Ensaios e Ciência
ISSN 1415-6938 e ISSN 2178-695X

DOI: https://doi.org/10.17921/1415-6938.2025v29n1p30-39

Mathematical Estimation of Leaf Area in *Brosimum gaudichaudii* Trécul. (Moraceae)

Estimativa Matemática da Área Foliar de *Brosimum gaudichaudii* Trécul. (Moraceae)

Recebido em: 13/08/2025
Aceito em: 12/04/2025

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Abstract

Leaf area analysis is a widely used method for assessing plant growth and vegetative development. This technique is efficient, economical, fast and non-destructive, and can be obtained from mathematical models. The aim was therefore to estimate the leaf area (AFE) of the species *Brosimum gaudichaudii* Trécul. (Moraceae) and to establish mathematical models using the dimensions of the leaf blade: length (C), width (L) and the product of these two measurements (CxL). We used 153 *B. gaudichaudii* leaves that were photographed and ImageJ® software was used to obtain the dimensional parameters "C", "L", "CxL" and the observed leaf area (AFO). AFO was determined using the leaves' linear dimensions (independent variables) and the observed leaf area (dependent variable) using linear, quadratic and potential regression equations. From a practical point of view, the mathematical equation obtained through linear regression using the length and width relationship is recommended, using the model Y = 3.5833 + 0.6715x, with a coefficient of determination of 0.9677. Therefore, the mathematical model that uses the product of the linear dimensions CxL is more suitable for estimating leaf area non-destructively for the *B. gaudichaudii* specie.

Keywords: Mama-Cadela. Linear Model. Medicinal Plant.

Resumo

A análise da área foliar é um método amplamente utilizado para avaliar o crescimento e o desenvolvimento vegetativo das plantas. Esta técnica é eficiente, econômica, rápida e não destrutiva, que pode ser obtida a partir de modelos matemáticos. Assim, objetivou-se estimar a área foliar (AFE) da espécie *Brosimum gaudichaudii* Trécul. (Moraceae) e estabelecer modelos matemáticos utilizando as dimensões da lâmina foliar: comprimento (C), largura (L) e o produto destas duas medidas (CxL). Foram utilizadas 153 folhas *B. gaudichaudii* fotografadas e analisadas com auxílio do software ImageJ® para a obtenção dos parâmetros dimensionais "C", "L", "CxL" e a área foliar observada (AFO). A AFE
foi determinada utilizando as dimensões lineares das folhas (variáveis independentes) e a área foliar observada (variável dependente) utilizando-se equações de regressão linear, quadrática e potencial. Do ponto de vista prático, recomenda-se a equação matemática obtida através da regressão linear por meio da relação comprimento e largura, utilizado o modelo Y = 3,5833 + 0,6715x, com coeficiente de determinação de 0,9677. Portanto, o modelo matemático que utiliza o produto das dimensões lineares CxL é mais adequado para estimar a área foliar de forma não destrutiva para a espécie *B. gaudichaudii*.

Palavras-chave: Mama-Cadela. Modelo Linear. Planta Medicinal.

1 Introduction

Brosimum gaudichaudii Trécul. (Moraceae), commonly known as "mama-cadela," stands out for its production of latex and rubber granules, as well as the use of its root bark and leaves in folk medicine, particularly for the treatment of vitiligo (Carvalho, 2014; Engelbrecht *et al*., 2021; Lorenzi, 1992). Its medicinal properties are attributed to furanocoumarins (Jacomassi; Moscheta; Machado, 2007), while the coumarins present in the fruits' ethanolic extract exhibit antioxidant and cytotoxic activities (Engelbrecht *et al*., 2021; Neves *et al*., 2002; Pozetti, 2005). However, the species is at risk of extinction due to habitat loss and the lack of studies on its growth and propagation (Maurano; Almeida; Meira, 2019).

Structural studies are essential to prevent the eradication of species with economic and medicinal importance, enabling proper management. Among the available tools, the use of non-destructive techniques to estimate leaf area stands out for its practicality and contribution to scientific and productive development. Leaf area is crucial for assessing plants' growth, as it is related to physiological parameters such as relative growth rate, CO_2 assimilation, and transpiration (Maracajá *et al*., 2008). Since leaves are the primary organs for gas exchange, leaf area is considered an indicator of productivity (Buchanan; Gruissem; Jones, 2015).

Allometry, by analyzing scaling relationships in biological attributes, aids in understanding vegetative growth (Taiz *et al*., 2017). Methods such as electronic meters, manual techniques, and mathematical equations-based on linear dimensions such as length (L) and width (W) and their relationship (L×W)-allow for fast, accurate, and accessible estimations (De Oliveira *et al*., 2015).

In this context, the objective was to estimate the leaf area of *Brosimum gaudichaudii* Trécul (Moraceae) and establish mathematical models using dimensional parameters of the leaf blade: length (L), width (W), and the relationship between these two measurements.

2 Material and Methods

For the study, 200 leaves were collected from 13 specimens of a population located in a cerrado area (21º14’16.35” S – 45º01’1.82” W – 911 m altitude), undergoing increasing anthropization, on the outskirts of the urban perimeter of the Municipality of Lavras (Minas Gerais). The selected leaves were from the fourth or fifth node of branches, fully developed, with no morphological alterations, irregular growth, or defects caused by herbivores or other predators.

After collection, the leaves were placed in plastic bags and taken to the laboratory, where a second screening was conducted to eliminate any deformed leaves, resulting in a total of 153 selected leaves. The screened leaves were pressed, without the petiole (similar to the pressing process for herbarium specimens), between newspaper sheets, left to dry at room temperature, and the paper was changed daily until complete drying. The leaves were then photographed using a Samsung WB380F digital camera (Samsung Electronics Co. Ltd.), ensuring that a scale (ruler) was included in each recorded image. The obtained photos were analyzed using ImageJ® software (National Institutes of Health, Bethesda, Maryland, USA) to obtain linear measurements of the leaf blade: length (L), width (W), and leaf area (Martin et al., 2013). The product of length and width (L×W) in cm^2 was calculated using StatSoft software (Electronic Statistics Textbook, Tulsa, OK).

The estimation of the leaf area of *Brosimum gaudichaudii* was carried out based on an adaptation of the methodology proposed by Cargnelutti *et al*. (2012). Frequency histograms and scatter plots were generated following Oliveira *et al*. (2023), employing linear regression ($Y = a + bx$), polynomial regression ($Y = a + bx + cx^2$), and power regression (Y = ax^b) to estimate the leaf area (ELA) using the linear measurements L, W, and L×W, resulting in a total of nine models (3 models × 3 independent variables).

The species characterization was based on a thorough analysis using the works of Durigan *et al*. (2004), Da Silva Júnior (2005), Martins and Pirani (2010), and Lorenzi (1992), as well as observations of specimens (herbarium sheets) deposited in the ESAL Herbarium, belonging to the Department of Biology (DBI) at the Institute of Natural Sciences (ICN) of the Federal University of Lavras (UFLA, Lavras, Minas Gerais, Brazil).

3 Results and Discussion

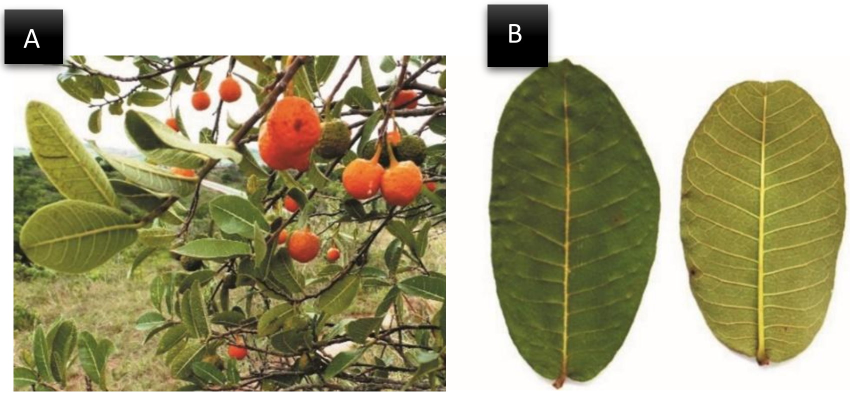
3.1 Plant Characteristics of *Brosimum gaudichaudii* Trécul. (Moraceae)

Brosimum gaudichaudii is a shrub to small tree species, reaching heights of up to 2.5 m, and rarely between 3.5 and 4.0 m. Its branches are twisted and latescent. The leaves are simple, alternate, with short to subsessile petioles and slightly pubescent; the leaf blade varies from elliptical to oblong-lanceolate (Figure 1B), with a texture ranging from chartaceous to subcoriaceous or coriaceous. The leaf apex can be acuminate to obtuse, while the base varies from acute to obtuse or slightly subcordate, with entire margins that are often revolute. The adaxial leaf surface is sparsely pubescent to hirtellous, with denser indumentum along the veins, while the abaxial surface is pubescent to hirtellous or slightly tomentose. The leaf venation follows a pinnate pattern, and the leaves produce an abundant white latex.

The ripe fruits have an orange coloration and measure approximately 2.0 to 3.0 cm, tending to a rounded shape and generally containing one to two seeds (Carvalho, 2014; Jacomassi; Moscheta; Machado, 2007; Lorenzi; Matos, 2021; Lorenzi *et al*., 2006; Pozetti, 2005). According to De Oliveira *et al*. (2015), the fruits (Figure 1A) mature from August to December in the Federal District, while Durigan *et al*. (2004) reported that maturation occurs from November to December in São Paulo. In the study area where the leaves were collected, in the municipality of Lavras, fruit maturation was observed from October to January.

This species can be found in the Atlantic Forest, Pantanal, and Cerrado biomes. In Minas Gerais, it has been observed in Cerrado stricto sensu (Hatschbach et al., 2005), Cerradão (Costa; Araújo, 2001), and Campo Cerrado (Brandão; Laca-Buendia; Saturnino, 1996; Brandão; Gavilanes, 1977; Gavilanes, 1996).

Figure 1 - Aspect of a specimen (A); Leaf morphology in adaxial and abaxial view (B)



Source: the authors**.**

The leaf blades of *Brosimum gaudichaudii*, excluding the petiole, have an average length of 9.87 cm, an average width of 4.67 cm, and an average leaf area of 37.94 cm². The leaf area ranged between 22.28 and 19.86 cm² (Table 1).

Table 1 - Length (L), Width (W), Length versus Width (L×W), and Leaf Area determined by digital photos (Y) of 153 *Brosimum gaudichaudii* leaves

Statistic	L (cm)	W (cm)	L × W (cm²)	Y (cm²)
Minimum	7.74	3.08	24.52	22.28
Maximum	12.48	6.18	96.55	55.26
Range	4.74	3.10	45.04	32.98
Average	9.87	4.67	46.57	37.94
Median	9.87	4.68	46.36	38.46
CV%	11.51	12.30	21.71	19.86

Source: research data.

The value of R^2 ranged from 0.79 to 0.96 (Table 2) for the leaf area (Y), and for the linear measurements C, L, and C×L, with the lowest value corresponding to the linear model of the independent variable C. The highest R^2 value was obtained from the independent variable C×L (0.96). The equations that allowed for leaf area estimates with determination coefficients (R^2) higher than 0.95 (95%) were: linear, quadratic, and power, using C×L of the leaf.

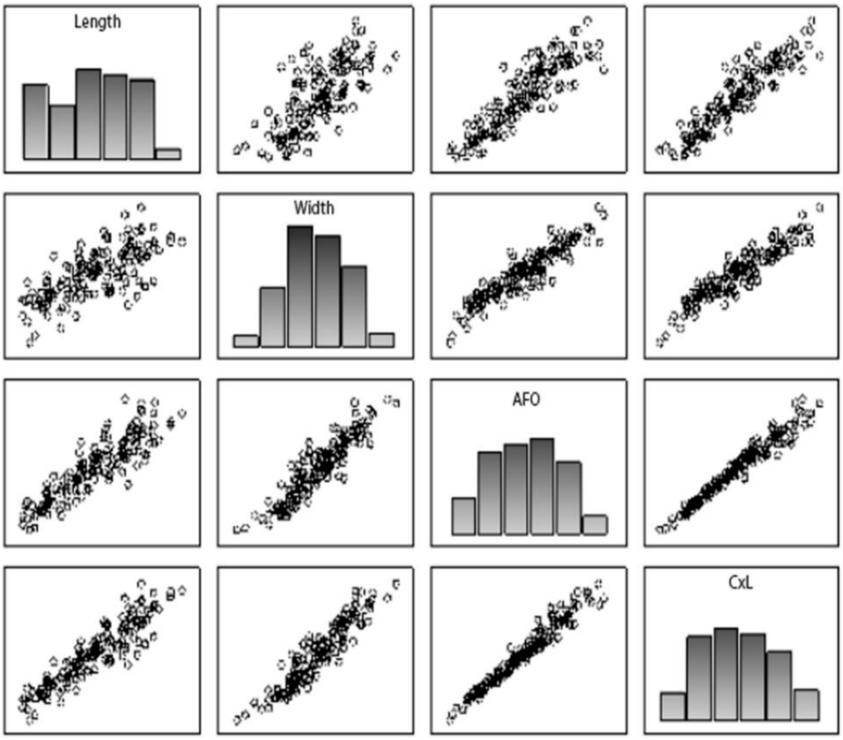
Table 2 - Mathematical models used to estimate leaf area from digital photos (Y) and determination coefficient (R^2

Model	Independent Variable (x)	Equation	Determination Coefficient (R^2)
Linear	C	$y = -20.196 + 5.8884x$	0.79
Linear	L	$y = -18.391 + 12.061x$	0.85
Linear	C×L	$y = 4.046 + 0.7277x$	0.96
Quadratic	C	$y = -55.187 + 13.083x - 0.365x^2$	0.79
Quadratic	L	$y = -10.947 + 8.8191x + 0.3476x^2$	0.85
Quadratic	C×L	$y = -6.266 + 1.4794x - 0.0022x^2$	0.96
Power	C	$y = 1.0099x^{1,5793}$	0.79
Power	L	$y = 3.706x^{1,5035}$	0.85
Power	C×L	$y = 0.9313x^{1,0753}$	0.96

Source: research data.

The highest R^2 values were obtained for the linear, quadratic, and power models for the variable C×L. This result is due to the product of these variables showing a high correlation (Table 2).

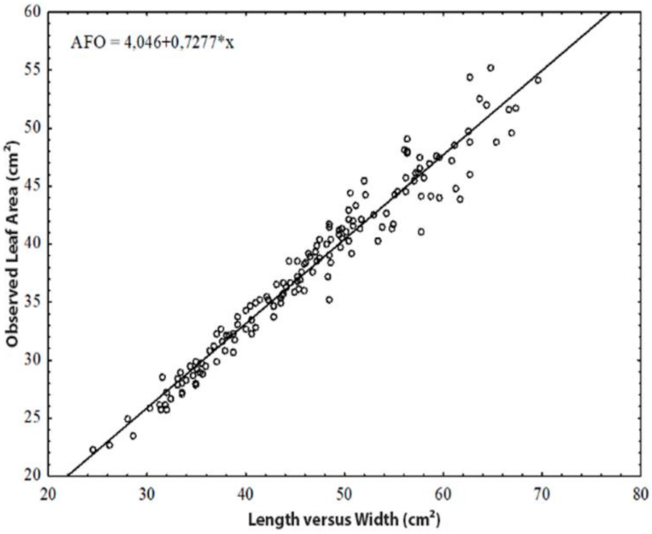
Figure 2 - Frequency histogram (on the diagonal) and scatter plots between length (L) in cm, width (W) in cm, the product length × width (L×W) in cm², and leaf area determined by digital photos (LAF) in cm², from 153 leaves of *Brosimum gaudichaudii*



Source: the authors.

From a practical point of view, the mathematical model that best fits the determination of leaf area for the species was the linear model (y = 4.046 + 0.7277x), with a determination coefficient (R^2) equal to 0.9545 (Figure 3).

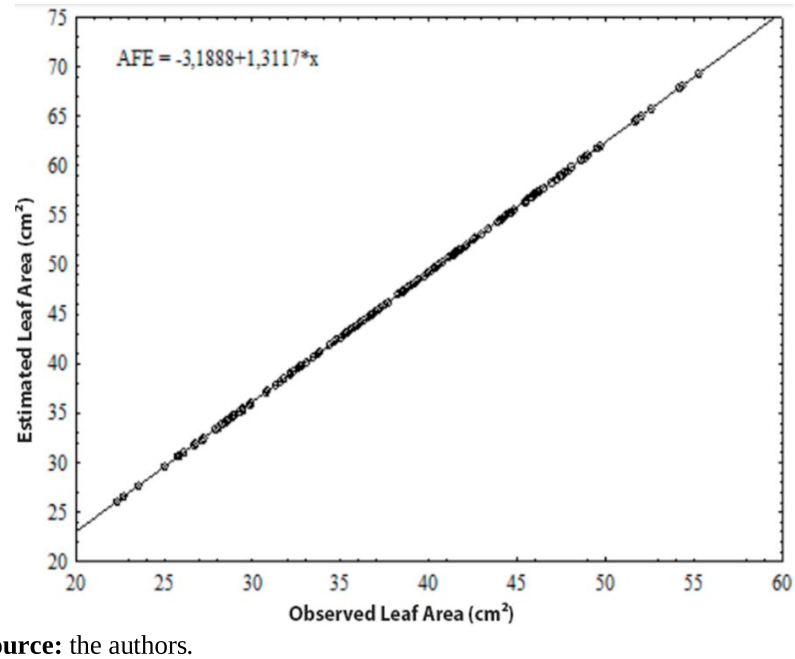
Figure 3 - Linear model of leaf area determined by digital photos (in cm²) as a function of the product length × width (in cm²).



Source: the authors.

The proposed model was validated for different leaf morphologies of the species (Figure 4), where the expected and observed leaf area values are compared, with an R^2 of 0.999.

Figure 4 - Relationship between the observed leaf area values (determined) through the digital photo method and the estimated leaf area based on the linear model of length × width



Source: the authors.

Several studies support that the use of mathematical models based on the product of length and width (CxL) is the most suitable approach for non-destructive leaf area analysis. Examples include *Cinnamodendron dinisii* Schwacke (R^2 = 0.98) (Oliveira et al., 2023), *Siparuna guianensis* Aubl. (R^2 = 0.96) (Santos *et al.*, 2022), *Turnera subulata* Sm. (R^2 = 0.99) (Castro *et al*., 2021), *Salvia hispanica* L.

($R^2 = 0.99$) (Goergen *et al.*, 2021), and *Tithonia diversifolia* (Hemsl.) A. Gray ($R^2 = 0.941$) (Holguin *et al.*, 2019).

The proposed mathematical equations allow for the non-destructive estimation of the leaf area of *Brosimum gaudichaudii*. To do this, it is necessary to measure the length and width of a fully developed leaf, preferably from the fourth or fifth node, calculate the product of these dimensions, and apply the corresponding formula. This method eliminates the need to remove the leaf, simplifying the process and preserving the plant's integrity. In addition to providing accurate data, the approach is particularly useful in studies related to plant's growth and development. Its application supports proper management and conservation of the species, contributing to efforts for the preservation and sustainable use of *Brosimum gaudichaudii*.

4 Conclusion

This study represents a significant contribution to the research on *Brosimum gaudichaudii* Trécul by validating a non-destructive method for determining leaf area. The linear equation obtained ($\hat{Y} = 4.046 + 0.7277x$), based on the product of leaf length and width, demonstrated an excellent fit, establishing it as an efficient and practical tool for estimating the species' leaf area. This model is especially valuable in studies aimed at understanding the plant's growth and development, as well as promoting its conservation by avoiding invasive practices.

Acknowledgments

We would like to thank the Coordination for the Improvement of Higher Education Personnel (Capes), the National Council for Scientific and Technological Development (CNPq), and the Foundation for Research Support of the State of Minas Gerais (FAPEMIG) for financial support and research productivity grants. We also thank the Universidade Federal de Lavras (UFLA) for their collaboration.

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