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

Noé dos Santos Anhanias HOFICO1,*, Emanuel Arnoni COSTA2, Frederico Dimas FLEIG3, César Augusto Guimarães FINGER3

1Department of Forest Engineering, Zambeze University – UniZambeze, Mocuba, Zambézia, Mozambique.  
2Department of Forest Engineering, Federal University of Uberlândia, Monte Carmelo, MG, Brazil.  
3Department of Forest Sciences, Federal University of Santa Maria, Santa Maria, RS, Brazil.  
*E-mail: noe.hofico@gmail.com

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 (chp) 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.

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 significant...
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).

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 morphology 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 Ltda (16°33’S and 36°32’E, 16°49’S and 36°47’E), located in Mocuba District, Zambezia 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 (HOFICO; 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 argisols 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, Zambezia Province, Mozambique.](image)

**Figure 1.** Área de estudo no Distrito de Mocuba, Provincia da Zambézia, Moçambique.

---

**Nativa, Sinop, v. 9, n. 3, p. 318-326, mai/jun. 2021.**
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; MOIJEREMANE; LUMBILE, 2016).

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; MOIJEREMANE; 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*.

2.3. Data acquisition

Data were obtained from 60 plots of 20 x 50 m (1000 m²) 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 [cd = h – cih]. Crown diameter (cd) was calculated in meters with the mean crown radius (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:

\[ y = \beta_0 \exp \left( \beta_1/x \right) + \varepsilon \]  

(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); \( \beta_0, \beta_1 \) – estimated regression coefficient; \( \varepsilon \) – 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:

\[ y = \beta_0 X^{\beta_1} + \varepsilon \]  

(02)

where: y – dimensional variable: SC; FC; SI; CI; x – DBH (diameter at breast height, measured at 1.30 m above ground, in cm); \( \beta_0, \beta_1 \) – estimated regression coefficient; \( \varepsilon \) – 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 (R²), 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).
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, 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 R² coefficient was 0.13 in the ch relationship, indicating the low adjusted in ch the increase of tree diameter, also confirmed by the RMSE of 0.86 m. The relationships of FC with R² = 0.34 and CI with R² = 0.35, confirmed the lower dependence to DBH. The adjusted regressions for the other variables had R² values higher than 0.80 and significant coefficients.

### Table 1. Biometric characteristics of *Pterocarpus angolensis* and *Bobgunnia madagascariensis* in Miombo woodland in Mocuba District, Mozambique.

| Variable | Unit | *Pterocarpus angolensis* | Range | *Bobgunnia madagascariensis* | Range |
|----------|------|--------------------------|-------|-------------------------------|-------|
| DBH      | cm   | 25.3 ± 12.9              | 10.0 - 66.7 | 19.4 ± 5.2                  | 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       | -    | 12.4 ± 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.

| Statistical criteria | Expression |
|----------------------|------------|
| Coefficient of determination | $R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$ |
| (Root Mean Square Error) | $RMSE = \sqrt{(n - p)^{-1}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}$ |
| Residual value (%) | $Residual \ value \ (%) = \frac{Y_i - \bar{Y}}{\bar{Y}} \times 100$ |

Where: $Y_i$ – observed variable; $\bar{Y}$ – estimated variable; $\bar{Y}$ – mean observed variable; n – number of observations; p – number of estimated 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 ($\beta_1$), 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.

| Variables | Species                 | n   | $\beta_0$ | $\beta_1$ | F value | $p$ value > F | $R^2$ | RMSE |
|-----------|-------------------------|-----|-----------|-----------|---------|--------------|-------|------|
| **h**     | *Pterocarpus angolensis* | 171 | 203.631   | -129.856  | 19426.1 | <0.0001      | 0.94  | 0.76 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| cih       | *Pterocarpus angolensis* |     | 99.362    | -117.056  | 7453.71 | <0.0001      | 0.83  | 0.63 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **ch**    | *Pterocarpus angolensis* |     | 5.284     | -3.472    | 2170.16 | <0.0001      | 0.13  | 0.89 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **cl**    | *Pterocarpus angolensis* |     | 9.998     | -8.429    | 17000.8 | <0.0001      | 0.87  | 0.86 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| cd        | *Pterocarpus angolensis* |     | 10.477    | -14.409   | 5929.56 | <0.0001      | 0.85  | 0.67 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **SC**    | *Pterocarpus angolensis* |     | 167.379   | -0.402    | 11703.8 | <0.0001      | 0.83  | 4.24 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **FC**    | *Pterocarpus angolensis* |     | 5.429     | -0.237    | 3405.19 | <0.0001      | 0.34  | 0.42 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **SI**    | *Pterocarpus angolensis* |     | 330.491   | -0.553    | 7964.05 | <0.0001      | 0.86  | 6.54 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **CI**    | *Pterocarpus angolensis* |     | 2.190     | -0.184    | 5923.58 | <0.0001      | 0.35  | 0.15 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **h**     | *Bobgunnia madagascariensis* | 115 | 17.165    | -8.201    | 2452.08 | <0.0001      | 0.36  | 1.69 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| cih       | *Bobgunnia madagascariensis* |     | 5.270     | -4.589    | 957.65  | <0.0001      | 0.07  | 1.01 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **ch**    | *Bobgunnia madagascariensis* |     | 7.532     | -9.461    | 1111.61 | <0.0001      | 0.25  | 1.03 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **cl**    | *Bobgunnia madagascariensis* |     | 2.866     | -6.729    | 1355.75 | <0.0001      | 0.18  | 0.41 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| cd        | *Bobgunnia madagascariensis* |     | 12.199    | -10.549   | 887.67  | <0.0001      | 0.24  | 1.77 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **SC**    | *Bobgunnia madagascariensis* |     | 274.6     | -0.529    | 2367.21 | <0.0001      | 0.45  | 9.27 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **FC**    | *Bobgunnia madagascariensis* |     | 1.117     | -0.190    | 276.58  | <0.0001      | 0.01  | 0.29 |
|           |                         |     | (<0.0375) | (<0.2451) |         |              |       |      |
| **SI**    | *Bobgunnia madagascariensis* |     | 118.173   | -0.587    | 1413.26 | <0.0001      | 0.37  | 4.37 |
|           |                         |     | (<0.0001) | (<0.0001) |         |              |       |      |
| **CI**    | *Bobgunnia madagascariensis* |     | 0.463     | -0.078    | 1002.74 | <0.0001      | 0.01  | 0.09 |
|           |                         |     | (<0.0001) | (<0.0365) |         |              |       |      |

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; $\beta_0$, $\beta_1$ – 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 HOLSBECK 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.
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 former is a latitudinal 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 umbrella-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 umbrella-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 4b). 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.

6. ACKNOWLEDGMENTS

We thank Sotomane concession staff and colleagues from the Department of Forest Engineering at UniZambeze for their support. Special thanks are due to Mr. Jaime Macuacua, Marchante Assura and Miguel da Costa for important contributions during the execution of this work. This research was supported by the National Research Fund of Mozambique (FNI: Project_12B/2018).

7. REFERENCES

ALI, A. C.; UETIMANE JUNIOR, E.; LHATE, I. A.; TERZIEV, N. Anatomical characteristics, properties and use of traditionally used and lesser-known wood species from Mozambique: a literature review. *Wood Science and Technology*, New York, v. 2, n. 6, p. 453-472, 2008. DOI: https://doi.org/10.1007/s00226-008-0186-5

BUNSTER, J. Commercial timbers of Mozambique: Technological Catalogue. Traforest Lda, Maputo, Mozambique. 2006. 63p.

CAMPBELL, B.; ANGELSEN, A.; CUNNINGHAM, A.; KATERE, Y.; SITOYE, A.; WUNDER, S. Miombo woodlands: Opportunities and barriers to sustainable forest management. Centre for International Forestry Research (CIFOR), Bogor, Indonesia. 2008. 41p.

CARO, T. M.; SUNGULA, M.; SCHWARTZ, M. W.; BELLA, E. M. Recruitment of Pterocarpus angolensis in the wild. *Forest Ecology and Management*, Amsterdam, v. 219, n. 2-3, p. 69–175, 2005. DOI: https://doi.org/10.1016/j.foreco.2005.07.004

CHIDUMAYO, E. N. Forest degradation and recovery in a Miombo woodland landscape in Zambia: 22 years of observations on permanent sample plots. *Forest Ecology and Management*, Amsterdam, v. 291, p. 154-161, 2013. DOI: https://doi.org/10.1016/j.foreco.2012.11.031

CHIDUMAYO, E. N. Management implications of tree growth patterns in Miombo woodlands of Zambia. *Forest Ecology and Management*, Amsterdam, v. 436, n. 1, p. 105-116, 2019. DOI: https://doi.org/10.1016/j.foreco.2019.01.018

CHITECULO, V.; SUROVY, P. Dynamic Patterns of trees species in Miombo Forest and management perspectives for sustainable production - case study in Huambo Province, Angola. *Forests*, Basel, v. 9, n. 6, p. 321, 2018. DOI: https://doi.org/10.3390/f9060321

COSTA, E. A.; FINGER, C. A. G.; FLEIG, F. D. Influência da posição social nas relações morfométricas de Araucaria angustifolia. *Ciência Florestal*, Santa Maria, v. 26, n. 1, p. 225-234, 2016. DOI: http://dx.doi.org/10.5380/rt/v:47/4-9667

DE CAUWER, V.; MUYS, B.; REVERMANN, R.; TRABUCCO, A. Potential, realised, future distribution and environmental suitability for Pterocarpus angolensis DC in southern Africa. *Forest Ecology and Management*, Amsterdam, v.315, n. 1, p. 211-226, 2014. DOI: https://doi.org/10.1016/j.foreco.2013.12.032

EGAS, A. Assessment of harvested volume and illegal logging in Mozambican natural forests. Faculty of Agronomy and Forest Engineering, Eduardo Mondlane University. Maputo, Mozambique. 2013. 176p.

FELDPAUSCH, T. et al. Height-diameter allometry of tropical forest trees. *Biogeosciences*, Hoboken, v. 8, p. 1081-1106, 2011. DOI: https://doi.org/10.5194/bg-8-1081-2011

GELDENHUYJS, C. J. Basic guidelines for silvicultural and management practices in Mozambique. Report FW-04-05, Forestwood, Pretoria, 2005. 78p.

GETZIN, S.; WORBES, M.; WIEGAND, T.; WIEGAND, K. Size dominance regulates tree spacing more than competition within height classes in tropical Cameroon. *Journal of Tropical Ecology*, Cambridge, v. 27, n. 1, p. 93-102, 2011. DOI: https://doi.org/10.1017/S026647410000453

GONÇALVES, F. M. P.; REVERMANN, R.; GOMES, A. L.; AIDAR, M. P. M.; FINCKH, M.; JUERGENS, N. Tree species diversity and composition of Miombo woodlands in South-Central Angola: A chronosequence of forest recovery after shifting cultivation. *International Journal of Forestry Research*, London, v. 2017, n. 1, p. 1-13, 2017. DOI: https://doi.org/10.1155/2017/620293

GONZALEZ-BENECKE, C. A.; GEZAN, S. A.; SAUMELISON, L. J.; CROPPER Jr., W. P.; LEDUC, D. J.; MARTIN, T. A. Estimating Pinus palustris tree diameter and stem volume from tree height, crown area and stand-level parameters. *Journal of Forest Research*, v. 25, n. 1, p. 43–52, 2014. DOI: https://doi.org/10.1007/s11676-014-0427-4

HESS, A. F.; MINATTI, M.; COSTA, E. A.; SCHMURR, L. P. B.; ROSA, G. T. da; SOUZA, I. de A.; BORSOI, G. A.; LIESTENBERG, V.; STEPKA, T. F.; ABATTI, R. Height-to-diameter ratios with temporal and dendro/morphometric variables for Brazilian pine in south Brazil. *Journal of Forest Research*, v. 32, p. 191–202, 2021. DOI: https://doi.org/10.1007/s11676-019-01084-8

HESS, A. F.; LOIOLA, T.; SOUZA, I. A. de; NASCIMENTO, B. Morphometry of the crown of Araucaria angustifolia in natural sites in southern Brazil. *Bosque*, Valdivia, v. 37, n. 3, p. 603-611, 2016. DOI: http://dx.doi.org/10.4067/S0717-92002016000300017

HOFICO, N. S. A.; COSTA, E. A.; FLEIG, F. D.; NANVONAMUQUITXO, S. J. A. Regulation of the diametric structure of the Miombo woodland using the De Liocourt method in Mozambique. *Nativa*, Sinop, v. 6, n. 4, p. 407-414, 2018. DOI: http://dx.doi.org/10.31413/nativa.v6i4.5396

HOFICO, N. S. A.; FLEIG, F. D. Diversity and structure of Miombo woodlands in Mozambique using a range of sampling sizes. *Journal of Agricultural Science and Technology*, Tarbat, v. 5, n. 10, p. 679-690, 2015. DOI: 10.17265/2161-6264/2015.10.005
JUCKER, T.; BOURIAUD, O.; COOMES, D. A. Crown plasticity enables trees to optimize canopy packing in mixed-species forests. *Functional Ecology*, Oxford, v. 29, p. 1078-1086, 2015. DOI: https://doi.org/10.1111/1365-2435.12428

KALABA, F. K.; QUINN, C. H.; DOUGILL, A. J.; VINYA, R. Floristic composition, species diversity and carbon storage in charcoal and agriculture fallows and management implications in Miombo woodlands of Zambia. *Forest Ecology and Management*, Amsterdam, v. 304, p. 99–109, 2013. DOI: https://doi.org/10.1016/j.foreco.2013.04.024

KALABA, F. K.; QUINN, C. H.; DOUGILL, A. J. The role of forest provisioning ecosystem services in coping with household stresses and shocks in Miombo woodlands, Zambia. *Ecosystem Services*, v. 5, p. 143-148, 2014. DOI: https://doi.org/10.1016/j.ecoser.2013.07.008

MAE. *Perfil do distrito de Mocuba. Província da Zambezia*. Ministério da Administração Estatal. Série Perif. Distritais, Maputo, Mozambique. 2005. 50p.

MALMER, A. General ecological features of Miombo woodlands and considerations for utilization and management. p. 34-42. 2007. (Working Papers of the Finnish Forest Research Institute, v. 50).

MATE, R.; JOHANSSON, T.; SITOE, A. Biomass equations for tropical forest tree species in Mozambique. *Forests*, Basel, v. 5, p. 535-556, 2014. DOI: https://doi.org/10.3390/f50303535

MATE, R.; JOHANSSON, T.; SITOE, A. Stem Volume Equations for Valuable Timber Species in Mozambique. *Journal of Sustainable Forestry*, v. 34, n. 8, p. 787-806, 2015. DOI: http://dx.doi.org/10.1080/10549811.2015.1039043

MITADER. *Inventario Florestal Nacional*. Ministry of Land, Environment and Rural Development, Maputo, Mozambique. 2018. 118p.

MOJEREMANE, W.; LUMBILE, A. U. A review of *Pterocarpus angolensis* DC. (Mukwa) an important and threatened timber species of the Miombo woodlands. *Research Journal of Forestry*, v. 10, n. 1, p. 8-14, 2016. DOI: https://doi.org/10.3923/rjf.2016.8.14

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.

MUGASHA, W. A.; BOLLANDSÅS, O. M.; EID, T. Relationships between diameter and height of trees in natural tropical forest in Tanzania. *Southern Forests: a Southern Africa Timber Market and Forest Industry Study*. Cape Town: Struik publishers, 2011. 536p.