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Non-destructive method for estimating *Annona muricata* leaf area using linear leaf dimensions

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Abstract: Estimating leaf area (LA) in fruit plants using non-destructive methods is a valuable parameter, since leaves function as the primary interface between plants and the environment and directly contribute to photosynthetic capacity. Therefore, the objective of this study was to determine allometric equations to estimate the leaf area of the soursop using linear dimensions (length and width) of the leaves. Eight hundred and twenty-five soursop leaves of the ‘Morada’ cultivar were randomly collected from healthy seedlings. Measurements of length (L), width (W), and leaf area (LA) were carried out by means of digitized images, followed by the calculation of the product between length and width (LW), length squared, and width squared. Linear, linear non-intercept, power, and exponential regression models were applied, based on the L and W dimensions of the leaves, to estimate the LA of the species. The best models and equations were chosen based on Pearson’s highest coefficients of determination and correlation, Willmott’s agreement index, Akaike’s lowest information criterion, root mean squared error, and mean absolute percentage error. LA can be estimated from the LW of leaves using the allometric equations $\hat{y} = 0.72 \times LW$ (linear model without intercept) and $\hat{y} = 0.69 \times LW^{1.00}$ (power model). Allometric equations are accurate and safe for estimating LA in soursop seedlings, allowing repeated measurements throughout development and contributing to agronomic studies.

Keywords: Soursop, biometry, leaf dimensions, mathematical model, allometric equations.

Introduction

Determining leaf area in fruit cultivation plays a crucial role in agronomic studies. Leaves serve as the primary interface between plants and their agroecosystems

(Rodriguez-Paez et al., 2024), directly influencing photosynthetic capacity and light interception (Delgado et al., 2024), which impacts biomass, energy balance, and overall vigor of the plants.

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In most cases, leaf area can be determined by direct methods, usually destructive, or by indirect methods, based on allometric models (Cabral et al., 2023). However, direct evaluation becomes unfeasible when it involves a large number of sheets, as it is laborious, time-consuming, costly, and requires specific equipment (Jaime-Guerrero et al., 2023). On the other hand, allometric models, based on regression analyses, allow the estimation of leaf area quickly, accurately, and non-destructively using simple leaf blade measurements (Gupta et al., 2023; Puntel et al., 2023; Rodriguez-Paez et al., 2024). In addition to reducing costs and evaluation time, these models enable monitoring leaf growth throughout plant development without removing leaves, making them important tools for agricultural management of fruit species (Delgado et al., 2024; Soysal, 2024). Allometric models for estimating leaf area as a function of leaf length and width have been developed for fruit species such as *Psidium guajava* L. (Gonçalves et al., 2022), *Spondias* sp. (Amorim et al., 2024a), *Spondias tuberosa* Arruda (Amorim et al., 2024b), and *Euterpe oleracea* and *Euterpe precatoria* (Delgado et al., 2024).

The soursop tree (*Annona muricata* L.) is one of the most economically and medicinally important fruit plants of the Annonaceae families, cultivated in tropical and subtropical regions, mainly in Brazil. Its fruits have high nutritional value due to the abundance of carbohydrates, calcium, phosphorus, iron, thiamine, niacin, and riboflavin (Leal and Paull, 2023). They are commercially preferred fresh due to their pleasant and sweet flavor. However, pulp production is the main destination (Santos et al., 2023). The soursop tree, because it has several phytochemicals, can also be used medicinally to treat a wide variety of diseases, such as diabetes, cancer, oxidative stress, hypertension, hemorrhagic diseases, and cholesterol reduction (Afzaal et al., 2022).

However, despite its agricultural and pharmaceutical potential, estimation of the crop's leaf area using allometric models is scarce. Thus, we hypothesize that the leaf area of the soursop tree can be accurately estimated using allometric models based on simple linear leaf measurements (length and width), providing a fast, low-cost, and non-destructive alternative. Thus, the objective of this study was to determine allometric equations to estimate the leaf area of soursop considering the leaves' linear dimensions (length and width).

Materials and Methods

The experiment was conducted in a greenhouse at the Federal University of the Semi-Arid Region (UFERSA), Mossoró, Rio Grande do Norte, Brazil (5° 12' 14.2" S, 37° 19' 29.3" W, at an elevation of 18 m), in 2023. The climate of the region, according to the Köppen climate classification, is of the BSh type (dry and very hot) (Alvares et al., 2013), with an average annual rainfall of 555 mm and an average annual temperature of 27.8°C (Climate-data, 2024). During the experiment, the minimum, mean, and maximum temperatures recorded inside the greenhouse were 24.9, 33.73, and 42.10 °C, respectively, while the relative humidity presented minimum, mean, and maximum values of 25.6, 39.0, and 71.9%. The data were recorded using a digital thermo-hygrometer model SH-122 (J.PROLAB Indústria e Comércio de Produtos para Laboratório Ltda., São José dos Pinhais, PR, Brazil).

The soursop seedlings of the 'Morada' cultivar were obtained from seeds extracted from healthy fruits of mother plants with good phytosanitary conditions in the rural area of Mossoró, RN. The seeds were pulped, rinsed under running water, and dried on paper towels in the shade for seven days. The sowing of three seeds was carried out at a depth of 1.5 cm in plastic bags with a capacity of 2 dm³, containing substrate composed of sand and commercial substrate Tropstrato® (Vida Verde, Mogi Mirim, SP,

Brazil) in the proportion 2:1 (v/v). After emergence, thinning was done, leaving only one seedling per bag. At 130 days, the seedlings were transplanted into 5 L plastic pots filled with the same substrate and proportion. The chemical characteristics of the substrate were analyzed at the Soil,

Water, and Plant Analysis Laboratory and the Plant Nutrition Laboratory of UFERSA Mossoró, RN, Brazil (Table 1). The spacing between rows was 1.0 m, and between seedlings within the row, 0.5 m.

Table 1. Chemical characteristics of the substrate used in the experiment.

pH	EC	O.M.	P	K ⁺	Na ⁺	Ca ²⁺	Mg ²⁺	SB	T	CEC	V	ESP
(H ₂ O)	(dS m ⁻¹)	(g kg ⁻¹)(mg dm ⁻³).....		(cmolc dm ⁻³).....		(%)......			
1:25	1:25											
4.82	1.00	27.84	214.30	225.10	251.48	5.60	2.60	9.87	9.87	12.84	76.90	8.50

pH – hydrogen potential; EC – saturated paste electrical conductivity; O.M. – organic matter; P, K⁺, and Na⁺ – phosphorus, potassium, and sodium were extracted with Mehlich 1 solution; Al³⁺, Ca²⁺, and Mg²⁺ – aluminum, calcium, and magnesium were extracted with 1 M KCl solution; SB – sum of bases; T – effective cation exchange capacity; CEC – potential cation exchange capacity at pH 7.0; V – base saturation; ESP – percentage of exchangeable sodium. Values for exchangeable aluminum (Al³⁺) and aluminum saturation (m) were both 0 cmolc dm⁻³.

Irrigation was carried out manually using the gravimetric method, based on daily weighing and replacement of the water lost by the substrate, with a graduated cylinder, until reaching a weight corresponding to 100% of field capacity, according to Souza et al. (2000). The weighings were carried out using a digital scale with a capacity of 31 kg.

The seedlings were fertilized weekly with nitrogen, potassium, and phosphorus (NPK), divided into twelve applications via fertigation, with 50% of 100 mg of N, 300 mg of P₂O₅, and 150 mg of K₂O per dm⁻³ of soil (Novais et al., 1991). For fertilization, 400 mg of urea, 1,250 mg of monoammonium phosphate, and 650 mg of potassium chloride were applied per pot. During the experiment, the seedlings received cultural and phytosanitary management, when necessary.

At 120 days after transplanting, 825 healthy leaves of soursop seedlings were randomly collected, without phytosanitary problems, visible symptoms of nutritional deficiencies or abnormal development, and with different sizes. The leaves were stored in plastic bags and transported to the Fruit Growing Laboratory of UFERSA, Mossoró, RN, Brazil. Then, the leaves were scanned with a flatbed scanner (model Samsung

Xpress SL-C480FW) with a resolution of 600 dpi. The images were analyzed and processed using the ImageJ[®] software version 1.53e in the public domain (Schneider et al., 2012).

The allometric measurements, length (L, cm) and width (W, cm) were obtained to develop allometric equations. The L was measured from the leaf tip to the point of intersection between the leaf and the petiole. The W was obtained by measuring the tip-to-tip between the widest part of the blade precisely perpendicular to the central vein of the blade (Figure 1). The L and W were the independent variables, while leaf area (LA, cm²) was the variable dependent. In addition, the product of L and W (LW), L × L (L²), and W × W (W²) were calculated and considered as independent variables.

The degree of collinearity between the parameters was evaluated to verify whether or not there is precision in the estimates of the regression coefficients between L and W. Therefore, the variance inflation factor (VIF) (Equation 1) (Marquardt, 1970) and the tolerance value (T) (Equation 2) (Gill, 1986) were calculated. High VIF (> 10) or low T (< 0.1) values indicate multicollinearity between L and W (Gill, 1986).



Figure 1. Soursop leaf used to estimate leaf area.

$$VIF = \frac{1}{1 - r^2} \tag{1}$$

$$T = \frac{1}{VIF} \tag{2}$$

Where: *r* – represents the correlation coefficient between *L* and *W*.

VIF ranged from 10.3 to 125.2, with corresponding *T* values between 0.007 and 0.09. Therefore, these values indicate multicollinearity between *L* and *W*.

The simple linear, linear non-intercept (0.0), power, and exponential regression models were applied to construct the allometric equations (Table 2).

Table 2. Models and descriptions of the models used to estimate soursop leaf area through the leaves' linear dimensions.

Models	Descriptions
Linear	$\hat{y} = \beta_0 + \beta_1 * x + \varepsilon_i$
Linear (0.0)	$\hat{y} = \beta_1 * x + \varepsilon_i$
Power	$\hat{y} = \beta_0 * x^{\beta_1} + \varepsilon_i$
Exponential	$\hat{y} = \beta_0 * \beta_1^x + \varepsilon_i$

\hat{y} – leaf area; *x* – linear dimensions of the leaves; β_0 and β_1 – model coefficients; ε_i – random error.

The best allometric models and equations were chosen based on the following criteria: highest coefficient of determination (R^2) (Equation 3), Pearson's correlation coefficient (*r*) (Equation 4), Willmott agreement index (*d*) (Equation 5), lowest Akaike information criterion (AIC) (Equation 6), root mean squared error (RMSE) (Equation 7), and mean absolute percentage error (MAPE) (Equation 8).

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y'_i)^2} \tag{3}$$

$$r = \frac{\sum_{i=1}^n (y_i - \bar{y})(x_i - \bar{x})}{\sqrt{\sum_{i=1}^n (y_i - \bar{y})^2 \sum_{i=1}^n (x_i - \bar{x})^2}} \tag{4}$$

$$d = 1 - \frac{\sum_{i=1}^n (\hat{y}_i - y_i)^2}{\sum_{i=1}^n (|\hat{y}'_i| + |y'_i|)^2} \tag{5}$$

$$AIC = -2 \ln L(x \setminus \hat{\theta}) + 2(p) \tag{6}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (\hat{y}_i - y_i)^2}{n}} \tag{7}$$

$$MAPE = \frac{\sum_{i=1}^n |\hat{y}_i - y_i|}{n} \times 100 \tag{8}$$

Where: \hat{y}_i – estimated values of the leaf area; y_i – values of the observed leaf area; \bar{y}_i – mean of the observed values; $\hat{y}'_i = \hat{y}_i - \bar{y}$; $y'_i = y_i - \bar{y}$; $L(x \setminus \hat{\theta})$ – maximum likelihood function; *p* – number of model parameters; *n* – number of observations; x_i and y_i – observations of variables *y* and *x*; \bar{y} and \bar{x} – mean of the variables *y* and *x*.

Descriptive data analysis was used to determine the minimum, maximum, mean, amplitude, median, variance, standard deviation, standard error, coefficient of variation, coefficient of asymmetry, and kurtosis of the independent (L, W, LW, L², and W²) and dependent (LA) variables. The normality of the data was verified using the Shapiro-Wilk test ($p \leq 0.05$) (Shapiro and Wilk, 1965). Student's t-test for paired samples ($p \leq 0.01$) compared the LA values of the observed (OLA) and estimated (ELA) leaves. Data analysis was performed using the R version 4.4.1 software (R Core Team, 2023).

Results

Descriptive statistics with the values of length (L), width (W), product of L and W (LW), $L \times L$ (L²), and $W \times W$ (W²), and leaf area (LA) were described in Figure 2. The measured leaves showed L and W ranging from 1.464 to 16.364 cm and 0.727 to 7.039 cm (Figures 2A and 2B, respectively).

The product LW ranged from 1.064 to 115.186 cm² in the soursop leaves (Figure 2C). The L² values ranged from 2.143 to 267.780 cm² (Figure 2D), while the W² values ranged from 0.529 to 49.548 cm² (Figure 2E). LA values of the soursop leaves ranged from 0.687 to 83.661 cm² (Figure 2F).

The coefficients of variation (CV) found for LW (50.46%), L² (55.81%), W² (50.64%), and LA (50.94%) (Figures 2C, 2D, 2E, and 2F, respectively) were higher than those of L (29.34%) and W (28.93%) (Figures 2A and 2B, respectively). The lowest asymmetry coefficients (a) were observed in L (-0.45) and W (-0.47) (Figures 2A and 2B, respectively) when compared to LW (0.22), L² (0.30), W² (0.20), and LA (0.25) (Figures 2C, 2D, 2E, and 2F, respectively). In addition, the kurtosis coefficients (k) of the dependent and independent variables showed similar data distributions, with platycurtic curves ($k < 3.26$), indicating that the data are flatter and have thinner tails than a normal distribution, in addition to a lower

probability of extreme events (Figures 2A-F).

The percentage distribution of the LA size classes of the 825 soursop leaves is shown in Figure 3. The leaves of the soursop seedlings showed that 32.36% of the LA is within the range $30.01 \leq LA \leq 45.00$ cm², characterizing most of the collected leaves as medium-sized.

Linear and nonlinear behaviors were obtained with the linear dimensions of the soursop leaves between the independent (L, W, LW, L², and W²) and dependent (LA) variables (Figure 4). Soursop leaves have linear relationships between LW and LA, L² and LA, W², and LA and nonlinear relationships between L and LA, and W and LA.

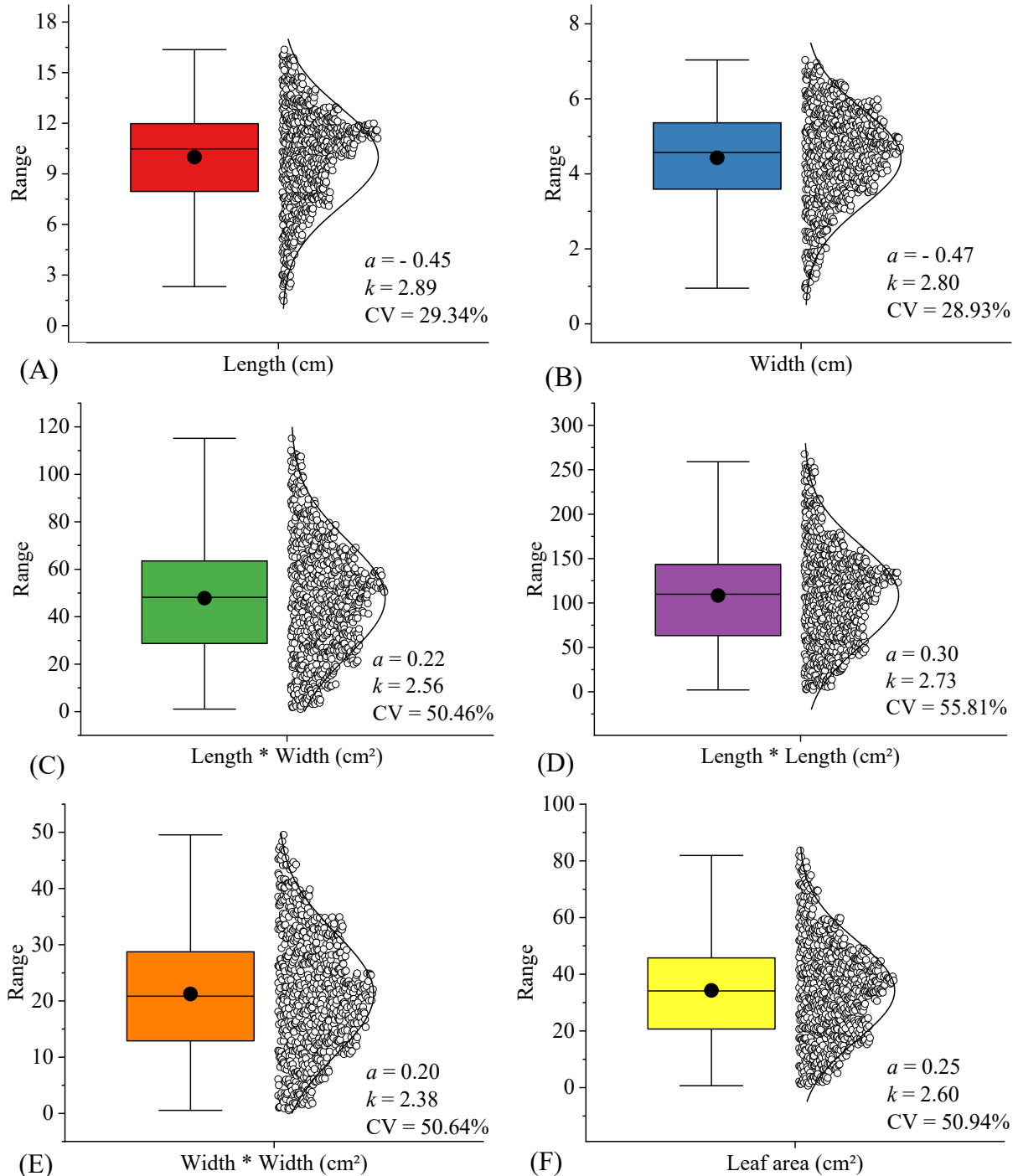
The most appropriate and accurate regression models and equations to estimate the leaf area of the soursop tree, according to the selection criteria, are presented in Table 3. The linear regression models without intercept and power, as a function of LW, showed the highest coefficient of determination (R²) (0.9984 and 0.9921), Pearson's correlation coefficient (r) (0.9980 and 0.9960), and Willmott agreement index (d) (0.9980 and 0.9980), along with the lowest Akaike information criterion (AIC) (3,064.9 and 3,063.6), root mean squared error (RMSE) (1.5449 and 1.5437 cm²), and mean absolute percentage error (MAPE) (0.0368 and 0.0364). Thus, the equations $\hat{y} = 0.72 \times LW$ and $\hat{y} = 0.69 \times LW^{1.00}$ best estimate the leaf area of seedlings of the species studied (Table 3).

The non-intercept linear regression and power models showed a high linear correlation between LA and LW, with R² of 0.9984 and 0.9921, respectively (Figure 5). In addition, the homogeneity and good distribution of the residues make these equations reliable for predicting the leaf area of the soursop tree.

The estimated leaf area (ELA) by the equations, compared to the observed leaf area (OLA), are shown in Figure 6. It is evident that ELA by linear models without intercept and power using LW have a high

and positive correlation with OLA, with R^2 (0.9961 and 0.9960) (Figures 6A and 6B, respectively). In addition, ELA and OLA in both models did not show significant

differences ($p \leq 0.01$), indicating that the proposed models can be used to estimate the leaf area of soursop using LW (Figure 6C).



The top and bottom ends of each box represent the 1/4 and 3/4 quartiles; the horizontal line of each box refers to the median; the distribution of the top and bottom points for boxes represents the extreme minimum and maximum values of the data; • – inside the boxes represent the averages; a – coefficients of asymmetry; k – coefficients of kurtosis; CV – coefficients of variation.

Figure 2. Descriptive analysis of length (A), width (B), product between L and W (C), $L \times L$ (D), $W \times W$ (E), and leaf area (F) of soursop leaves.

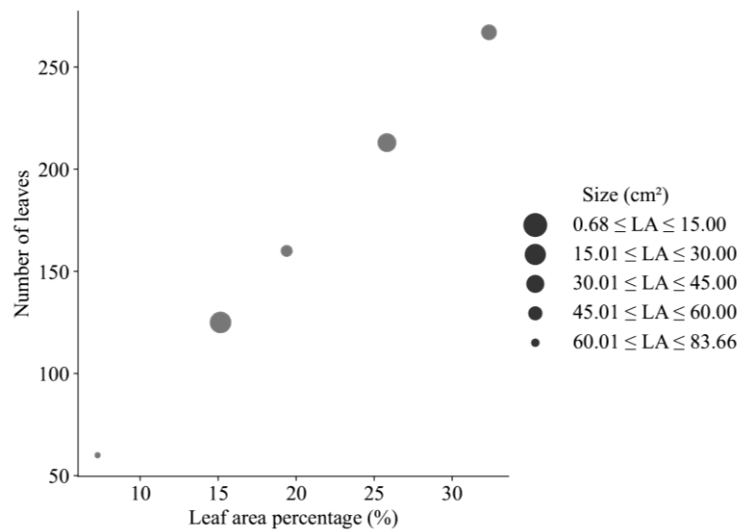


Figure 3. Relationship between the number of soursop leaves and the percentage of leaf area classified into size classes.

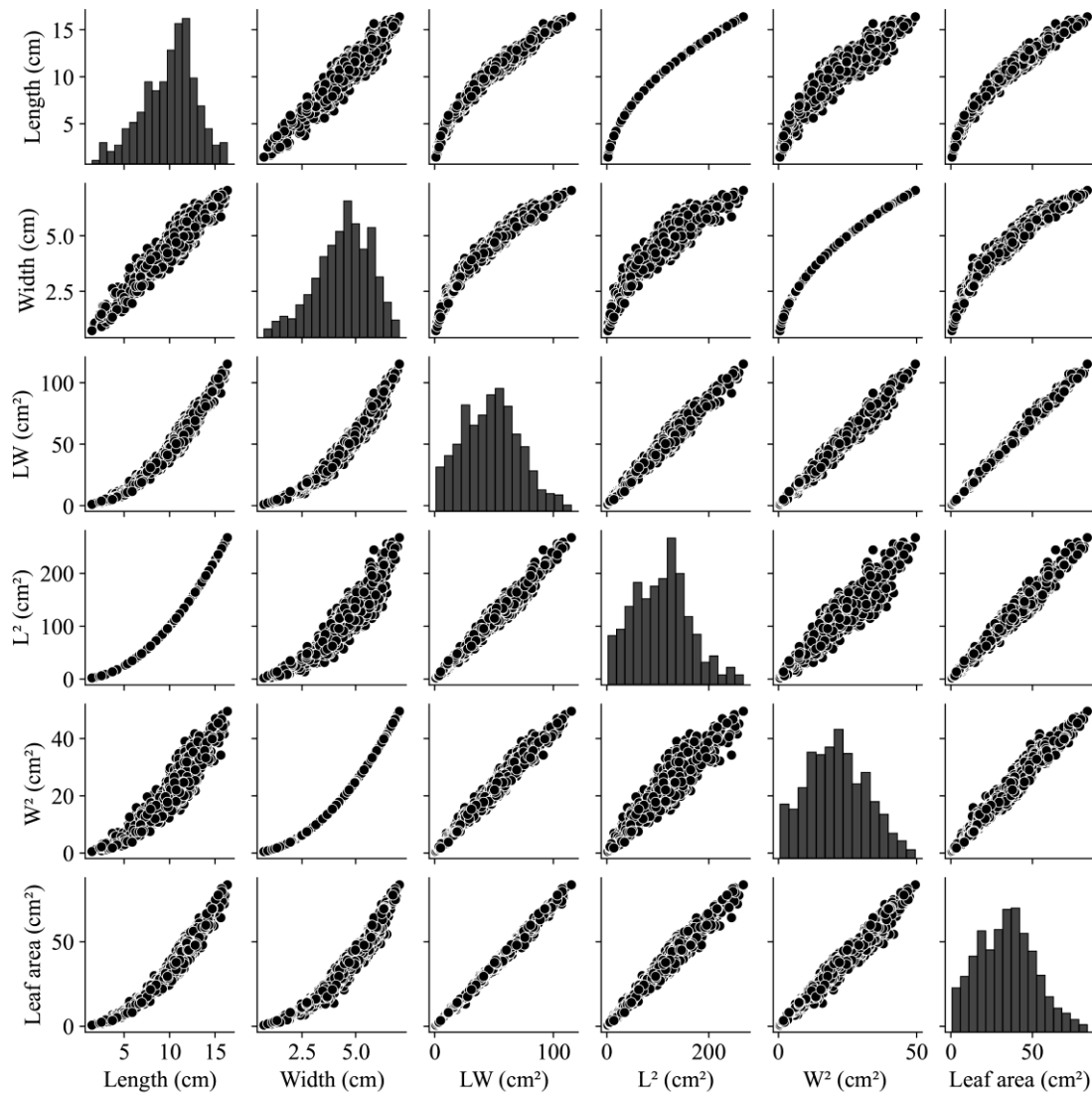


Figure 4. Frequency histogram (diagonally) and data dispersion between length (L), width (W), L and W product (LW), $L \times L$ (L^2), $W \times W$ (W^2), and leaf area (LA) of soursop.

Table 3. Regression model, equations, coefficient of determination (R^2), Pearson’s correlation coefficient (r), Akaike’s information (AIC), Willmott agreement index (d), mean squared error (RMSE), and mean absolute percentage error (MAPE) obtained as a function of soursop leaf dimensions.

Models	R^2	r	d	AIC	RMSE	MAPE	Equations
$\hat{y} = \beta_0 + \beta_1 * L + \varepsilon_i$	0.9350	0.9670	0.9829	4810.7	4.4504	0.2675	$\hat{y} = -23.28 + 5.76*L$
$\hat{y} = \beta_0 + \beta_1 * W + \varepsilon_i$	0.9252	0.9619	0.9802	4927.4	4.7768	0.4094	$\hat{y} = -23.80 + 13.12*W$
$\hat{y} = \beta_0 + \beta_1 * LW + \varepsilon_i$	0.9922	0.9960	0.9980	3065.4	1.5449	0.0368	$\hat{y} = -0.19 + 0.72*LW$
$\hat{y} = \beta_1 * LW + \varepsilon_i$	0.9984	0.9960	0.9980	3064.9	1.5449	0.0368	$\hat{y} = 0.72*LW$
$\hat{y} = \beta_0 + \beta_1 * LL + \varepsilon_i$	0.9663	0.9830	0.9913	4269.6	3.2061	0.0857	$\hat{y} = 0.93 + 0.31*LL$
$\hat{y} = \beta_0 + \beta_1 * WW + \varepsilon_i$	0.9583	0.9789	0.9892	4445.8	3.5676	0.0938	$\hat{y} = 0.52 + 1.59*WW$
$\hat{y} = \beta_0 + L^{\beta_1} + \varepsilon_i$	0.9667	0.9832	0.9914	4260.6	3.1886	0.0837	$\hat{y} = 0.38 * L^{1.92}$
$\hat{y} = \beta_0 + W^{\beta_1} + \varepsilon_i$	0.9583	0.9789	0.9892	4445.7	3.5672	0.0938	$\hat{y} = 1.71 * W^{1.96}$
$\hat{y} = \beta_0 + LW^{\beta_1} + \varepsilon_i$	0.9921	0.9960	0.9980	3063.6	1.5437	0.0364	$\hat{y} = 0.69 * LW^{1.00}$
$\hat{y} = \beta_0 + LL^{\beta_1} + \varepsilon_i$	0.9667	0.9832	0.9914	4260.6	3.1886	0.0837	$\hat{y} = 0.38 * LL^{0.96}$
$\hat{y} = \beta_0 + WW^{\beta_1} + \varepsilon_i$	0.9583	0.9789	0.9892	4445.7	3.5672	0.0938	$\hat{y} = 1.70 * WW^{0.98}$
$\hat{y} = \beta_0 + \beta_1^L + \varepsilon_i$	0.9459	0.9725	0.9846	4695.8	4.1512	0.1310	$\hat{y} = 5.58 * 1.18^L$
$\hat{y} = \beta_0 + \beta_1^W + \varepsilon_i$	0.9456	0.9724	0.9849	4685.1	4.1243	0.1326	$\hat{y} = 5.09 * 1.49^W$
$\hat{y} = \beta_0 + \beta_1^{LW} + \varepsilon_i$	0.9258	0.9622	0.9777	4971.4	4.9057	0.1483	$\hat{y} = 13.77 * 1.01^{LW}$
$\hat{y} = \beta_0 + \beta_1^{LL} + \varepsilon_i$	0.8875	0.9420	0.9654	5303.9	6.0010	0.1714	$\hat{y} = 14.65 * 1.00^{LL}$
$\hat{y} = \beta_0 + \beta_1^{WW} + \varepsilon_i$	0.9031	0.9503	0.9715	5169.7	5.5322	0.1679	$\hat{y} = 13.58 * 1.04^{WW}$

\hat{y} – estimated leaf area; β_0 and β_1 – regression parameters; ε_i – random error; L – leaf length; W – leaf width; LW – product of length and width; LL – length squared; WW – width squared.

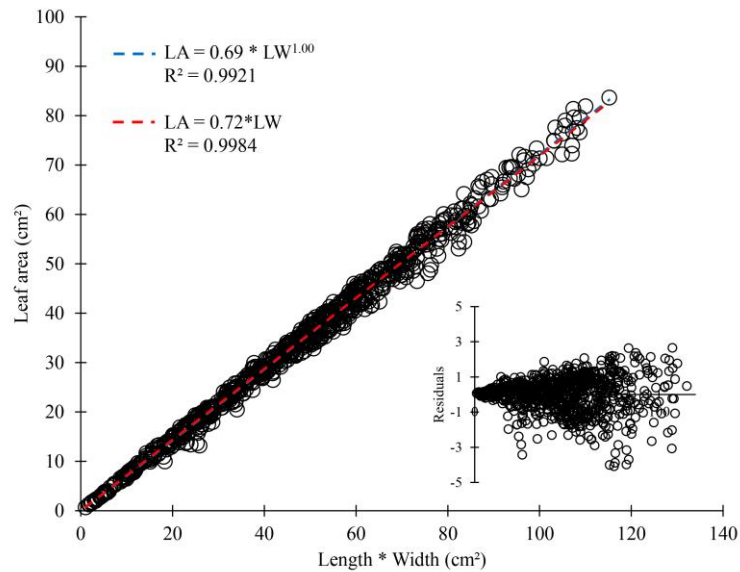
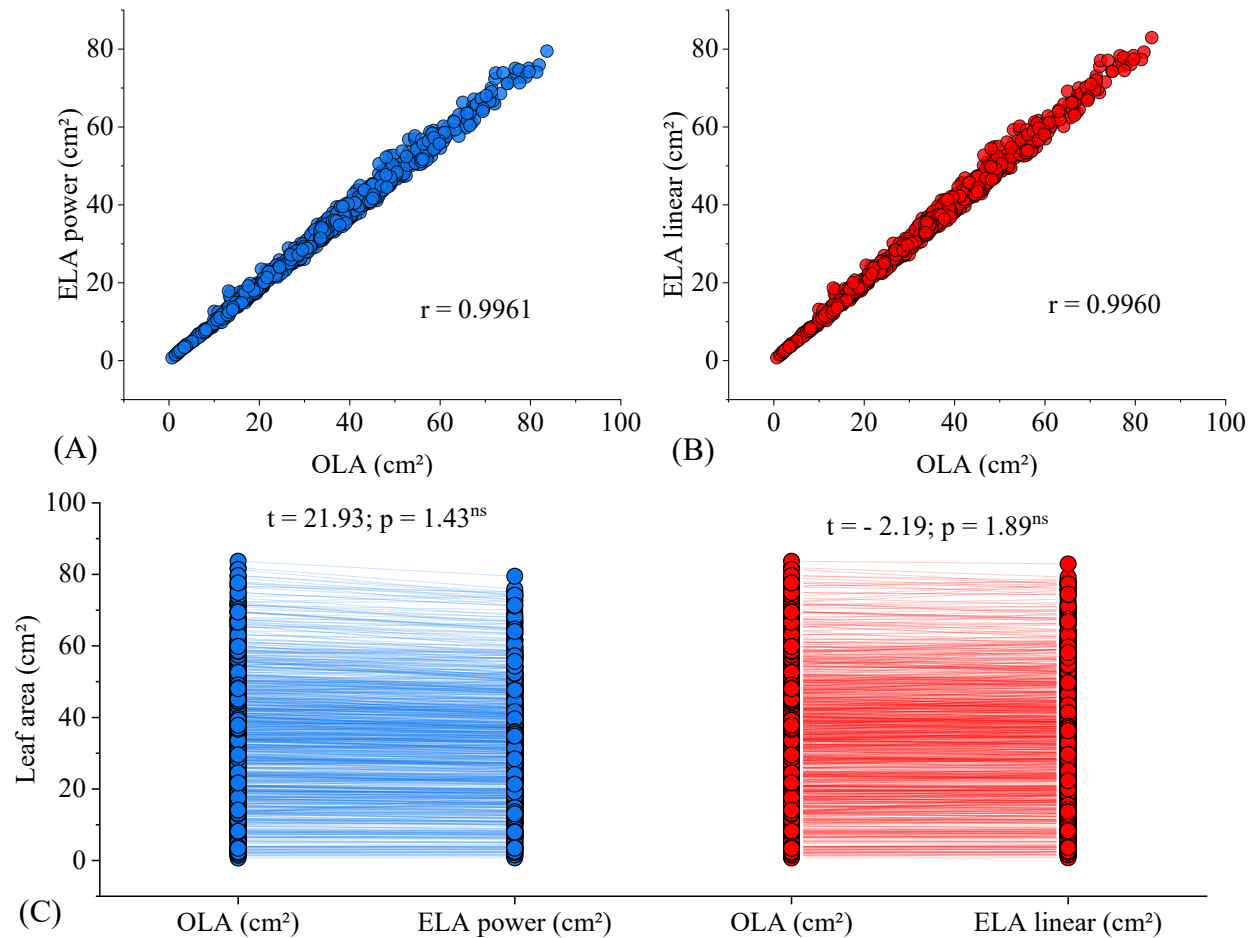


Figure 5. Relationship between the actual leaf area and the product between length and width of soursop leaves, from the linear without intercept and power models. The dispersion analysis of the residues is presented in the insertion.



ns – not significant by Student’s t-test ($p \leq 0.01$).

Figure 6. Relationship of the observed leaf area (OLA) and estimated leaf area (ELA) using the linear models without intercept (A) and power (B) as a function of the product of the width and length of the soursop tree leaves. Leaf area was compared by Student’s t-test ($p \leq 0.01$) (C).

Discussion

Allometric modeling is a reliable, accurate, and inexpensive tool for the nondestructive estimation of plant leaf area (Dias et al., 2022). Thus, it contributes to research in the cultivation of agricultural species. Our study is one of the few that estimates leaf area in soursop seedlings of the cultivar ‘Morada’ non-destructively.

The high variability observed in the independent variables occurs mainly from the heterogeneity of leaf sizes, which contributes to the construction of more representative models that are close to the actual area since they have both large and small leaves (Gupta et al., 2023; Ribeiro et al., 2024). In addition, the high number of leaves associated with the different leaf area size classes was adequate for this high

variability of the sample, providing an efficient model adjustment for estimating leaf area in several dimensions (Barbosa et al., 2020; Cabral et al., 2023). These characteristics of the collected data reduce biased equations with low reliability in the estimation of leaf area (Silva et al., 2023).

Our study revealed the need for linear and nonlinear models to accurately estimate leaf area in soursop seedlings (cv. ‘Morada’), yielding more significant results with good fit and data validation (Ribeiro et al., 2024). Thus, several models were generated, but the best fits, considering the highest R^2 , r , d , and lowest AIC, RMSE, and MAPE, were found in the non-intercept linear regression and power models, which applied LW. In previous studies, these models were also more suitable for

predicting the leaf area of other species, such as *Manilkara zapota* L. (Ribeiro et al., 2023), *Spondias* sp. (Amorim et al., 2024a), *Spondias tuberosa* Arruda (Amorim et al., 2024b), *Ipomoea batatas* L. (Ribeiro et al., 2024), and *Euterpe oleracea* (Sousa et al., 2024).

In addition, the relationship between LA and LW of the chosen models and equations confirms that the LA of the soursop seedlings of cv. 'Morada' can be estimated using LW, since R^2 explains more than 99% of the data's variability. The results corroborate the research of Jaime-Guerrero et al. (2023), who also proved that to estimate the leaf area of *Passiflora edulis* fo. *edulis*, the highest R^2 and the best relationship between leaf area and independent variables was found between leaf LW. It is worth noting that the equations chosen $\hat{y} = 0.72 \times LW$ and $\hat{y} = 0.69 \times LW^{1.00}$ showed homoscedasticity and good residue dispersion, pointing out that the values are homogeneous and reiterating the good fit of the selected models (Junges and Anzanello, 2021).

However, the study also provides significant results for models using unique leaf dimensions, suggesting that adjusted models can be used to estimate the leaf area of soursop seedlings of the 'Morada' cultivar. These models based on simple leaf dimensions, such as length and width, facilitate a quick and accurate assessment of plant growth (Junges and Anzanello, 2021; Gonçalves et al., 2022; Puntel et al., 2023). However, our study demonstrated greater accuracy in two-dimensional models, which may be associated with a more significant amount of information provided.

In the adjustment and validation of linear models without intercept and power, the positive correlation and statistical similarity between OLA and ELA reaffirm that the models can be considered reliable and accurate for estimating the leaf area of soursop seedlings. According to Soysal (2024), validating the accuracy of a leaf area model is an important step to overcome

the implications of the equations produced for leaf area prediction.

It is worth noting that the allometric equations proposed in this study were derived from data obtained from soursop seedlings of cultivar 'Morada', cultivated under the experimental conditions already described. Thus, the application of these models to plants, adults, individuals cultivated in the field, or other cultivars should be carried out with caution, since morphological and physiological variations between developmental stages, cultivation environments, and genetic materials can compromise the accuracy of the estimates. Therefore, additional studies are needed to validate these equations for different phenological phases, cropping systems, and cultivars. Finally, it is worth noting that estimating leaf area using allometric equations for soursop seedlings of the 'Morada' cultivar is essential for researchers and producers.

Morphophysiological studies of leaves have aroused agronomic interest, especially with regard to the use of natural resources such as water, nutrients, and light (Dias et al., 2022), since they directly influence plant performance, yield, and productivity.

Conclusions

A nondestructive method using allometric equations of the linear model without intercept and power can accurately and safely estimate the leaf area of soursop seedlings.

The allometric equations $\hat{y} = 0.72 \times LW$ and $\hat{y} = 0.69 \times LW^{1.00}$ were the most suitable for accurately and quickly estimating the soursop leaf area.

In general, the proposed models are recommended for practical use, as they constitute a simple, efficient, low-cost, and non-destructive alternative to direct methods, allowing repeated measurements throughout seedling development and contributing to agronomic studies.

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