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Crown morphometry for two valuable timber species from Miombo woodland in Mozambique

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ABSTRACT: *Pterocarpus angolensis* DC and *Bobgunnia madagascariensis* (Desv.) J. H. Kirkbr. & Wiersema are two hardwood species found in Miombo woodland. Crown size, being closely related to the photosynthetic capacity of a tree, is an important parameter in studies of the growth of individual trees. In this sense, the present study aimed to study the morphometric relationships of *P. angolensis* and *B. madagascariensis* as a resource to describe the morphometric features of these species. Data were sampled in 60 rectangular plots of 20 x 50 m, systematically distributed within the forest. In each plot, the diameter at breast height (DBH), height (h), crown insertion point (cih) and four crown radii of all trees with DBH ≥ 10 cm were measured. Results indicated that crown diameter and crown length of *P. angolensis* grow as DBH and height increase, the larger the crown, the greater the trees dimensions; as for *B. madagascariensis*, crown features have shown low correlation when considering DBH. It was concluded that crown features influence on tree growth and are important measures of description and planning of silvicultural activities to be performed in natural forests. The results are of interest to forest managers since they make decisions about silvicultural operations.
Keywords: crown dimensions; prediction models; umbila; pau-ferro; forest management.

Morfometria da copa para duas espécies madeireiras comerciais da floresta de Miombo em Moçambique

RESUMO: *Pterocarpus angolensis* DC e *Bobgunnia madagascariensis* (Desv.) J. H. Kirkbr. & Wiersema são duas espécies de madeira de lei encontradas na floresta de Miombo. O tamanho da copa, está intimamente relacionado à capacidade fotossintética de uma árvore, e é um parâmetro importante nos estudos do crescimento de árvores individuais. Nesse sentido, o presente estudo teve como objetivo estudar as relações morfométricas de *P. angolensis* e *B. madagascariensis* como recurso para descrever as características morfométricas dessas espécies. Os dados foram obtidos em 60 parcelas retangulares de 20 x 50 m, distribuídas sistematicamente na floresta. Em cada parcela, foram medidos o diâmetro à altura do peito (DAP), altura (h), altura de inserção da copa (hic) e quatro raios da copa de todas as árvores com DAP ≥ 10 cm. Os resultados indicaram que o diâmetro e o comprimento da copa de *P. angolensis* crescem com o aumento do DAP e da altura; quanto maior a copa, maior dimensão das árvores, enquanto que para *B. madagascariensis*, as características da copa mostraram baixa correlação ao considerar o DAP. Concluiu-se que as características da copa influenciaram no crescimento das árvores e são importantes medidas de descrição e planejamento das atividades silviculturais a serem realizadas na floresta. Estes resultados são de interesse dos manejadores florestais, pois são eles que tomam decisões sobre as operações silviculturais.
Palavras-chave: dimensões da copa; modelos preditivos; umbila; pau-ferro; manejo florestal.

1. INTRODUCTION

Pterocarpus angolensis DC (known as Umbila) and *Bobgunnia madagascariensis* (Desv.) J. H. Kirkbr. & Wiersema (known as Pau-ferro) are deciduous trees species of the *Fabaceae* family found in Dry tropical forests in Southern and Eastern Africa, including Miombo woodland (VAN WIK; VAN WIK, 2011). Miombo woodland is a vast African Dryland Forest ecosystem covering close to 2.7 million km² across Angola, Democratic Republic of the Congo, Malawi, Mozambique, Tanzania, Zambia and Zimbabwe. The Miombo woodland is dominated by trees of the genera *Brachystegia*, *Julbernardia* and *Isoberlinia*, in association with others species (CAMPBELL et al., 2008). The woodland plays a crucial role in formal and informal economies, supporting the livelihoods of millions of rural and urban people, by providing important resources such as timber, food, medicines, also play an important role in the ecosystem dynamics, particularly with respect to biodiversity, water, carbon and energy balance (KALABA et al., 2014; RYAN et al., 2016).

In Mozambique, forestry is one of the 10 largest industries in the country and accounted for a significants share of annual exports. For example, in 2019 the overall forest sector accounted for approximately $570 million to the gross domestic product (WORLD BANK, 2020). Despite the large number of valuable tree species in Mozambique, two species – *P. angolensis* and *B. madagascariensis*, represented the bulk (44%) of timber harvest between 1999 and 2014, and despite strict national-level Regulation of harvest, many are concerned that harvest may be occurring in an unsustainable manner (EGAS et al., 2013; MITADER, 2018).

Recently (March 2018), as a result of massive illegal logging and exports the Government of Mozambique has banned the harvest of two out of the six most exploited timber species (e.g., *Combretum imberbe* and *Bobgunnia madagascariensis*) and the export of *Afzelia quanzensis*, *Millettia stuhlmannii* and *Pterocarpus angolensis* and has suspended the development of new timber concession areas (REMANE; THERRELL, 2019). Even with reforms in the forestry sector, there remains doubt regarding strategies that could allow interventions of sustainable management and ways to optimize timber production in forests and raised the need for their conservation.

Despite the economic value of these species, relatively little research has focused on determining appropriate, biological-based crown variables and morphometric features schemes to help ensure that it is growth (including biomass), productive potential of several native species in Mozambique and make decisions about silvicultural operations (GELDENHYUS, 2005; HOFIÇO et al., 2018; MITADER, 2018). The current demand for timber from these species in the country, creates a need for tools for specific measurements that support the management and use of the existing stock.

A detailed investigation about crown features can contribute to understanding the management of ecosystem features such as forest productivity, biodiversity, and wildlife habitats (WEISKITTELL et al., 2011). Thus, in order to manage native forest species, it is necessary to know the characteristics of tree dynamics throughout time, what requires the description of morphometric relationships of species to optimize silvicultural techniques (SEIFERT et al., 2014; HESS et al., 2016).

Understanding morphometric relationships allows to provide information about features of the adjustment of crown morphology caused by competition for environmental resources in forest communities (SEIFERT et al., 2014; HESS et al., 2016), and studies about crown features (size and architecture) are fundamental to model tree growth (PRETZSCH, 2009). Modelling factors that influence on tree growth, reflected on the variation of size and shape, allow to establish strategies for the management of forest resources (WEISKITTELL et al., 2011).

Considering individual trees, it allows to infer about each one specifically by applying directly in forests and populations of different ages, in trees of distinct social positions because it mainly provides information about the suitable living space according to tree size (SEIFERT et al., 2014). Thus, size, structure, shape, and distribution of crowns are intimately related to tree growth, growth strength and productivity (GONZALEZ-BENECKE et al., 2014), volume and biomass (MATE et al., 2014; JUCKER et al., 2016), as well as wood quality, branch diameter, length of growth ring, trunk conicity, knot features, core and sapwood proportion (GONZALEZ-BENECKE et al., 2014; VON HOLSBEECK et al., 2016).

Moreover, crown dimensions reflect the competition the tree was subject to during its past growth (RUSSELL et al., 2014, FU et al., 2017), this being relevant information for the forester. Models that describe growth regarding individual trees are usually based on diameter at breast height, crown length and its interactions with dendrometric variables, with emphasis on the morphometric indexes such as h/DBH relationship, crown proportion, salience index, coverage index and formal of crown (COSTA et al., 2016; HESS et al., 2016).

In light of this, the present study aimed to investigate the dimensional relationships of *P. angolensis* and *B. madagascariensis* as a resource for the description of morphometric features of these species in a Miombo woodland in Mozambique. The proposed model can be used for predictions of crown morphometry involving these important species and provide resources for the country's management plans and make decisions about silvicultural operations.

2. MATERIAL AND METHODS

2.1. Study area

The study was performed in a forest concession that managed by Sotomane Construction and Industry Lda (16°33'S and 36°32'E, 16°49'S and 36°47'E), located in Mocuba District, Zambézia Province, in central Mozambique (FIGURE 1). The main activity in the forest concession is the selective cut for wood-producing purposes. However, family subsistence agriculture is the predominant activity of local communities, characterized by slash and burn of the whole forest cover (clear cuts), resulting in annual fires and degradation of these areas (HOFIÇO; FLEIG, 2015).

The climate in the region is Aw (tropical savanna) according to the Köppen classification system, with well-defined seasons, dry winter from April to October, and wet season from November to March. The annual mean rainfall is 1200 mm and mean temperature is 24.3 °C. Soils are predominantly red argisoils in hydromorphic conditions (MAE, 2005). Topography is slightly undulated between 200 m and 400 m above sea level.

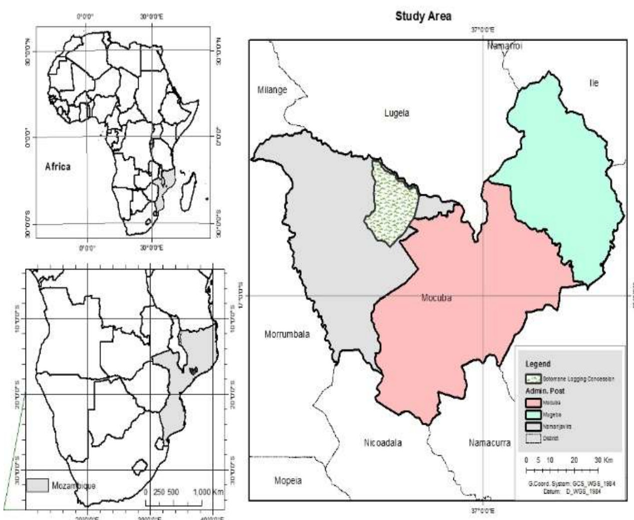

Figure 1. Study area in Mocuba District, Zambézia Province, Mozambique.
Figura 1. Área de estudo no Distrito de Mocuba, Província da Zambézia, Moçambique.

2.2. Description of studied species

The Miombo woodland covers an area of 26.9 million ha in Mozambique and corresponds to 67% of its total forest area, being the main source of hardwood in the country (MITADER, 2018). *P. angolensis* is a medium to large-sized tree, up to 16 m tall that can reach 28 m. It has a rectilinear and uniform trunk, a robust round-shaped crown, with a dark-brown core and yellow-greyish sapwood, wood is hard and moderately heavy, relatively easy to handle (Figure 2a). As for *B. madagascariensis*, it is a small-sized tree varying between 4 and 16 m tall, with rectilinear uniform trunk and dense, robust and round-shaped crown (Figure 2b), its wood is hard and very heavy, hard to be handled, and it shows no significant difference in colour between core and sapwood (BUNSTER, 2006; MOJEREMANE; LUMBILE, 2016).

Figure 2. Typical growth forms of tree species in Miombo woodland, in Mocuba District, Mozambique, dry season 2020. (a) *Pterocarpus angolensis*; and (b) *Bobgunnia madagascariensis*.
Figura 2. Formas de crescimento típicas das duas espécies árboreas na floresta de Miombo, no Distrito de Mocuba, Moçambique, estação seca de 2020. (a) *Pterocarpus angolensis*; e (b) *Bobgunnia madagascariensis*.

Due to their physico-mechanical features such as durability, resistance, density and colour, *B. madagascariensis* and *P. angolensis* are species of high commercial value used in the construction, naval and furniture industry, as well as vehicle bodies, railroad ties, wood floor and decks, and beehives (BUNSTER, 2006; ALI et al., 2008). Additionally, parts of these species are widely used in traditional medicine to treat diseases such as malaria, cornea ulcer, mycosis, fever, and syphilis (STEVENSON et al., 2010; MOIEREMANE; LUMBILE, 2016).

2.3. Data acquisition

Data were obtained from 60 plots of 20 x 50 m (1000 m^2) systematically distributed within a forest concession, with a distance of 50 m between plots, and 100 m between lines. For each objective tree, dendrometric and morphometric variables of all trees with DBH ≥ 10 cm were measured, totaling 171 trees of *P. angolensis* and 115 trees of *B. madagascariensis*, covering the full range of diameters. The measured variables were diameter at breast height (DBH) at 1.3 m above ground; height (h), corresponding to the distance between ground level and crown top; commercial height (ch), corresponding to the trunk with commercial value; and height from the crown insertion point (cih) corresponding to the distance between ground level and the beginning of living crown. DBH was measured with a precision dendrometric caliper (cm), height (m) with the Blume-Leiss tool, and four crown radii in the cardinal points north, south, east, and west, with a measuring tape and compass. Crown length (cl) was obtained with the difference between h and cih, in the expression [cl = h – cih]. Crown diameter (cd) was calculated in meters with the mean crown radium (cr), in the expression [cd = cr × 2] obtained from four radii.

2.4. Data analysis

Descriptive statistics characterized the measured variables. The diametric distribution was determined with the class range of 5 cm, with the lower limit of the first class at 10.0 cm, and 14.9 cm as upper limit. For the analysis of the morphometric relationships, the variables used were crown length (cl), crown diameter (cd), the h/DBH relationship, or slenderness coefficient (SC), the cd/cl relationship, known as formal of crown (FC), the cd/DBH relationship, or salience index (SI), and the cd/h relationship, or coverage index (CI), according to the methodology described by Roman et al. (2009), Hess et al. (2016) and Costa et al. (2016). From the sampled data, the mean, minimal and maximum values of the morphometric variables and dimensional relationships of *P. angolensis* and *B. madagascariensis* were obtained, as shown in Table 1.

To describe the dimensional characteristics (h, cih, ch, cl, cd) according to DBH, the biometric model 1 was adjusted in the non-linear model:

$$y = \beta 0.\exp^{(\beta 1/x)} + \varepsilon i \quad (01)$$

where: y – dimensional variable: h; cih; ch; cl; cd; x – DBH (diameter at breast height, measured at 1.30 m above ground, in cm); β_0, β_1 – estimated regression coefficient; ε_i – residual error.

And in order to describe the relationship of the morphometric variables (SC, FC, SI, CI), the biometric model was adjusted in the non-linear model:

$$y = \beta_0.X^{\beta 1} + \varepsilon_i \quad (02)$$

where: y – dimensional variable: SC; FC; SI; CI; x – DBH (diameter at breast height, measured at 1.30 m above ground, in cm); β_0, β_1 – estimated regression coefficient; ε_i – residual error.

All statistics were processed with the SAS software version 9.1 (SAS Institute Inc. 2004). For the performance of the model, the coefficient of determination (R^2), root mean squared error (RMSE), and the graphic distribution of residues in percentage (Table 2). The dimensional variable by DBH and morphometric relationship of *P. angolensis* and *B. madagascariensis* was used to draw graphs in eight figures using the Microsoft Excel (2019).

Table 1. Biometric characteristics of *Pterocarpus angolensis* and *Bobgunnia madagascariensis* in Miombo woodland in Mocuba District, Mozambique.
Tabela 1. Características biométricas de *Pterocarpus angolensis* e *Bobgunnia madagascariensis* na floresta de Miombo no Distrito de Mocuba, Moçambique.

Variable	Unit	*Pterocarpus angolensis*		*Bobgunnia madagascariensis*	
		Mean – SD	Range	Mean – SD	Range
DBH	cm	25.3 ± 12.9	10.0 - 66.7	19.4 ± 5.20	10.0 - 38.6
h	m	11.1 ± 3.10	5.60 - 17.6	11.0 ± 2.10	6.5 - 16.0
cih	m	5.70 ± 1.60	2.60 - 8.80	4.10 ± 1.00	2.00 - 6.0
ch	m	4.50 ± 0.90	1.50 - 7.80	4.50 ± 1.20	2.00 - 7.0
cl	m	5.40 ± 1.70	2.50 - 10.5	6.90 ± 2.00	2.00 - 12.0
cd	m	6.70 ± 1.30	3.80 - 9.30	2.00 ± 0.50	0.80 - 3.6
SC	-	0.48 ± 0.10	0.26 - 0.72	0.58 ± 0.12	0.31 - 0.90
FC	-	2.61 ± 0.51	1.69 - 4.20	0.64 ± 0.29	0.21 - 2.20
SI	-	61.0 ± 17.4	27.6 - 103.9	21.4 ± 5.60	7.70 - 36.0
CI	-	1.24 ± 0.18	0.95 - 1.81	0.36 ± 0.09	0.17 - 0.63

where: SD – standard deviation; DBH – diameter at breast height, measured at 1.30 m above ground (cm); h – total height (m); cih – height from the crown insertion point (m); ch – commercial height (m); cl – crown length (m); cd – crown diameter (m); SC (slenderness coefficient) – h/DBH; FC (formal of crown) – cd/cl; SI (salience index) – cd/DBH; CI (coverage index) – cd/h.

Table 2. Statistic criteria used to evaluate the adjusted models.
Tabela 2. Critérios estatísticos usados para avaliar os modelos ajustados.

Statistical criteria	Expression
Coefficient of determination (3)	$R^2 = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i - \hat{Y}\right)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}\right]$
(Root Mean Square Error (4)	$RMSE = \sqrt{(n-p)^{-1}\sum_{i=1}^{n}(Y_i - \hat{Y})^2}$
Residual value (%) (5)	$\text{Residual value (\%)} = \frac{Y_i - \hat{Y}}{Y_i} \cdot 100$

Where: Y_i – observed variable; $\hat{Y}$ – estimated variable; $\bar{Y}$ – mean observed variable; n – number of observations; p – number of estimated coefficients.

3. RESULTS

3.1. Population structure

The studied population of *P. angolensis* showed a typically decreasing diameter distribution, with trees up to the class of 67.5 cm. *B. madagascariensis* also showed a decreasing distribution, with a smaller number of trees in the first class, probably resulting from the already established lack of natural regeneration, what can lead to population decrease throughout time (Figure 3). In the sample, 171 *P. angolensis* (10.0 ≤ DBH ≤ 66.7 cm) and 115 *B. madagascariensis* (10.0 ≤ DBH ≤ 38.6 cm) were measured in 6 ha, corresponding to 28.5 and 19.2 trees.ha^{-1}, respectively.

3.2. Morphometric relationship

The mean height for the two species was ≈ 11.0 m, with a similar height range for both *P. angolensis* (5.6 m and 17.6 m) and *B. madagascariensis* (6.5 m and 16.0 m). The measured values of crown diameter varied between 3.80 ≤ cd ≤ 9.30 for *P. angolensis*, and 0.80 ≤ cd ≤ 3.6 for *B. madagascariensis*. DBH also showed an expressive difference between the two species, being 10.0 ≤ DBH ≤ 66.7 cm and 10.0 ≤ DBH ≤ 38.6 cm, respectively, for *P. angolensis* and *B. madagascariensis*. The other measured variables showed homogeneous dimensions. The biometric model showed a specific performance for each morphometric variable assessed as dependent variable for *P. angolensis* and *B. madagascariensis* (Table 3).

All *P. angolensis* regressions that describe the morphometric variables according to DBH as well as the regression coefficient (for α = 5%) were significant. The lowest expression of the R^2 coefficient was 0.13 in the ch relationship, indicating the low adjusted in cl the increase of tree diameter, also confirmed by the RMSE of 0.86 m. The relationships of FC with R^2 = 0.34 and CI with R^2 = 0.35, confirmed the lower dependence to DBH. The adjusted regressions for the other variables had R^2 values higher than 0.80 and significant coefficients.

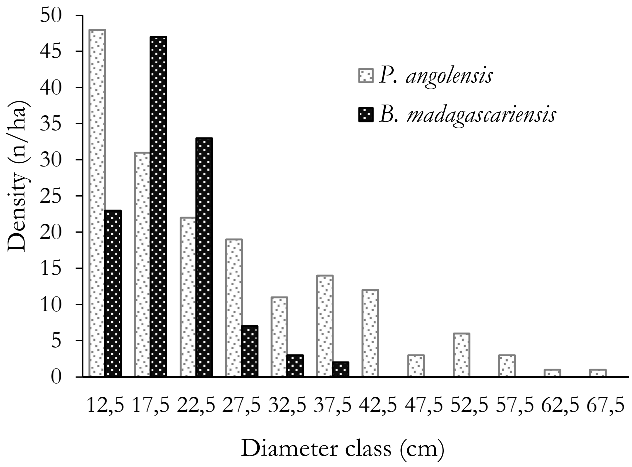

Figure 3. Diameter distribution of *Pterocarpus angolensis* (grey pillar) and *Bobgunnia madagascariensis* (black pillar) in Mocuba District, Mozambique.
Figura 3. Distribuição diamétrica de *Pterocarpus angolensis* (pilar cinza) e *Bobgunnia madagascariensis* (pilar preto) no Distrito de Mocuba, Moçambique.

The evaluated for *B. madagascariensis* showed similar results for the variables FC and CI with a non-significant regression coefficient (β1), indicating that there is no trend data for the assessed equations. Though the morphometry of *P. angolensis* and *B. madagascariensis* was adjusted with distinct accuracy, the biometric model allowed to precisely describe the mean development of morphometric variables of the two species. The graphs in Figure 4, evidence the variables cd and cih as the ones with the highest difference between species, affecting the other morphometric indexes that contain these variables.

Table 3. Estimated regression coefficients and statistics of adjustment and precision of the dimensional variables of *Pterocarpus angolensis* and *Bobgunnia madagascariensis,* in Miombo woodland in Mocuba District, Mozambique.
Tabela 3. Coeficientes de regressão estimados e estatísticas de ajuste e precisão das variáveis dimensionais de *Pterocarpus angolensis* e *Bobgunnia madagascariensis*, na floresta de Miombo no Distrito de Mocuba, Moçambique.

Variables	Species	n	β_0	β_1	F value	*p* value > F	R²	RMSE
h	*Pterocarpus angolensis*	171	203.631 (<0.0001)	-129.856 (<0.0001)	19426.1	<0.0001	0.94	0.76
cih			99.362 (<0.0001)	-117.056 (<0.0001)	7453.71	<0.0001	0.83	0.63
ch			5.284 (<0.0001)	-3.472 (<0.0001)	2170.16	<0.0001	0.13	0.89
cl			9.998 (<0.0001)	-8.429 (<0.0001)	17000.8	<0.0001	0.87	0.86
cd			10.477 (<0.0001)	-14.409 (<0.0001)	5929.56	<0.0001	0.85	0.67
SC			167.379 (<0.0001)	-0.402 (<0.0001)	11703.8	<0.0001	0.83	4.24
FC			5.429 (<0.0001)	-0.237 (<0.0001)	3405.19	<0.0001	0.34	0.42
SI			330.491 (<0.0001)	-0.553 (<0.0001)	7964.05	<0.0001	0.86	6.54
CI			2.190 (<0.0001)	-0.184 (<0.0001)	5923.58	<0.0001	0.35	0.15
h	*Bobgunnia madagascariensis*	115	17.165 (<0.0001)	-8.201 (<0.0001)	2452.08	<0.0001	0.36	1.69
cih			5.270 (<0.0001)	-4.598 (<0.006)	957.65	<0.0001	0.07	1.01
ch			7.532 (<0.0001)	-9.461 (<0.006)	1111.61	<0.0001	0.25	1.03
cl			2.866 (<0.0001)	-6.729 (<0.0001)	1355.75	<0.0001	0.18	0.41
cd			12.199 (<0.0001)	-10.549 (<0.0001)	887.67	<0.0001	0.24	1.77
SC			274.6 (<0.0001)	-0.529 (<0.0001)	2367.21	<0.0001	0.45	9.27
FC			1.117 (<0.0375)	-0.190 (<0.2451)	276.58	<0.0001	0.01	0.29
SI			118.173 (<0.0001)	-0.587 (<0.0001)	1413.26	<0.0001	0.37	4.37
CI			0.463 (<0.0001)	-0.078 (<0.3653)	1002.74	<0.0001	0.01	0.09

where: n – number of measured trees in the 6.0 ha sampled; h – total height, in m; cih – crown insertion height, in m; ch – commercial height, in m; DBH – diameter at breast height, in cm; cl – crown length, in m; cd – crown diameter, in m; SC (slenderness coefficient) – h/DBH; FC (formal of crown) – cd/cl; SI (salience index) – cd/DBH; CI (coverage index) – cd/h; β_0, β_1 – estimated regression coefficients; R^2 – coefficient of determination; RMSE – root mean squared error; *p* value > *F* – probability value of the *F*-test; ( ) – probability value of *t*-test for estimated regression coefficients.

4. DISCUSSION

The negative exponential diametric distribution (Figure 3) for *P. angolensis* suggests that the natural regeneration process and the continued survival of the species in the forest are ensured (CARO et al., 2005; DE CAUWER et al., 2014; VAN HOLSBEECK et al., 2016; HOFIÇO et al., 2018). According to Caro et al. (2005), this behaviour is due to the fact that the species is adapted to survive and tolerate severe environmental conditions such as fires and droughts.

Nevertheless, the unimodal diametric distribution of *B. madagascariensis* can indicate the critical absence of natural regeneration or plant mortality due to anthropic action, which is recurrent in the region, as reported by Williams et al. (2008) and Ryan; Williams (2011), in woodland recovery during Miombo regeneration in Central Mozambique.

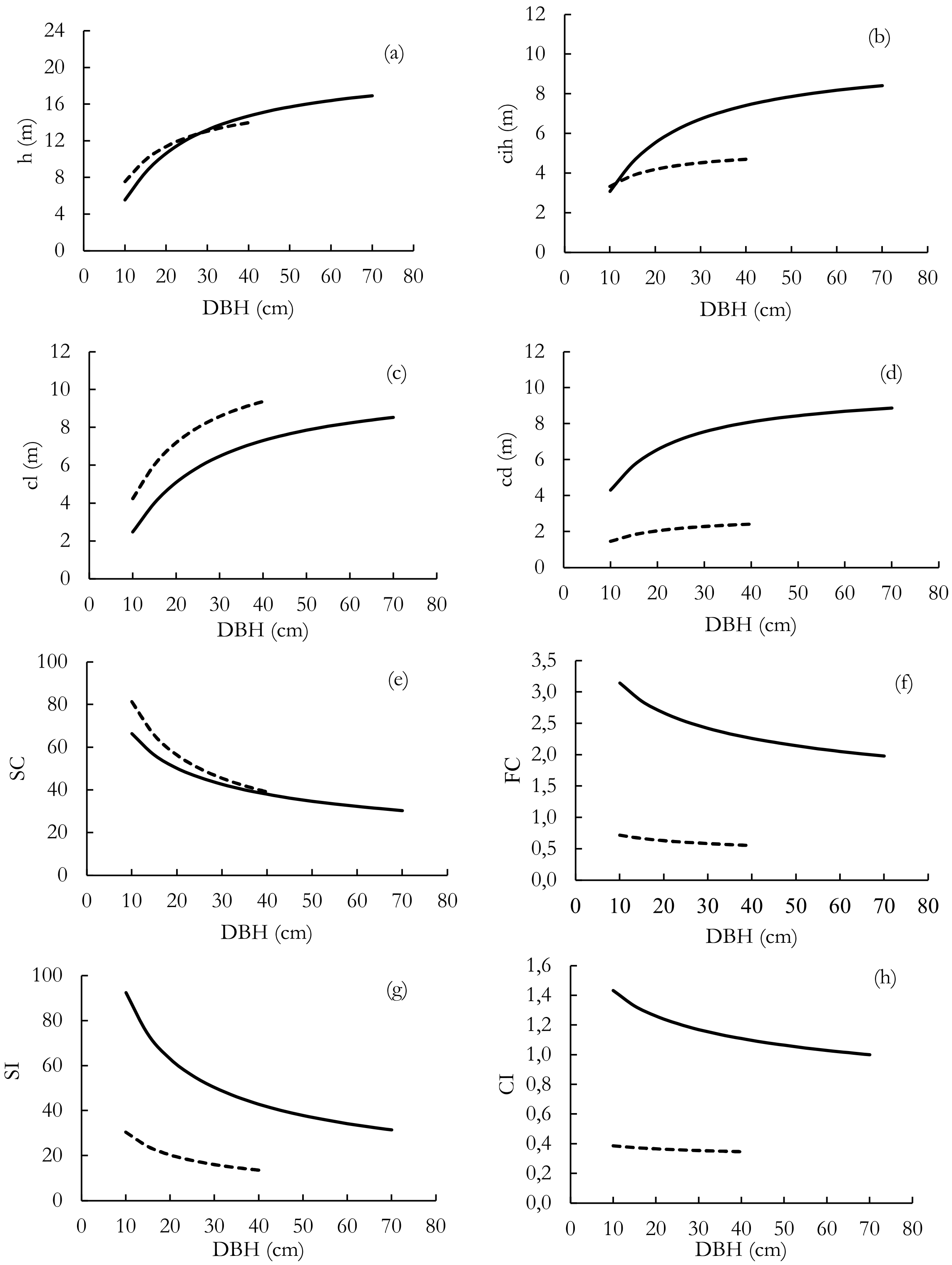

Figure 4. Adjusted regressions lines according to the dimensional variables for *Pterocarpus angolensis* (solid line) and *Bobgunnia madagascariensis* (dotted line) trees in Miombo woodland in Mocuba District, Mozambique.
Figura 4. Linhas de regressões ajustadas de acordo com as variáveis dimensionais para árvores de *Pterocarpus angolensis* (linha contínua) e *Bobgunnia madagascariensis* (linha pontilhada) na floresta de Miombo no Distrito de Mocuba, Moçambique.

In addition to the anthropic action in the area, there is the hypothesis that it occurs due to fires, which eliminate a considerable number of regenerating trees when it goes beyond human control, altering the structure of specific populations in the Miombo ecosystem (WILLIAMS et al., 2008; CHIDUMAYO, 2013; RIBEIRO et al., 2017). This fact is integrated with studies in the Miombo ecosystem, in which the negative influence of fires and the anthropic disturbances in species ecological process – including natural regeneration – are reported (CARO et al.; 2005; WILLIAMS et al., 2008; SYAMPUNGANI et al., 2016). In the specific case of *P. angolensis*, it is possible to affirm that there still is anthropic action for wood extraction in the study site.

Heights had a great significance in the understanding of the features of these two species, which showed a high structural complexity, reflected in the low R^2 values of the equations developed for the analysed morphometric variables of *B. madagascariensis*. Sampled *B. madagascariensis* trees were relatively young, with low variability of the analysed dimensional characteristics.

These differences can be explained by the phenotypical resilience of tree response to climate and other environmental conditions such as altitude and soil features (KALABA et al., 2013; SEIFERT et al., 2014), as well as the action of fires, observed in the woodland, in which some trees of *B. madagascariensis* had their trunks and crowns damaged. It is important to mention that both *B. madagascariensis* and *P. angolensis* are species of the same forest formation and belong to the same family (Fabaceae) but to different ecological groups: the first is a late-climax secondary species whereas the latter is a pioneer species (GONÇALVES et al., 2017; CHITECULO; SUROVY 2018), in other words, ecological strategies are different to obtain better results for species growth and survival (WILLIAMS et al., 2008; CHIDUMAYO, 2013). Chidumayo (2019) report different strategies of trees in the Miombo canopy where he found that most pioneer species grow slower in the initial stages.

Crown length (cl) increased with DBH for both species (Figure 3c), and *B. madagascariensis* was higher than *P. angolensis*. This fact can be *B. madagascariensis* explained by the shape of some *B. madagascariensis* trees observed in the studied forest, which had multiple high stems and sparse crown, contrary to the common feature of trees in the Miombo woodland, which typically have flat and round umbel-shaped crowns like *P. angolensis* (MATE et al., 2014; DE CAUWER et al., 2014). Feldpausch et al. (2011) observed that the apical growth speed of leafy species is higher for some species than the mortality of branches in the crown basis, what results in a higher crown proportion, being this variable an indicator of tree vitality as well as an indicator of degree of competition.

The same increase was verified for crown diameter in which *P. angolensis* and *B. madagascariensis* varied between 3.8 and 9.3 m, and 0.8 and 3.6 m, respectively (Table 1). It was noted that *B. madagascariensis* showed a slight reduction in the increase rate of crown diameter in higher DBH classes (Figure 4d), what can indicate that a smaller space is needed for side growth, consequently displaying a smaller area of crown projection (ROMAN et al., 2009; SYAMPUNGANI et al., 2016; HESS et al., 2016). *P. angolensis* showed an increase in insertion height crown and crown diameter as trees grew in diameter (Figure 4b and 4d). The high variability in the dimensions of the crown can be related to the different degrees of competition to which the tree is subjected (SEIFERT et al., 2014; HESS et al., 2021).

However, this aspect, in the present work, is conflicting, since the trees of *P. angolensis* and *B. madagascariensis* have little influence from competition (MUGASHA et al., 2013; DE CAUWER et al., 2014; MATE et al., 2015), as competition becomes relevant only when there is light restriction (PRETZSCH, 2009; ROMAN et al., 2009). Mugasha et al. (2013) reported that as crowns grow their height increases, and crowns are wider and need more space for growth, what justifies the crown dimensions and tree height relationship. Trees with large and healthy crowns are related to higher growth rates as a result of the increase in the photosynthesis rate (VON HOLSBEECK et al., 2016; FU et al., 2017).

Taking the slenderness coefficient (h/DBH) into consideration, *B. madagascariensis* showed higher values than *P. angolensis* (Table 1; Figure 4e). However, this feature tends to decrease as DBH increases, indicating a higher stability of trees, provided by the smaller DBH/total tree height relationship, regardless of age (FELDPAUSCH et al., 2011; MUGASHA et al., 2013). The decrease of the slenderness coefficient is a positive physiological factor for stability since trees with very high stems and small diameters are more unstable, specially under the action of wind, which is impossible to be controlled (MUGASHA et al., 2013; SEIFERT et al., 2014) and can cause irreversible damage such as crown breakage or tree fall (GONZALEZ-BENECKE et al., 2014).

The FC with mean value of 2.61 for *P. angolensis* (Table 1) indicates large crowns distinctive of the species, which has ellipsoidal, flat or umbel-shaped crowns according to De Cauwer et al. (2014). *B. madagascariensis* showed mean FC of 0.64, with slender and sparse crowns. The SI which expresses how larger the crown diameter is than the DBH (MUGASHA et al., 2013; HESS et al., 2021), was 61.0 for *P. angolensis*, in other words, the crown diameter is 61 times larger than the DBH – and 21.4 for *B. madagascariensis* (Table 1, Figure 4g).

A lower value of the SI means that the tree has a proportionally higher crown surface area, making a more efficient use of space, thus considering a given crown projection area. Therefore, as trees grow within the forest, this index can be used as a thinning indicator, establishing the space to be cleared (GETZIN et al., 2011; GONZALEZ-BENECKE et al., 2014).

The variable of the CI can also be used for species management as it indicates the necessary space for the target height (JUCKER et al., 2015; HESS et al., 2016). The mean value for *P. angolensis* and *B. madagascariensis* was 1.24 and 0.36, respectively (Table 1). This index showed an almost curvilinear tendency as trees grew in height, as demonstrated by this study (Figure 4h). This trend is a result of the small increase of crown diameter with the increase of height in the sampled classes, although no increase in height was observed. The higher the value for this index, evidences that their growth is larger in height than in DBH (FELDPAUSCH et al., 2011).

We believe that for these activities to be successful, growth data for valuable timber species such as those presented in this study need to be widely available and we hope this information can help inform the sustainable management of timber in Mozambique.

5. CONCLUSIONS

There are significant and statistically precise relationships for interdimensional and morphometric features of *P. angolensis*, where crown diameter and crown length increase as DBH and height increase, the larger the crown, the larger the species growth, except for *B. madagascariensis*, whose crown features were little related to DBH.

The high variability of canopy diameters probably occurs due to the specific and adverse environmental conditions that influence the growth of the species, confirming the resilience characteristic of the same, high adaptation capacity. Crown features are the main factors that influence tree growth and timber quality, and they are important information for forest management measures, due to the simplicity and practicality of application in natural forests.

This study can contribute through silvicultural interventions that result in better increment rates and native species growth in the context of management of individual tree and conservation of species in a natural forest. The results are relevant to conservation and sustainable management for *P. angolensis* and *B. madagascariensis* trees in central of Mozambique.

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