Pesquisa Agropecuária Brasileira

Forestry/ Original Article

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Evolution of canker severity and stem quality on African mahogany growth

Abstract – The objective of this work was to investigate the influence of the qualitative traits canker severity and stem quality on the mean annual increment (MAI) in diameter, total height, and stem height of an African mahogany (*Khaya grandifoliola*) stand. The study area is located in the state of Minas Gerais, Brazil, where continuous forest inventories were conducted over six years for data collection. Given the nonparametric characteristic of the data, an aligned rank transform analysis of variance was performed for each factor, and the averages were compared by Dunn's multiple test. There was no significant effect of the interaction between the classes of canker severity and stand age. Increased canker severity has a significant effect on MAI values, causing reductions of 13% in diameter, 11% in total height, and 21% in stem height in trees from the highest canker severity class, when compared with the healthy ones. Age interacts significantly with stem quality, and MAI values tend to be similar in younger trees, differing over time in the oldest ones. In addition, the highest MAI values are recorded in trees with the best stem classification.

Index terms: *Khaya grandifoliola*, forest management, forest protection, silviculture.

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Received
May 17, 2023

Accepted
September 11, 2023

How to cite
RIBEIRO, A.; SANGIOGO, M.; SOUSA, R.M. de; FERRAZ FILHO, A.C. Evolution of canker severity and stem quality on African mahogany growth. **Pesquisa Agropecuária Brasileira**, v.58, e03380, 2023. DOI: https://doi.org/10.1590/S1678-3921.pab2023.v58.03380.

Evolução da severidade do cancro e qualidade de fuste no crescimento do mogno-africano

Resumo – O objetivo deste trabalho foi investigar a influência das características qualitativas severidade do cancro e qualidade do fuste sobre o incremento médio anual (IMA) em diâmetro, altura total e altura de fuste de um talhão de mogno-africano (*Khaya grandifoliola*). A área do estudo se localiza no estado de Minas Gerais, Brasil, onde inventários florestais contínuos foram realizados por seis anos para a coleta dos dados. Pela característica não paramétrica dos dados, foi realizada uma análise de variância de transformação de postos alinhados para cada fator, e as médias foram comparadas pelo teste múltiplo de Dunn. Não houve interação entre as diferentes classes de severidade de cancro e a idade do talhão. O aumento da severidade do cancro tem efeito significativo sobre os valores de IMA, causando reduções de 13% em diâmetro, 11% em altura total e 21% em altura do fuste nas árvores da classe de severidade mais alta, em comparação às sadias. A idade interage significativamente com a qualidade do fuste, e o valores de IMA tendem a ser semelhantes nas árvores mais jovens, diferenciando-se posteriormente nas mais velhas. Além disso, os maiores valores de IMA são registrados nas árvores com melhor classificação de fuste.

Termos para indexação: *Khaya grandifoliola*, manejo florestal, proteção florestal, silvicultura.

Introduction

The expansion of African mahogany plantations in Brazil, predominantly of *Khaya grandifoliola* C.DC. (Ferraz Filho et al., 2021), implies the need for more research on the domestication of the species, improving silvicultural and forest management practices to achieve satisfactory growth, while ensuring adequate economic returns.

African mahogany stands are commonly affected by stem canker, a disease first reported in Brazil in 1998, in the state of Bahia (Müller et al., 2002). The causal agent of *K. grandifoliola* canker is yet unknown, although, according to Coelho et al. (2021), cankers are frequently related to *Ectomyelois muriscis* (Dyar, 1914) (Lepidopetra: Pyralidae) larvae and have also been associated with the fungus *Lasiodiplodia theobromae* (Pat.) Griffon & Maubi, 1909, considered a secondary pathogen that likely penetrates into mahogany wood through wounds caused by other biotic and abiotic agents (Tremacoldi et al., 2013; Webber et al., 2021). The presence of lesions and cankers along the stem of species from the genus *Khaya* have been documented by Tremacoldi et al. (2013) and Coelho et al. (2021), but without investigating possible influences of this disease on tree growth.

Tree growth is largely controlled by the abiotic and biotic conditions prevailing in the stand (Bourque et al., 2019) and is commonly expressed by the mean annual increment (MAI) in different variables (West, 1980; Bourque et al., 2019). However, management planning and decision making must also consider the value of forest outputs, which requires realistic evaluations of tree quality. In this context, investigating tree growth as a function of stem quality is important, which is unprecedented for African mahogany stands.

Stem quality can be evaluated during a forest inventory due to its visible properties and signs, differently from internal wood quality, whose physical properties are difficult to determine on standing trees (Bosela et al., 2016). It is also an important characteristic in trees intended for noble uses (e.g. sawn wood) since, when logs are mechanically processed, tortuous ones potentially generate a greater amount of residual wood and, consequently, a lower sawn-wood yield than straight ones (Nassur et al., 2013; Anjos & Fonte, 2017). Therefore, information on stem quality is a key variable for planning precision forestry operations, enabling the optimization of thinning and harvesting activities (Söderbergh & Ledermann, 2003; Holopainen et al., 2014; Holzleitner et al., 2019). However, studies that relate the growth of forest species with qualitative characteristics, such as stem quality and plant health, are still scarce in the literature, especially for African mahogany.

The objective of this work was to investigate the influence of the qualitative traits canker severity and stem quality on the MAI in diameter, total height, and stem height of an African mahogany stand.

Materials and Methods

The trial was conducted in an area of 56.5 hectares with a *Khaya grandifoliola* stand, planted in March 2010, in a wide spacing of 6x6 m, without any thinning operation up to the last measurement date. The area is located in the Florestas da Canastra farm, in the municipality of São Roque de Minas, in the state of Minas Gerais, Brazil (20º07'S, 46º28'W, at 840 m altitude). According to Köppen-Geiger's classification, the climate of the region is Cwb, subtropical highland, with an average monthly temperature of 18.8°C (ranging from 15.4 to 20.9°C in July and February, respectively) and an annual rainfall from 1,200 to 1,800 mm (Alvares et al., 2013). The Latossolo, i.e., Ferralsol, is the predominant soil class in the region (Santos et al., 2018).

The evaluation of tree growth through continuous forest inventories began in 2011. However, the qualitative variables (canker severity and stem quality) were monitored from the fifth measurement onwards, that is, starting at 5.2 years, in 2015, and the study database was computed from that age up to 11.4 years, in 2021 (Table 1).

Table 1. Average values and standard deviation obtained for the dendrometric variables of an African mahogany (*Khaya grandifoliola*) stand, planted in 2010, in the municipality of São Roque de Minas, in the state of Minas Gerais, Brazil, using data collected from 2015 to 2021.

Stand age (years)	Diameter (cm)	Total height (m)	Stem height (m)
5.2	17.6±2.5	12.7±1.7	7.2±1.2
6.2	20.7±3.2	14.6±2.4	8.7±1.7
7.2	23.2±3.8	16.3±2.4	8.5±1.4
8.4	25.2±4.4	18.4±2.5	8.3±1.3
9.3	26.9±4.8	19.9±2.5	8.4±1.4
10.4	28.3±5.3	20.7±2.6	8.5±1.8
11.4	29.5±5.7	21.0±2.7	8.5±1.7

Quantitative and qualitative variables were measured in all trees of a 27 sample in a fixed circular area of 800 m^2 per plot. To obtain tree diameter at breast height (cm), circumference was determined at 1.30 m from the soil using a measuring tape and, then, converted to diameter at breast height. Tree height (total and stem), expressed in meters, was measured using the Vertex IV hypsometer (Haglöf Sweden, Långsele, Sweden).

For the classification of the variables stem quality and canker severity in *K. grandifoliola* trees, two visual scales, following an ordinal dimension, were created by the authors of the present study (Figure 1). Stem quality was classified in the three following classes: SQ1, straight stems, yielding at least two 3.0 m logs for sawn wood production and with no large visible defects, such as tree damage, forking, and large lower branches; SQ2, stems with small defects, yielding at least one 3.0 m log for sawn wood production; and SQ3, stems with a large curvature or large defects, not yielding at least one log for sawn wood, indicating trees that should be preferably removed in thinning operations (Figure 1 A). The canker classes were: C0, with no visible canker incidence in the tree stem; and C1 to C3, with an increasing severity of canker

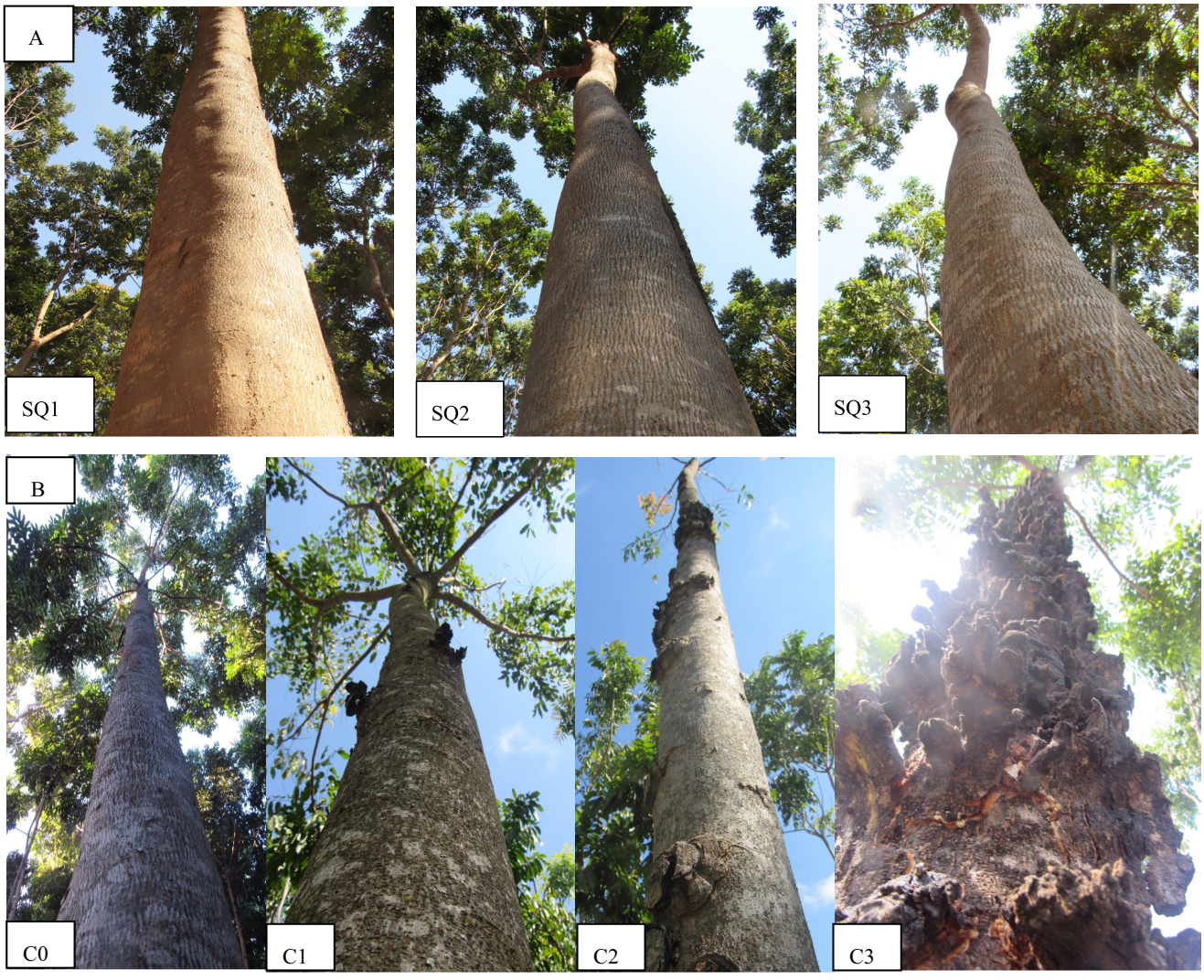

Figure 1. Visual scales established by the authors for the classification of stem quality (A) and canker severity (B) in the evaluation of African mahogany (*Khaya grandifoliola*) trees. Stem quality classes: SQ1, no visible defects; SQ2, small defects; and SQ3, large curvature or large defects. Canker severity classes: C0, no visible canker incidence; and C1 to C3, an increasing severity of canker occurrence, covering around 10, 10–50, and > 50% of the stem area, respectively. Photos by Andressa Ribeiro.

occurrence, covering around 10, 10–50, and > 50% of stem area, respectively (Figure 1 B).

The MAI was used to indicate possible effects of tree quality attributes on single-tree growth. The MAI in diameter and heights was calculated by tabulating all data in a spreadsheet and excluding mortality and resprout data in the stand from the database, totaling 579 trees in each measurement and 4,053 observations over the ages of the stand. The average tree canker incidence at a plot level, defined as the percentual of trees from C1, C2, and C3 in relation to the healthy trees from C0, was also assessed.

Statistical analyses were performed in the R software (R Core Team, 2021), evaluating the evolution of the percentage of plants in the different classes of the qualitative characteristics. Given the nonparametric characteristic of the data, the aligned rank transform analysis of variance (ANOVA-ART), available in the ARTools package (Kay et al., 2021), was used for the statistical analyses, at 5% probability. Since the interaction between the analyzed variables was significant, Dunn's nonparametric multiple comparison test was applied at 5% probability, using Bonferroni's correction, with the dunn.test function (Dinno, 2017).

Results and Discussion

The studied qualitative characteristics of the *K. grandifoliola* stand showed that the percentage of healthy trees decreased from approximately 80 to 20% from 5 to 11 years of age (Figure 2). Contrastingly, trees with canker incidence (C1, C2, and C3) increased, especially those with a high canker severity (C3) (Figure 2 A), which was generally more pronounced after the stand reached 8 years of age. This implies in a considerable increase in the incidence of trees with canker over time if phytosanitary measures are not implemented. Coelho et al. (2021) studied a 4.5-year-old *K. grandifoliola* stand, located in the municipality of Prata, also in the state of Minas Gerais, and found an average canker incidence at plot level of 12% (maximum of 45%), similar to that of 17% (also maximum of 45%) at 5 years of age observed in the present study. In addition, by 11.4 years of age, average canker incidence at plot level increased to 73%, with a maximum value of 92%. Regarding the values of stem quality, significant variations were registered between 5 to 6 years, with a subsequent stabilization, mainly for the best stem quality, i.e., for SQ1 (Figure 2 B).

There was no significant interaction between canker severity effect and the MAI values of the dendrometric variables diameter and heights over the years on the different stand ages ($p=0.756$ for total height, $p=0.357$ for stem height, and $p=0.717$ for diameter at breast height). However, there was a significant difference ($p<0.05$) between canker severity classes and MAI values, using Dunn's test for mean comparison (Figure 3). Regardless of the origin of canker, there are no known studies about its impacts on the dendrometric parameters of commercial stands of *K. grandifoliola*. Therefore, this is the first report describing the effects of canker on the MAI values of diameter at breast height, total height, and stem height of *K. grandifoliola* stands in Brazil over the years.

Regarding canker severity, MAI values were not influenced by stand age (Figure 3). However, as the canker class increased, the average MAI values decreased from

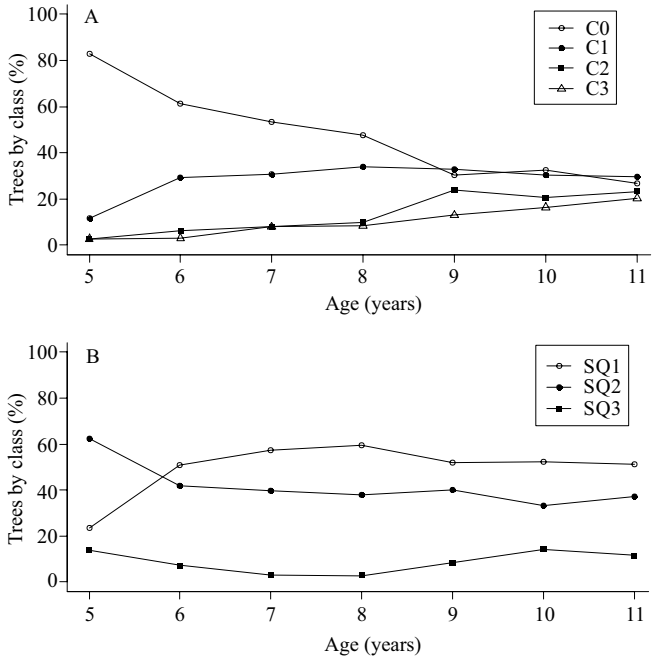

Figure 2. Evolution of percentage of trees by classes of canker severity (A) and stem quality (B) of an African mahogany (*Khaya grandifoliola*) stand, planted in 2010, in the municipality of São Roque de Minas, in the state of Minas Gerais, Brazil. Canker severity classes: C0, no visible canker incidence; and C1 to C3, an increasing severity of canker occurrence, covering around 10, 10–50, and > 50% of the stem area, respectively. Stem quality classes (SQ): SQ1, no visible defects; SQ2, small defects; and SQ3, large curvature or large defects.

1.2 to 0.9 m per year for stem height (Figure 3 A), from 2.3 to 1.9 m per year for total height (Figure 3 B), and from 3.1 to 2.7 cm per year for diameter at breast height (Figure 3 C) from the highest to the lowest canker severity class, i.e., from C3 to C0. For all evaluated variables, the lowest canker severity classes differed significantly from the highest ones, except C2 and C3 for stem height, which presented similar MAI values.

The results of the ANOVA-ART for stem quality showed an interaction between stand age and MAI values ($p<0.05$), which is why the effect of age was included in the average comparison test for total height, stem height, and diameter at breast height (Figure 4 A, B, and C). At almost all evaluated ages, MAI values differed between all evaluated variables, being the highest in the best stem classes, except at

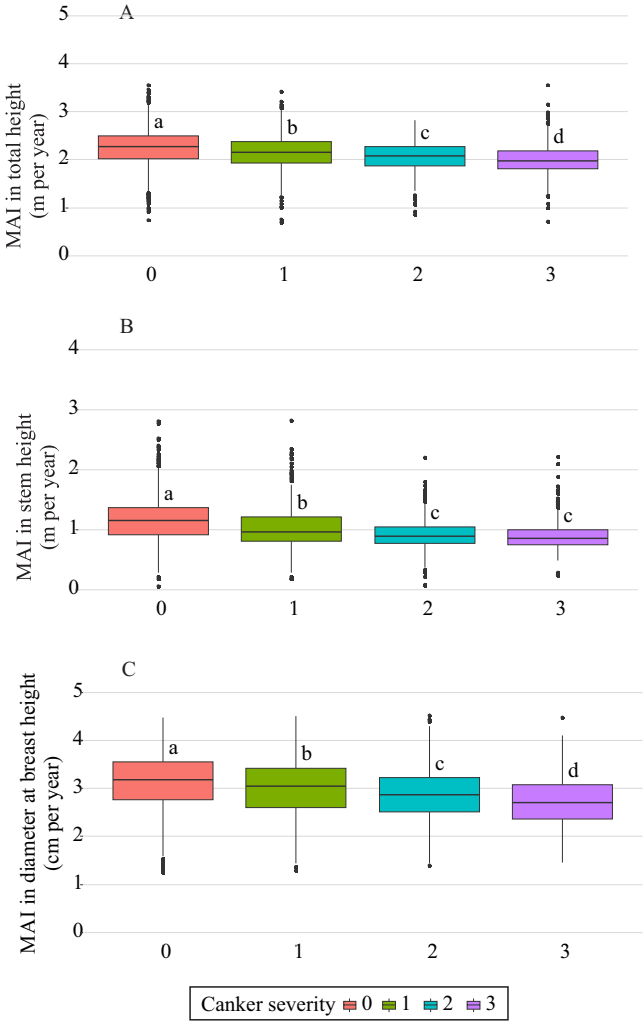

Figure 3. Dunn's multiple comparison test relating the effect of the different canker severity classes to the mean annual increment (MAI) in total height (A), stem height (B), and diameter at breast height (C) in an African mahogany (*Khaya grandifoliola*) stand, planted in 2010, in the municipality of São Roque de Minas, in the state of Minas Gerais, Brazil. Canker severity classes: C0, no visible canker incidence; and C1 to C3, an increasing severity of canker occurrence, covering around 10, 10–50, and > 50% of the stem area, respectively.

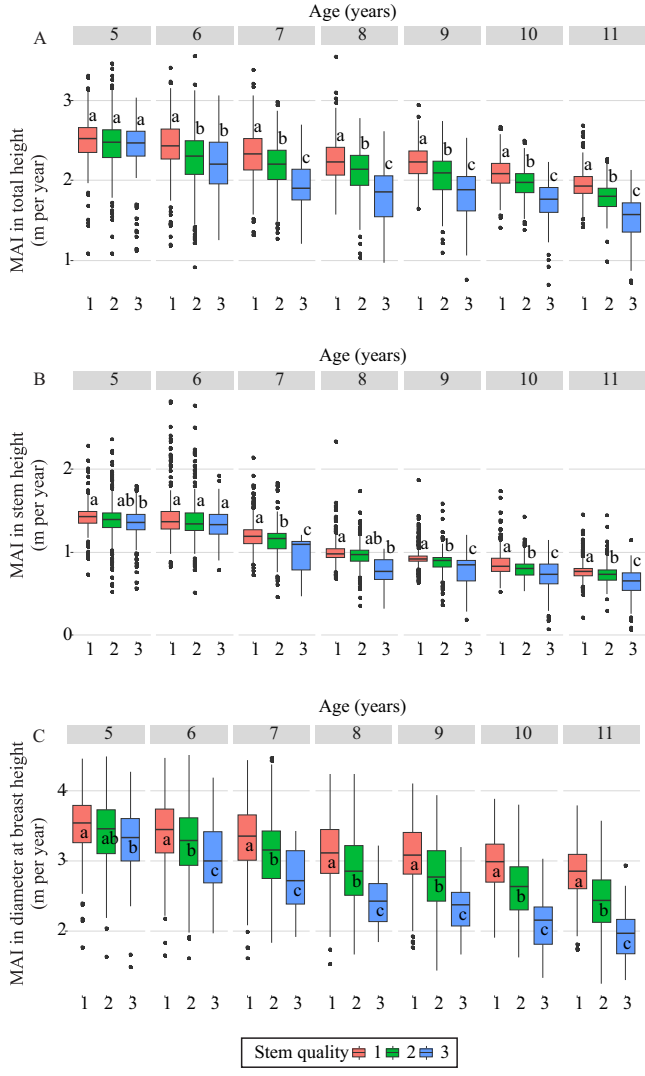

Figure 4. Dunn's multiple comparison test relating the effect of stem quality classes to the mean annual increment (MAI) in total height (A), stem height (B), and diameter at breast height (C) at different ages of an African mahogany (*Khaya grandifoliola*) stand, planted in 2010, in the municipality of São Roque de Minas, in the state of Minas Gerais, Brazil. Stem quality classes: 1, no visible defects; 2, small defects; and 3, large curvature or large defects.

the youngest ages, which showed similar values. According to Diao et al. (2022), although plantations with a larger initial spacing (as is the case of most *Khaya* spp. stands in Brazil) are widely used to reduce the number of thinning treatments, shorten rotation age, reduce establishment costs, and accelerate the growth of individual trees, there are also negative effects, including a large stem taper and branch sizes.

According to Nicoletti et al. (2016) and Krajnc et al. (2019), stem shape varies from plant to plant according to site conditions, initial planting density, applied silvicultural treatments, and sociological position in which each tree develops, as well as to age, either as a natural evolutionary phenomenon or as a result of the several stages of competition between neighboring trees. From the age of 6 years onwards, trees begin to compete with each other, showing reduced growth rates, which requires stand thinning to promote growth. Therefore, evaluating tree growth according to qualitative characteristics is crucial to support silvicultural treatments, such as thinning, resulting in important data for forest management.

The obtained results are an indicative that trees with a better stem quality (SQ1) have higher MAI values for diameter at breast height (3.1 cm per year) and height (2.2 m per year) than those with more tortuous stems (2.5 cm per year and 1.9 m per year, respectively). Reis et al. (2021) characterized the morphometry of *Khaya senegalensis* (Desr.) A.Juss. trees in a 4-year-old stand in the state of Minas Gerais, concluding that stem quality has a linear relationship with diameter, with MAI values of 2.3 cm per year for diameter at breast height and 1.3 m per year for total height. Ribeiro et al. (2017) studied the production of *Khaya* spp. in Brazil and observed an average diameter of 18.3 cm at 4.4 years of age, with a MAI of 4.2 cm per year. However, despite the relatively close age between these stands, previous studies have indicated that the growth of *K. senegalensis* is slower than that of other *Khaya* species (Reis et al., 2021). Contrastingly, Araujo (2016), found no significant correlation between stem quality and MAI in diameter when evaluating the growth of 31 Amazonian commercial timber species.

Since the shape and health of trees are affected by several environmental factors, studying each one individually can lead to premature conclusions due to the many interactions found in ecosystems (Krajnc et al., 2019). Therefore, to better infer forest management and domestication of African mahogany, further studies should be conducted, including more variables such as crown size, thinning effect, and wood quality.

In addition, the influence of canker on *K. grandifoliola* wood quality and suitability for use is not yet known. However, in the municipality of Caçu, in the state of Goiás, Brazil, where farmers are applying the first commercial thinning in young stands around 10 years of age, irregular and peculiar grain patterns can be observed in sawn wood from trees with canker (Figure 5). The

Figure 5. Irregular grain patterns in African mahogany (*Khaya grandifoliola*) sawn wood caused by the presence of canker on a ten-year-old tree planted in the municipality of Caçu, in the state of Goiás, Brazil. Photo by Daniela Cursino Romão.

eccentric grain patterns that canker incidence causes on African mahogany sawn wood might be desirable for design purposes, which could lead forest managers to actively select these trees for the final crop. For instance, the wood from tree burls, characterized as an abnormal growth on the outside layer of a tree, presents a highly irregular and unique grain pattern that is highly prized for its beauty and rarity, used in the manufacturing of fine furniture and wood sculptures (Schoonover, 1955; Huang et al., 2020). Therefore, a possible higher price of sawn wood from a tree with canker incidence might offset the reduction in tree growth caused by this disease. However, further investigation on the possible negative effects of *K. grandifoliola* canker on physical and mechanical wood properties are still necessary to confirm these statements.

Conclusions

1. Increased canker severity has a significant effect on the mean annual increment of dendrometric variables, reducing diameter at breast height, total height, and stem height in 13, 11, and 21%, respectively, when comparing *Khaya grandifoliola* trees from the highest canker severity class to the healthy ones.

2. The effect of stem quality on tree growth becomes more evident in older trees, and the greatest increment values are recorded in the best stem classes.

Acknowledgments

To Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for financial support (grant number 306738/2018-0).

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