ diameter\ (\mu m)}{fiber\ width\ (\mu m)} \times 100 \quad (2)$$

$$Slenderness\ ratio = \frac{fiber\ length\ (mm)}{fiber\ width\ (\mu m) \div 1000} \quad (3)$$

$$Wall\ fraction (\%) = \frac{2\ x\ wall\ thickness\ (\mu m)}{fiber\ width\ (\mu m)} \times 100 \quad (4)$$

The results for each variable of the anatomical characterization of *Acacia mearnsii* woods from seed production area (SPA) and clonal planting area (CPA) were submitted to descriptive statistics, to calculate the number of observations, minimum, maximum, average and standard deviation, using the statistical program R (R CORE TEAM, 2020).

RESULTS AND DISCUSSION

Microscopic description of Acacia mearnsii woods

Figure 2 (A, C, E) shows photomicrographs of *Acacia mearnsii* wood from the SPA, whose microscopic anatomical description is presented below:

Vessels: few (13 ± 2.2 (10 – 17) pores/mm^2) with diffuse porosity, radial multiple pores of 2 – 5 (49%), solitary (40%), and multiple clusters of 3 – 6 (11%), circular or oval (113 ± 22 (60 – 160) µm), thin to thick walls (5.8 ± 1.2 (3.8 – 7.5) µm) (Figure 2A). Short vascular elements (323 ± 72 (200 – 460) µm), with simple perforation plates, oblique or transverse to the vessel, short appendices (34 ± 22 (10 – 100) µm), usually at one end. Small and rounded intervessel pits (6.3 ± 0.6 (5.2 – 7.2) µm), alternate, vestured, sometimes, coalescent, with slit-like aperture included. Vessel-ray pits, similar tointervessel pits, but smaller (4.7 ± 0.4 (4.2 – 5.2) µm). Spiral thickenings, absent. Contents, present. Tylosis, absent.

Axial parenchyma: little abundant; scarce paratracheal, unilateral. Contents, uncommon (Figure 2A). Rare fusiform cells 338 ± 60 (275 – 400) µm high. Parenchymal series 346 ± 87 (175 – 487) µm high, with 2.5 ± 0.7 (2 – 4) cells.

Rays: numerous (6 ± 0.9 (4 – 7) rays/mm), homogeneous, composed entirely of procumbent cells (Figure 2C). Predominant biseriates (48%) of 330 ± 162 (143 – 812) µm and 11 – 66 cells high, triseriates (41%), less commonly tetraseriates (4%); uniseriates (7%), 113 ± 58 (55 – 313) µm and 4 – 19 cells high. Aggregate rays, fused rays and content, absent. Surrounding cells, radial cells with disjoint walls and perforated cells, absent.

Fibers: libriform, 1.160 ± 0.205 (0.800 – 1.520) mm length, 21 ± 3.7 (15 – 28) µm width, and thin to thick walls 3.5 ± 0.6 (2.5 – 4 .4) µm, occupying approximately three fourths of the wood volume (Figure 2A). Gelatinous fibers, present; spiral thickenings, septate fibers and tracheids, absent.

Other characters: cambium variants, laticiferous and tannin tubes, intercellular channels, oil cells, mucilaginous cells, stratification, and medullary macules, absent. Crystals, present.

Figure 2 (B, D, F) shows photomicrographs of *Acacia mearnsii* wood from the CPA, whose microscopic anatomical description is presented below:

Vessels: numerous (22 ± 5.6 (13 – 38) pores/mm^2) with diffuse porosity. Radial multiple pores of 2-8 (44%), solitary (39%), and multiple clusters of 3-10 (17%), circular or oval (123 ± 28 (70 - 163) µm) and thin to thick walls (5 ±1.2 (2.5 – 7.5) µm) (Figure 2B). Medium vascular elements (358 ± 52 (250 – 450) µm), with simple perforation

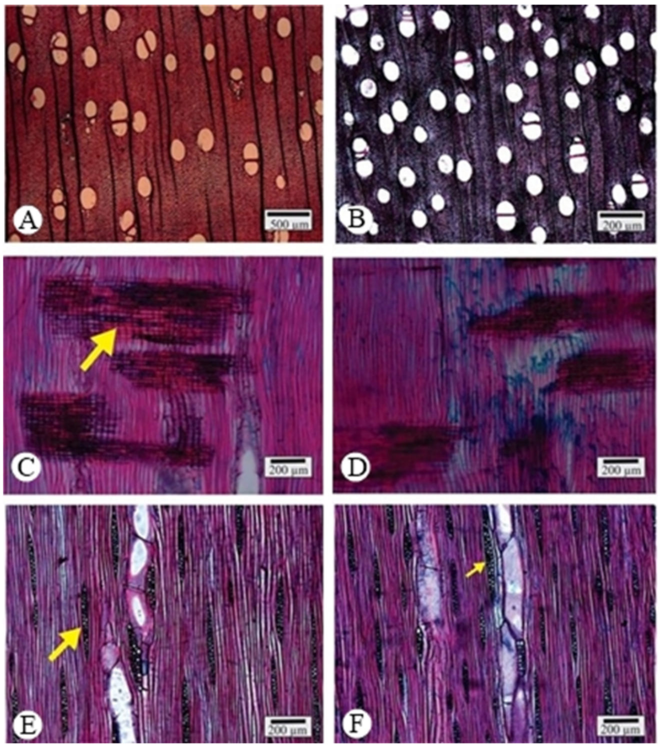

Figure 2 - Photomicrographs of *Acacia mearnsii* wood from the seed production area (SPA) and the clonal population area (CPA).
Source: authors.
Where: A (SPA) and B (CPA) - Cross section: diffuse porosity, solitary and radial multiple pores. C (SPA) and D (CPA) - Radial section: homogeneous radial tissue composed entirely of procumbent cells (arrow). E (SPA) and F (CPA) - Tangential section: multiserial rays with more than 3 cells wide (arrow).

plates, oblique or transverse to the vessel; short appendices (57 ± 41 (10 – 100) µm), usually at one end. Small and rounded intervessel pits (5.5 ± 0.4 (5.2 – 6.2) µm), alternate, vestured, sometimes coalescent, with slit-like aperture included. Vessel-ray pits, similar tointervessel pits, but smaller (4.3 ± 0.6 (3.1 – 5.2) µm). Spiral thickenings, absent. Contents, present. Tylosis, absent.

Axial parenchyma: little abundant, scarce paratracheal, unilateral. Contents, uncommon (Figure 2B). Parenchymal series 295 ± 70 (200 – 450) µm high, with 2.7 ± 0.9 (2 – 5) cells. Rare prismatic crystals.

Rays: numerous (7 ± 0.9 (5 – 8) rays/mm), with cells 21 ± 4.2 (15 – 25) µm wide; homogeneous, composed entirely of procumbent cells (Figure 2D). Predominant biseriates (75%), 228 ± 82 (88 – 438) µm and 5 – 29 cells high, less commonly triseriate (9%); uniseriate (16%), 81 ± 36 (50 – 188) µm and 3 – 13 cells high. Aggregate rays, fused rays and content, absent. Surrounding cells, radial cells with disjoint walls and perforated cells, absent.

Fibers: libriform, 1.042 ± 0.167 (0.700 – 1.420) mm long, 17 ± 3.8 (11 – 25) µm wide, and thin to thick walls 3.2 ± 0.6 (2.5 – 5) µm, occupying approximately two thirds of the wood volume (Figure 2B). Gelatinous fibers, present; spiral thickenings, septate and tracheid fibers, absent.

The anatomical description is close to that described by MARCHIORI & SANTOS (2011), for *Acacia mearnsii* wood. Xylem histometry, *i.e.,* the proportional relationship and the distribution of the tissues that make up the wood, is in accordance with the description by FOELKEL (2008).

Morphological characterization of Acacia mearnsii wood

The dimensions of wood anatomical elements become important in the process of producing pulp for several reasons, ranging from the entry of white liquor into the wood, with the requirement that its capillaries be available and well distributed (FOELKEL, 2008), until the paper properties (FLORSHEIN et al., 2009; NIGOSKI et al., 2012).

The vessel length of *Acacia mearnsii* woods from SPA and CPA were 323 and 358 µm, respectively. These results are in the range of average values (between 200 and 600 µm) found for eucalypt vessel length used for pulp production (FOELKEL, 2007).

The vessel diameters were 113.0 and 122.8 µm and the abundance were 13.0 and 22.0 vessels/mm², for *Acacia mearnsii* woods from SPA and CPA, respectively. These values are within the ranges cited by FOELKEL (2007), for eucalypts used in the manufacture of pulp, where vessel diameters ranged from 60 to 250 µm and frequencies from 3 to 25 vessels per mm². The vessels, with their different dimensions and distributions in the wood, can affect the impregnation stage, because they are anatomical elements that contribute to the penetration and diffusion of the cooking liquor into the interior of the wood (ALVES et al., 2011).

It is important to emphasize that; although, the vessels contribute to the impregnation of chips and, consequently, improve the pulping performance, a high fraction of vessels may be undesirable, because it implies in lower density wood, providing lower productivity at the mill and higher wood consumption (ALVES et al., 2011). For pulps that will be destined for the production of printing and writing papers, QUEIROZ et al. (2004) mentioned that these vessels can be yanked from paper surface during printing, by a process called vessel-picking. This phenomenon is due to vessels adhering to the paper surface, which are easily yanked at the time of printing, resulting in an unprinted area and dirt in the printer (QUEIROZ et al., 2004).

The proportions of axial parenchyma of *Acacia mearnsii* woods from SPA and CPA were 3.16 and 3.83%, respectively. Due to their dimensional characteristics, these cells interfere unfavorably in the inter-fiber bonds, damaging the paper strength (BARRICHELO & BRITO, 1976). However, the values obtained for the woods in this study are lower when compared to those found for the *Eucalyptus* genus (OLIVEIRA et al., 2012).

In addition to the vessels, the proportion of radial parenchyma and its distribution can influence the entry of white liquor into the wood (FOELKEL, 2007). The values reported for the proportions of radial parenchyma of *Acacia mearnsii* woods from SPA and CPA were 10 and 11%, respectively, which is close to the values found by RAMOS et al. (2011) for *Eucalyptus grandis* wood (11 to 13%). Conversely, FOELKEL (2008) reported that *Acacia mearnsii* wood contains a lower proportion of radial parenchyma (5 to 7%) when compared to the *Eucalyptus* genus.

The abundant presence of parenchymal cells does not favor pulp refining, because they are anatomical elements that produce many fines during this process (LI & HE, 2009). In addition, the parenchyma cells, when present in the pulp, increased the adhesion of the sheet to the rolls in the paper machine, increasing the frequency of breaks of the formed sheet (SPERANZA et al., 2009).

Fiber characteristics, mainly morphology and anatomy, have a great impact on the strength properties of the paper sheet (SHARMA et al., 2020b). The proportions of fibers in *Acacia mearnsii* woods from SPA and CPA were 74 and 67%, respectively, being considered high (CHOWDHURY et al., 2013), indicating that these woods would produce pulps with high yield.

Fiber lengths of *Acacia mearnsii* woods from SPA and CPA were 1.16 and 1.04 mm, respectively, being considered average, because they comply between the range from 0.9 to 1.6 mm (METCALFE & CHALK, 1983). These results are close to those found by SEGURA (2012) and MARCHIORI (1990) for fiber lengths of *Acaciamearnsii*, i.e., 0.94 mm and from 0.95 to 1.52 mm, respectively. The fiber length influences the tensile strength, tear strength, formation and uniformity of the paper sheet (SHARMA et al., 2020b).

The values for fiber cell wall thickness of *Acacia mearnsii* woods from SPA and CPA were 3.4 and 3.2 µm, respectively, allowing them to be classified as thick-walled fibers, because they comply between the range from 3 to 5 µm, according to the classification proposed by MANIMEKALAI et al. (2002). These results are close to those reported by MARCHIORI (1990) and SEGURA (2012) for *Acacia mearnsii* woods, i.e. 3.3 µm and smaller than 4.2 µm, respectively. However, they are smaller than those found for *Eucalyptus* woods by FERREIRA et al. (2006) and GOMIDE et al. (2005), i.e. 4.83 µm and 4.8 to 5.2 µm, respectively.

Fiber lumen diameters of *Acacia mearnsii* woods from CPA (10.8 µm) and SPA (13.6 µm) were close to those evaluated by SEGURA (2012) for *Acacia mearnsii* wood and also by ALZATE

(2004) and FERREIRA et al. (2006), for *Eucalyptus* sp. woods. These lumen diameter and fiber wall thickness dimensions indicate that the woods used in this study will favor the liquor impregnation step in the wood, resulting in greater uniformity and yield cooking (FOELKEL, 2007).

Fiber quality ratios for pulp and paper production

Although, all the cellular elements making up the wood are important, the indication of a species for pulp and paper production must meet the requirements determined by the ratios derived from the fibers, whose results for *Acacia mernsii* wood fibers from SPA and CPA are presented in table 1.

The smaller the Runkel ratio value in relation to the unit, the greater the pulp strength, and the better the bounds between the fibers in the paper (FOELKEL & BARRICHELO, 1975). *Acacia mearnsii* woods from SPA and CPA are within category III (between 0.5 and 1.0) for the Runkel ratio, being considered good for paper (RUNKEL, 1952).

According to FLORSHEIM et al. (2009) and NISGOSKI et al. (2012), the higher the value of the flexibility coefficient, the more flexible and the less susceptible to break the fiber will be; consequently, producing papers with greater tensile and burst strength. The flexibility coefficients of *Acacia mearnsii* woods from PSA (66.3%) and CPA (62.6%) are in the range from 50 to 75%, according to the classification presented by NISGOSKI (2005), indicating good contact surface and bond between the fibers in the paper structure. The values observed for the fiber flexibility coefficients of *Acacia mearnsii* woods in this study were higher than those of *Eucalyptus* sp., verified by FERREIRA et al. (2006), FLORSHEIM et al. (2009) and COSTA (2011).

Fiber slenderness ratio is directly related to the paper tear and double folds strength (FOELKEL & BARRICHELO, 1975). ROCHA & POTIGUARA (2007), and BENITES et al. (2015) mentioned that this value must be greater than 50 for paper production, which was found for *Acacia mearnsii* wood from CPA (60.4) and SPA (56.6) in this study.

For NISGOSKI et al. (2012), high wall fraction values indicate that the fibers are rigid, reducing the number and the strength of bonds between fibers in paper production, damaging its strength. The wall fraction values for *Acacia mearnsii* woods from SPA (33.7%) and CPA (37.4%) are below 40%, a limit established for the fiber wall fraction aiming paper manufacturing (FOELKEL & BARRICHELO, 1975). The values reported in this study were lower than 42.25%, found by BUSNARDO et al. (1986) for fiber wall fraction of *Acacia mearnsii* wood.

CONCLUSION

The results obtained from the anatomical characterization of *Acacia mearnsii* woods allowed the following conclusions: The values of Runkel ratio, flexibility coefficient, slenderness ratio and wall fraction are within the acceptable range for pulp and paper production. The *Acacia mearnsii* wood from SPA and CPA are indicated as a source of raw material for the pulp and paper production.

Table 1 - Fiber quality ratios of *Acacia mearnsii* woods from seed production area (SPA) and clonal planting area (CPA) for pulp and paper production.

Qualityratios	---------------------------------------*Acaciamearnsiiwoods*---------------------------------------	
	SPA	CPA
Runkelratio	0.51	0.60
Flexibilitycoeficient (%)	66.34	62.61
Slendernessratio	56.60	60.43
Wall fraction (%)	33.66	37.39

Source: authors.

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DECLARATION OF CONFLICT OF INTEREST

We have no conflict of interest to declare. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

The R. C., B. M. G., C. P., P. F. M., H. W. D. C. authors contributed equally for the conception and writing of the manuscript. M. A. V., L. D., C. M. G. contributed for the writing of the manuscript. All authors approved of the final version.

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