








## ORIGINAL ARTICLE

# Morphometric characterization of *Khaya senegalensis* in southern Minas Gerais State, Brazil

*Caracterização morfométrica de Khaya senegalensis no sul de Minas Gerais, Brasil*

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## Abstract

Understanding the morphometry patterns of planted trees is an essential forestry methodology to develop accurate silvicultural practices. The genus *Khaya* comprises several economically important tree species due to its high quality of the wood and it has been broadly implemented in economical plantations. Here, we analyzed the morphometric characteristics of *Khaya senegalensis* (Desv.) A. Juss. from 484 trees in a 4 years-old plantation located in Southern Minas Gerais state, Brazil. Therefore, we measured the diameter at breast height (DBH), total height (TH), and crown insertion height (CIH). Using those variables, we estimated the crown length (CL), the slenderness ratio (SR), and the crown proportion (CP). The crown quality (CQ) and stem quality (SQ) were estimated by visual grading. We then performed regression models for all morphometric variables to analyze the distribution of each one. The survival analysis and mean annual increment at 4 years of age (48 months) were calculated. We used the Spurr model to estimate the population volume. The SR and CL variables showed high levels of variation. Most morphometric variables, except for SC, presented a significant correlation with DBH. The SQ and CQ presented a linear relationship with the size of the tree. As expected, tree diameter increased with the best quality of crowns and stems. We found a low morphometric relationship between TH and DBH. On the other hand, a linear trend was found with the increase of DBH, CL, and CP. The percentage of survival and the mean annual increment at 4 years of age were 97.2% and 3.31 m<sup>3</sup>/ha/year, respectively. The characterization revealed a good adaptation of the species within the plantation area in Southern Minas Gerais State. However, further and periodical analysis should create a robust database and make more assertive inferences of the morphometric variables.

**Keywords:** African mahogany; Alternative species; Silvicultural characteristics.

## Resumo

Compreender os padrões morfométricos das árvores plantadas é uma metodologia florestal essencial para desenvolver práticas silviculturais precisas. O gênero *Khaya* compreende várias espécies de árvores economicamente importantes devido à alta qualidade da madeira e tem sido amplamente implantado em plantações econômicas. Aqui, analisamos as características morfométricas de *Khaya senegalensis* (Desv.) A. Juss. de 484 árvores em uma plantação de 4 anos localizada no sul do Brasil. Medimos o diâmetro na altura do peito (DAP), altura total (HT) e altura de inserção da coroa (CIH). Usando essas variáveis, estimamos o comprimento da copa (CL), o grau de esbeltez (SR) e a proporção da coroa (CP). A qualidade da copa (CQ) e qualidade do fuste (SQ) foram estimadas por meio de notas visuais. Em

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seguida, utilizamos modelos de regressão para todas as variáveis morfológicas com o objetivo de analisar a distribuição de cada variável. A análise de sobrevivência e incremento médio anual (IMA) aos 4 anos de idade (48 meses) foram calculados. Usamos o modelo de Spurr para estimar o volume da população. As variáveis SR e CL apresentaram altos níveis de variação. A maioria das variáveis morfológicas, exceto o CL, apresentou correlação significativa com o DAP. O SQ e o CQ apresentaram relação linear com o tamanho da árvore. Como esperado, o diâmetro da árvore aumentou com a melhor qualidade da copa e fuste. Encontramos uma relação morfológica baixa entre HT e DAP. Por outro lado, foi encontrada uma tendência linear com o aumento do DAP, CL e CP. A análise de sobrevivência resultou em 97,2% de sobrevivência aos 4 anos de idade com incremento médio anual (IMA) de 3,31 m<sup>3</sup>/ha/ano. A caracterização revelou uma boa adaptação da espécie dentro da área de plantio no Sul de Minas Gerais. No entanto, análises posteriores e periódicas devem ser realizadas para criar um banco de dados robusto e fazer inferências mais assertivas sobre as variáveis morfológicas.

**Palavras-chave:** Mogno africano; Espécies alternativas; Características silviculturais.

## INTRODUCTION

The intensive need for forest products along with the increasing awareness about deforestation has intensified the use of forest species with economic potential. In the last decades, exotic species with superior performances have been mainly used to supply the intensive demand for timber and wood products, in which reforestation programs have become sustainable alternatives with huge economic interest (Pinheiro et al., 2011; Corcioli et al., 2016). As a result, species of the genus *Khaya*, popularly known as “African mahogany” have aroused interest as an option for reforestation in Brazil, since its wood presents similar characteristics to the Brazilian mahogany (*Swietenia macrophylla*). After the prohibition of the exploitation and commercialization of *S. macrophylla* in Brazil, the mahogany species have been intensely planted as an alternative (Couto et al., 2004)

Among the several species of the genus *Khaya*, four species are the most planted in the Brazilian reforestation programs: *Khaya ivorensis*, *Khaya senegalensis*, *Khaya anthotheca*, and *Khaya grandiflora* (Pinheiro et al., 2011). The first plantations of *Khaya* spp. in Brazil occurred in 1976 located in the northern region. However, the growing demand for tropical timber has been driving investments of commercial plantations throughout the country (Ribeiro et al., 2017). Furthermore, it is expected that more than 30,000 hectares have now been planted throughout Brazil (Indústria Brasileira de Árvores, 2019).

The rapid growth and the resistance of African mahogany against the shoot borer *Hypsipyla grandella*, the main pest of the Brazilian mahogany (*S. macrophylla*), contributed to the expansion of its plantations in Brazil (Ribeiro et al., 2017). According to Lunz et al., (2009), the African mahogany presents a good adaptation to the Brazilian climate that allows the plantation through almost all regions of the country. Casaroli et al. (2018) evaluated the edapho-climatic aptitude for *Khaya ivorensis* in the Brazilian territory and have found that the country shows great potential for the cultivation of this species since they found 56% of the Brazilian territory was considered suitable for this species, 12% presenting slight restrictions and 25% are appropriate with moderate restrictions

*K. senegalensis* presents several advantages over other species, such as better resistance against pests and water deficit during drought periods up to seven months. The species also presents efficient adaptations for regions with precipitation between 650 and 1,800 mm (Pinheiro et al., 2011). Despite being a promising economic species, the commercial plantation of *K. senegalensis* is still recent and it is in the first domestication stages (Nikles et al., 2008).

Several studies have been carried out in order to understand the behavior of African mahogany species in Brazil (Corcioli et al., 2016; Ribeiro et al., 2017; Casaroli et al., 2018). However, there is a lack of information about the best conditions for its implantation and growth, which may imply lower production and, consequently, create financial losses (Casaroli et al., 2018). Understanding the silvicultural, qualitative, and quantitative characteristics of *K. senegalensis* is an important step that may contribute to its cultivation. Additionally, it is also important to choose the best type of silvicultural intervention, the intensity of exploitation, the regeneration capacity, and growth patterns (Ribeiro et al., 2017).

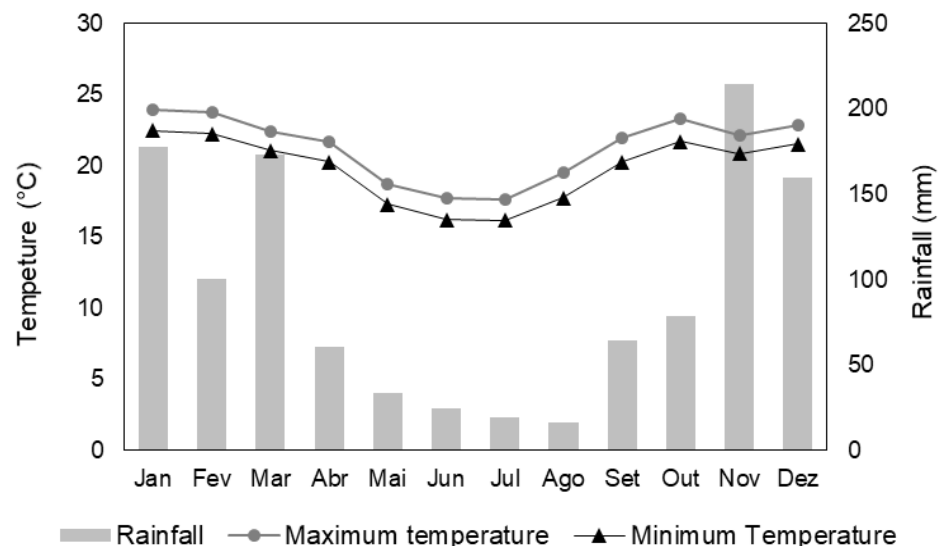
The analysis of morphometric relationships and tree dynamics is essential to improve silvicultural practices (Roman et al., 2009). Morphometry is also focused on understanding the interdimensional relationships, reconstructing the space that each tree occupies along with its development, determining the degree of competition between species, and inferring about the stability, vitality, and productivity of tree individuals (Cunha et al., 2013; Costa et al., 2016). The main morphometric characters of the tree species are diameter, area, projection, volume, crown percentage, slenderness ratio, salience, and comprehensiveness (Durló & Denardi, 1998).

Information about shape and dimension comprises useful data for the development of mathematical and statistical models of tree growth and competition between individuals (Hasenauer et al., 1994). In Brazil, some studies have been carried out to analyze morphometric variables considering the diameter at breast height (*DBH*) of several species (Durló, 2001; Cunha & Finger, 2013; Roman et al., 2009). The crown biomass can also be determined from the study of morphometric relationships, such as total height, crown height, crown diameter with total height, and *DBH* (Wink et al., 2012). Given the lack of information about the *Khaya* spp. plantations in Brazil and the eminent importance of generating information about this species; in this work we aimed to describe the silvicultural characteristics and morphometric parameters of a four-year-old plantation of the species *K. senegalensis* in Southern Minas Gerais state, Brazil.

## MATERIAL AND METHODS

### Characterization of the study area

The area of study is located in Carmo da Cachoeira, southern of the Minas Gerais State, Brazil (21°30'16" 45°07'23") and presents an average altitude of 1,050 meters. The period of the growth stand had an average of annual temperature of 20.5 °C and 1123 mm mean annual rainfall. The data were obtained from the Instituto Nacional de Meteorologia (INMET) database at the nearest meteorological station in the town of Varginha, located approximately 25 km from the plantation (Figure 1).



**Figure 1.** Monthly rainfall and averages of the maximum and minimum temperatures obtained at the weather station of Varginha, MG, from January 2014 to December 2017.

The seedlings were produced using bulk seeds from the Brazilian Institute of Forests, with unknown origin. However, most of the *K. senegalensis* seedlings in Brazil originated from the first plantations of the species in northern Brazil in the 1990s (Reis et al., 2019). The stand

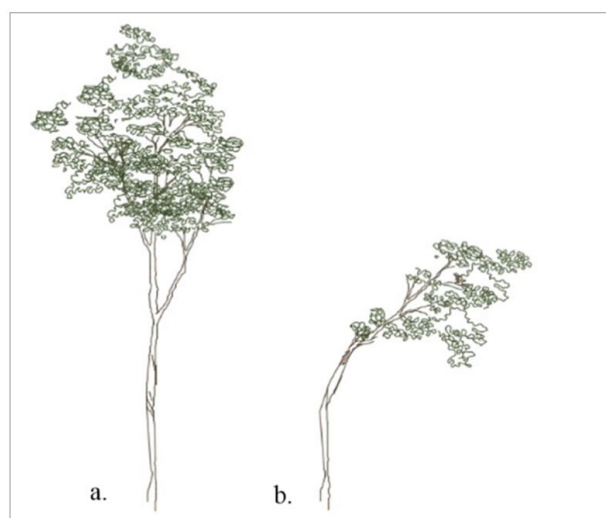
implementation occurred in January 2014, with a total area comprising 1 hectare (ha), using 500 seedlings with a line space of 5 m between individuals and 3.5 m between lines.

*K. senegalensis* seedlings were planted in soil classified as dystrophic Red-Yellow Latosol. The chemical analysis of the soil before the implantation of the stand was: pH=5 (CaCl<sub>2</sub>); P=8 and K=103 (mg/dmc); Ca=2.2, Mg=0.6, Al=0.1, H+Al=3.6 (cmolc/dmc); MO=2.5 (dag/kg); S=12.2, B=0.2, Zn=3.9 (mg/dmc); effective cation exchange capacity (ECEC) = 3.2 and cation exchange capacity (CEC) = 6.7 (cmolc/dmc).

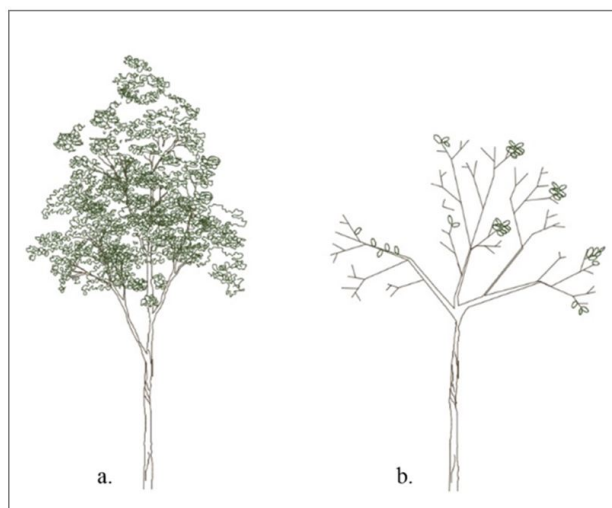
Before the implantation, the area was cleaned and weeded. According to the soil analysis and *K. senegalensis* needs, the soil received 120 g per meter of calcium oxide with 12% of magnesium oxide with an effective calcium carbonate rate (ECC) of 85 for the acidity correction. A fertilization using a 500 g per meter of single superphosphate was also performed (18% of P<sub>2</sub>O<sub>5</sub>, 16% of calcium, and 8% of sulfur). After planting the seedlings were fertilized with a N-P-K formulation (20-05-20). Two cover fertilizations were carried out at 60 and 90 days after the implementation using the same fertilization formulation. The plantation also received an application of gypsum in the total area using 1.5 tons/ha four years after planting. The control of leaf-cutting ants was performed using granular baits distributed around the stand. Invasive plants were periodically eliminated using applications of glyphosate. The trees were pruned every year starting the first year after planting to avoid tree knots. After pruning, the tree cutting wounds had a Bordeaux mixture applied to them in order to prevent diseases.

### Data analysis

Four years after the stand implementation (January 2018), a total census of the dendrometric data was performed on the 484 remaining living trees. First we measured the diameter at breast height (DBH) using a diameter tape. The total height (TH) and crown insertion height (CIH) were both measured using a Blume-Leiss hypsometer. Finally, we estimated the morphometric variables according to the following expressions: crown length ( $CL = HT - CIH$ ), the slenderness ratio ( $SR = HT / DAP$ ) and, crown proportion ( $CP = DAP / CL$ ). The crown quality (CQ) and stem quality (SQ) were analyzed using visual classification giving grades (1, 2, 3, 4, and 5), where 1 was given to the worse individuals and 5 to the best trees (Figures 2 and 3). The morphological parameters evaluated were the crown shape, leaf quantity, trunk shape, presence of bifurcations or deformations, tree vigor, tree size, and health.



**Figures 2.** Stem quality. Where: a. represents trees with the best stem quality (class 5); b. represents a tree with the worst stem quality grade (class 1).



**Figures 3.** Crown quality. Where: a. represents trees with the best crown quality (class 5); b. represents a tree with the worst crown quality grade (class 1).

We applied different regression models for the analysis of the morphometric variables (Table 1). The significance coefficients were estimated using the *t* test at a 5% probability of error. The choice of the best equation was made based on the standard error of the estimate (Syx %) and the determination coefficient adjusted in percentage ( $R^2_{aj}$  %). Considering the logarithmic equations, since they tend to underestimate the height values, a conversion factor was used by multiplying the estimated heights by the Meyer Factor (FM) to recalculate the standard error of the estimates, as described by Machado et al. (2015). Therefore, the Schulaegel adjustment index (SAI) was used to allow a comparison with the adjusted coefficient of determination ( $R^2_{aj}$ %) for equations with different attributes (Machado et al., 2015).

**Table 1.** Mathematical models for adjusted equations considering the total height, crown insertion height, crown length, slenderness coefficient, and crown ratio of *Khaya senegalensis* in Southeastern Brazil.

Equation	Mathematical model
Linear	$Y = \beta_0 + \beta_1 DBH + \varepsilon$
Trorey	$Y = \beta_0 + \beta_1 DBH + \beta_2 DBH^2 + \varepsilon$
Assmann	$Y = \beta_0 + \beta_1 / DBH + \varepsilon$
Henricksen	$Y = \beta_0 + \beta_1 \ln(DBH) + \varepsilon$
Stoffels	$\ln(Y) = \beta_0 + \beta_1 \ln(DBH) + \varepsilon$
Curtis	$\ln(Y) = \beta_0 + \beta_1 / DBH + \varepsilon$
Petterson	$Y = [1 / (\beta_0 + \beta_1 / DBH)]^3 + 1,3 + \varepsilon$
Naslund (1)	$Y = \frac{DBH^2}{\beta_0 + \beta_1 DBH + \beta_2 DBH^2} + \varepsilon$
Naslund (2)	$Y = \left( \frac{DBH^2}{\beta_0 + \beta_1 DBH^2} + 1,30 \right) + \varepsilon$
Naslund (3)	$Y = \left( \frac{DBH^2}{\beta_0 + \beta_1 DBH + \beta_2 DBH^2} + 1,30 \right) + \varepsilon$

Where: *DBH* = Diameter at Breast Height; *ln* = Napierian Logarithm;  $\beta_i$  = Parameters of the Adjusted model ( $i = 0, 1, 2 \dots n$ );  $\varepsilon$  = estimation error. Source: Schneider & Schneider (2008).

The survival analysis of *K. senegalensis* planting was carried out using the percentage of live plants at 4 years of age in relation to the total number of seedlings planted at the time of installation of the experiment.

We calculated the mean annual increment for the *K. senegalensis* stand at 4 years of age (48 months). We used the Spurr model ( $v = \beta_0 + \beta_1 * (DHB^2 * TH)$ ) to estimate the population volume ( $m^3/hectare/year$ ), by the parameters  $\beta_0 = 0.001585$  and  $\beta_1 = 0.000037$ , where *DBH* is the diameter at breast height (1.3 m) and *TH* is the tree total height (m), estimated by Silva et al. (2016) in *K. ivorensis* planted in spacing 4 × 3 meters and age between 30 and 47 months, located in the city of Pirapora, Minas Gerais.

## RESULTS AND DISCUSSION

### Stand description and morphometric characterization

After grouping the diameters into five different classes, the third diameter class (9 and 12 cm), presented a higher number of individuals (268). The lower diameter class presented only 7 individuals and the higher one comprised the other 14 individuals. The mean average of the morphometric variables is shown in table 2.

**Table 2.** Parameters evaluated at 4 years of age in African mahogany trees (*Khaya senegalensis*) located in southern Minas Gerais State, Brazil.

Variables	Minimum	Mean	Maximum	CV (%)	Mean dev.
Diameter at breast height ( <i>DBH</i> )	2.00	9.26	15.4	21.55	2.00
Total height ( <i>TH</i> )	1.60	5.07	8.80	25.50	1.29
Crown insertion height ( <i>CIH</i> )	0.60	3.29	7.00	29.62	0.97
Slenderness ratio ( <i>SR</i> )	0.16	0.58	2.25	39.60	0.23
Crown length ( <i>CL</i> )	0.20	1.78	4.50	47.85	0.85
Crown proportion ( <i>CP</i> )	0.04	0.19	0.54	44.96	0.08

Where: CV = Coefficient of variation; Mean dev. = Mean deviation.

The significant correlation values ranged from -0.385 (*SR* and *CP*) to 0.664 (*CL* and *TH*) (Table 3). Most of the dendrometric and morphometric variables presented a significant correlation with the diameter (*DBH*), except the slenderness ratio. The other variables also presented significant values except for the *CL* and *CIH* (-0.002); and the variables *CP* and *CIH* (-0.023).

**Table 3.** Correlation matrix between dendrometric and morphometric variables in a *Khaya senegalensis* plantation with 4 years of age.

	<i>DBH</i>	<i>TH</i>	<i>CIH</i>	<i>CL</i>	<i>SR</i>
<i>TH</i>	0.578*				
<i>CIH</i>	0.218*	0.438*			
<i>CL</i>	0.461*	0.664*	-0.002		
<i>SP</i>	-0.344*	0.540*	0.263*	0.299*	
<i>CP</i>	0.076	-0.259*	-0.023	-0.284*	-0.385*

Where: *DBH* = Diameter at breast height; *TH* = Total height; *CIH* = Crown insertion height; *CL* = Crown length (m); *SR* = Slenderness ratio; *CP* = Crown proportion.

The coefficients for the adjustment of the models considering the evaluated morphometric variables are shown in table 4. The models were evaluated according to its coefficient of determination ( $R^2$ ); the significance of the *F* value; and by standard error the mean observed in the adjustment.

**Table 4.** Regression models for morphometric variables of *Khaya senegalensis* in southern Minas Gerais State, Brazil.

Variable	Equation	$R^2_{adjusted}$	$S_{yx}\%$
Total height (TH)	$Y = 6,812 - 15,10 / DBH$	0.71	21.74
Crown insertion height (CIH)	$Y = -1,382 + 2,933Ln(DBH)$	0.34	20.70
Slenderness coefficient (SC)	$Y = 0,754 - 0,021DBH$	0.12	21.03
Crown length (CL)	$Y = 2,259 - 6,524 / DBH$	0.73	22.04
Crown proportion (CP)	$Y = 0,164 + 0,250 / DBH$	0.66	24.52

Where:  $R^2$  = Coefficient of determination;  $S_{yx}$  = standard error;  $P > F$ : Probability of significance ( $F$  value).

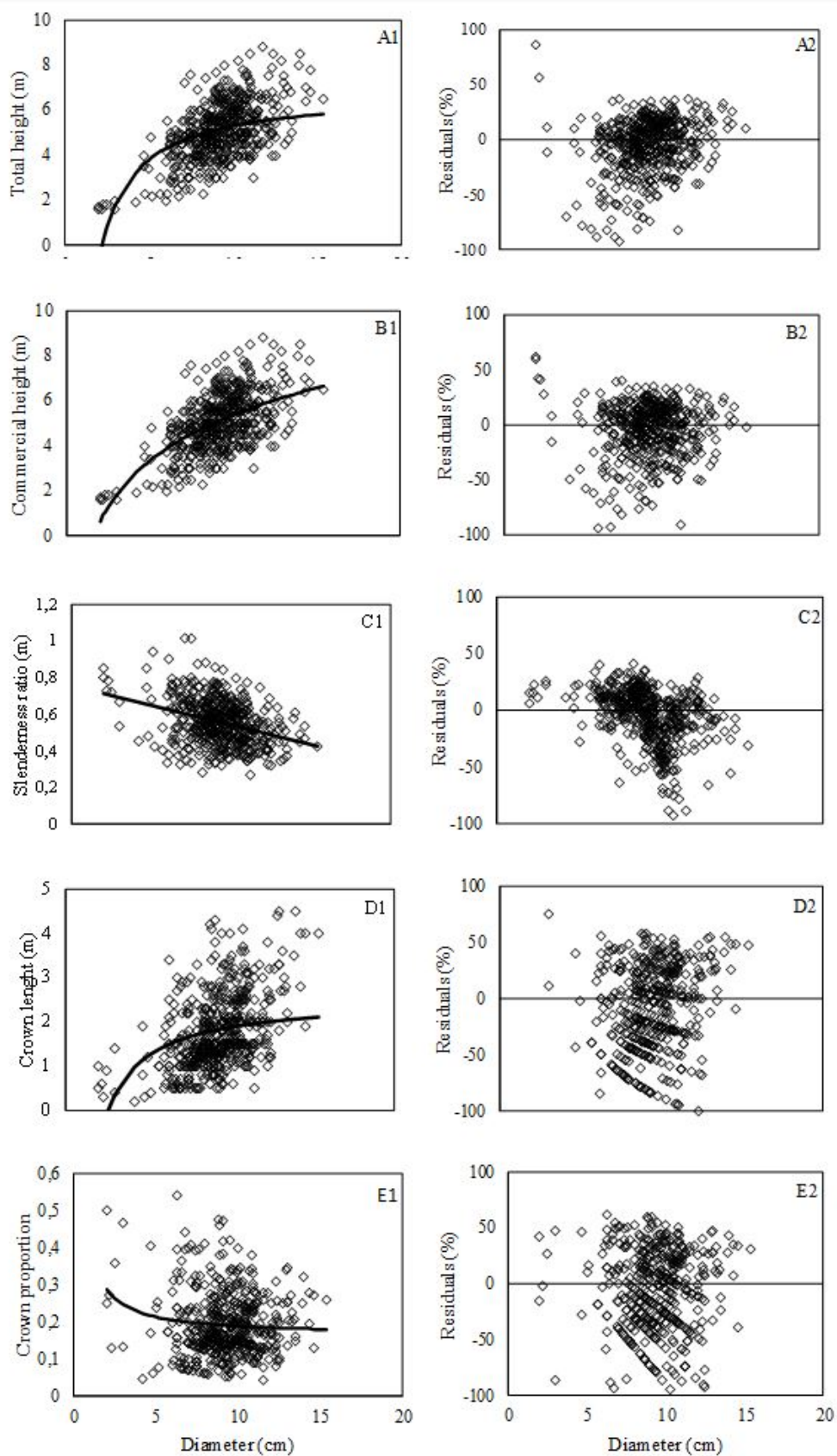
According to the model adjustment for total height and canopy insertion height, the values of the adjusted coefficient of determination ( $R^2_{adjusted}$ ) were low, showing that there is a low morphometric relationship between height and diameter (Table 3). The standard error ( $S_{yx}\%$ ) was high, which implies high levels of dispersion between observed and estimated values (Figure 4 – A1 and B). A similar pattern was also found for the variable crown length (CL) (Figure 4 – D1). However, a linear trend was found between the increase in diameter (DBH), crown length (CL), and crown proportion (CP) (Figure 4- D2 and E2).

The slenderness coefficient (SC) presented the lowest coefficient of determination (0.12) and a standard error of 21.03% (Table 3). We found a negative exponential relationship between variables, indicating a decrease in the slenderness coefficient with an increase of diameter (DBH) (Figure 4D). So, the initial growth is higher considering the height than other variables. Besides, when the individuals reach around 6 cm in diameter, the trees become more stable and start to increase in diameter.

Our results indicated a high homogeneity in a *K. senegalensis* planting originating from seeds. This result is very crucial in commercial plantations of tree species, especially when the main goal is the wood production for furniture. Ribeiro et al. (2017) evaluated the production of *Khaya* spp. in Brazil and observed an average DBH of 18.3 cm for *Khaya ivorensis* at 4.4 years of age. However, despite the relatively close age between these stands, *Khaya ivorensis* and *K. senegalensis* species present different growth characteristics. Previous studies have indicated that *K. senegalensis* grows slower than *Khaya ivorensis* species. On the other hand, *K. senegalensis* is less demanding in water availability and consequently showing a higher capacity to withstand water deficit conditions.

According to Pinheiro et al. (2011), the total height of *K. senegalensis* at three and four years of age reaches around 2 m per year. In the present study, the total height achieved these expected values, indicating a good adaptation of the species to the planting site. Carmo et al. (2018) studying the initial development of the species *K. ivorensis* in an irrigated planting also located in the state of Minas Gerais, reported a 3 years-old plantation with 6.8 m of height and 8.25 cm of DBH. These values show a superiority of the height variable of *K. ivorensis* considering the height increment. However, our results indicated a higher mean value of diameter for *K. senegalensis* (9.26 cm). As discussed before, although both species are from the genus *Khaya*, the species present different growth patterns and were planted under different conditions, thus resulting in different growth pattern development.

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**Figure 4.** Observed individual (circles) of total height (A1), commercial height (B1); slenderness degree (C1); crown length (D1) and crown proportion (E1) and estimated regression curve (line) with model depending on diameter at breast height. A2, B2, C2, D2, E2: Estimated residuals according to tree diameter.

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Here, the crown length variable showed a variation coefficient of 47.85 m. This variation in forest plantations may be related to the high heterogeneity of the total height and the crown insertion length (Table 2). The crown insertion height and the stem length are interconnected by simple algebraic relations, which are related to several and important uses in forestry (Rijal et al., 2012). In fact, the crown length is fundamental to assess the tree development, since it directly affects the accumulation of leaf biomass, which is strongly correlated with the forest growth (Wink et al., 2012; Tonini & Arcoverde, 2005). According to Costa & Finger (2017), crown measurements are important covariates when it is desired to obtain vigorous characteristics of trees and their application in growth equations. In addition, this variable can be highly influenced by competition, and thus is suitable for the modeling of individual tree growth (Costa et al., 2016; Hasenauer, 1997).

The slenderness ratio (*SR*) implies on tree stability because of wind resistance (Klein et al. 2017). Therefore, larger slenderness ratios indicate greater tree instability, thus being associated with several factors such as high tree competition. Therefore, this variable is indicative of the need for vegetation suppression near suppressed trees (Roman et al. 2009). The results found here showed the slenderness ratio ranging from 0.16 to 2.25, with an average of 0.58 (Table 2). Slenderness degrees higher than "1" indicate that the trees are more unstable, with greater height growth in comparison to diameter growth, resulting in tall trees but with small diameter increment (Tonini & Arcoverde, 2005; Klein et al., 2017).

The decrease in the slenderness ratio revealed by the increase in diameter of *K. senegalensis* shows a higher growth in height than in diameter (Figure 4-D). This phenomenon occurs because of the growth pattern of juvenile individuals, where the increase in height is normally greater than the increase in diameter. Since the evaluated area is a plantation for commercial purposes, the decrease in *SC* positively affects the stability of the trees. Plant morphometry may go through changes in different phases because of the influence of several factors, such as edaphic-climatic conditions, canopy competition, and silvicultural treatments (Condé et al., 2013). Roman et al. (2009) studied the morphometric variables and interdimensional relationships for *Cordia trichotoma*. These authors also found significant statistical relationships between *DBH* and variables such as total height, crown diameter, crown length, crown proportion, and slenderness ratio.

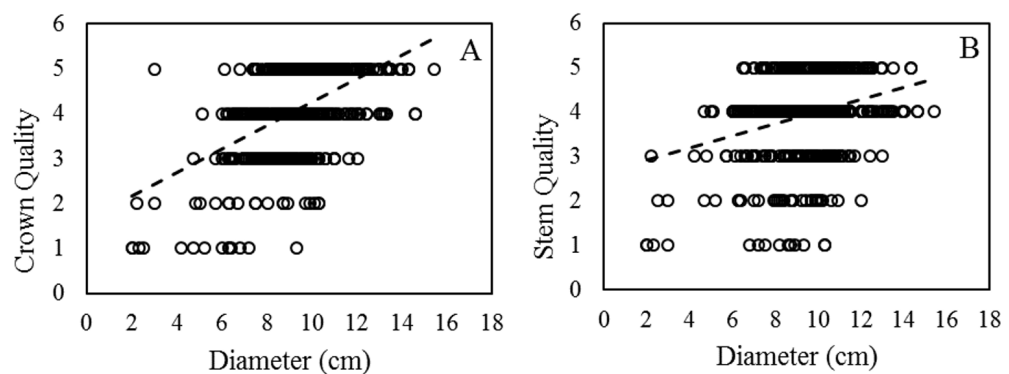
This study is important in order to evaluate and compare the morphometric parameters of *K. senegalensis* plantations. As a secondary result, our study may also help the recommendation of silvicultural practices for the species. The heterogeneous data found here is strongly related to the relatively young age of the population as well as the population origin from seeds, which generates high patterns of genetic variability. Oliveira et al. (2018) found a

similar result for *Khaya ivorensis*, reinforcing the scarce amount of information in the literature and the importance of new investigations. In fact, despite the increasing plantations of *Khaya* spp. worldwide, the information about morphometric characterization is very scarce.

### Stem and crown quality

Overall, the trees presented a low occurrence of branches with good stem quality. Therefore, most of the trees were divided into classes 4 and 5, representing 75% of the individuals. Specifically, class 4 comprised 47% of the trees and class 5 represented 28% of the individuals. As expected, class 1 comprised only 2.9% of the total population (14 individuals). Similarly, the crown quality also presented high quality. Thus, classes 4 and 5 comprised 74% of the individuals, from which 32% were present in class 4 and 42% were in class 5.

The stem and canopy quality presented a linear relationship with the size of the tree. We found a tendency of increase of the tree diameter with the improvement of the stem and crown quality (Figure 5). Additionally, the crown quality was strongly correlated with the crown size and crown length, together with crown quantity (Table 3).



**Figure 5.** Dispersion graph considering the diameter at breast height (DBH) as related to: (a) stem quality and (b) crown quality of *Khaya senegalensis* in southern Minas Gerais State.

The high patterns of stem and crown quality found herein indicates that *K. senegalensis* has a good adaptation to the climatic and edaphic conditions of southeastern Brazil, especially in southern Minas Gerais State. Although the period of time after plantation is relatively short, our study indicated that the species presents adequate characteristics to guarantee the growing demand for wood from the lamination industries. The results of crown quality also demonstrated good patterns of growth considering the spacing between plants and lines, indicating low competition between plants. The crown quality found here is strongly correlated with the size and length of the canopy and the number of leaves (Figure 2). The measurement of tree crown is a particularly important strategy for plant evaluation since its variables it is highly correlated with the diameter increment (Silveira et al., 2015).

Trees with canopies with good health conditions tend to increase its light absorption, and consequently increase its diameter and stem quality. As a result, dominated and co-dominated individuals normally grow more intensely in height due to the lack of light availability (Costa et al., 2016). Consequently, the characterization of crown and stem quality of trees is important to determine the canopy development over time. Silveira et al. (2015) studied a relationship between morphometry and the growth of the species *Trichilia clausenii* and observed that the larger the crown, the greater is the growth. Therefore, trees with higher crowns and less competition normally present high patterns of growth. Adjusting the plant density through silvicultural treatments may result in higher growth, resulting in important data for silvicultural management.

## Survival and Growth Analysis

The survival analysis showed that of the 500 seedlings planted in 2014, only 16 seedlings did not survive, resulting in a percentage of survival at 4 years of age equal to 97.2%. The mean annual increment (MAI) was 3.31 m<sup>3</sup>/ha/year at 4 years of age.

The population survival analysis showed a good adaptation of the species to the climate and soil conditions of the region of Carmo de Cachoeira, MG. *Khaya senegalensis* prefers deep and well-drained soils, being the most drought-tolerant species compared to other *Khayas*, with annual precipitation estimates between 650 and 1800 mm with drought periods of four to seven months (Pinheiro et al., 2011; Reis et al., 2019). The region's soil class and climate seem to contribute to the survival and growth of *K. senegalensis*.

The mean annual increment (MAI) for the *K. senegalensis* stand was 3.31 m<sup>3</sup>/ha/year at 4 year of age. Carmo et al. (2018) evaluating the initial development of *K. ivorensis* in Janaúba, northern Minas Gerais state, under irrigated planting with a spacing of 5m x 5m, found IMA 2.33 m<sup>3</sup>/ha/year at 24 months and 3.37 m<sup>3</sup>/ha/year at 36 months. These results are similar to those obtained in this study, although we did not use irrigation in our stand, reinforcing the view of the good adaptation of the species to these conditions.

MAI varies according to species, planting conditions, silvicultural operations and, mainly, to the age of the stand. Young populations tend to have a lower MAI than stands at the cutting age. Our stand's IMA was similar to species of the same family, with similar age and edaphic-climatic conditions. In Brazil, the average annual increase in neem (*Azadirachta indica*) does not exceed 12 m<sup>3</sup>/ha/year (Neves, 2004). Pure plantings of *Cedrela fissilis* are not recommended due to the attack of *Hypsipyla grandella*, which makes the growth of the species extremely variable, with a very low MAI, less than 4 m<sup>3</sup>/ha/year (Angeli & Müller, 2017). In an experiment with Brazilian mahogany (*Swietenia macrophylla*), not irrigated, the MAI ranged from 2.7 to 4.8 m<sup>3</sup>/ha/year at 58 months of age, in a 4.0 m x 1.5 m spacing (Fernandes et al., 2009).

Compared to other results found, the MAI of our stand was very close to that observed in other countries in stands with advanced age, such as in Ivory Coast and Malaysia, with an MAI of approximately 8 m<sup>3</sup>/ha/year around 30 years of age (Ribeiro et al., 2017), showing the potential of the species for commercial plantations in Brazil.

## CONCLUSIONS

Higher growth in the diameter of *K. senegalensis* resulted in greater growth in height and crown length. On the other hand, increasing the diameter reduced the slenderness ratio, indicating a higher growth in diameter than height, resulting in higher tree stability. The qualitative evaluation indicated that the trees presented good crown and stem quality. We suggest the development of periodical measurements to obtain more robust results on the morphometric variables. In addition it is good to plant the species in new, different areas, in order to assess the applicability of the results in different environments. However, we found that *K. senegalensis* has a great potential to be cultivated in southern Minas Gerais State, Brazil.

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