Non-destructive models for leaf area estimation in chickpea cultivars (*Cicer arietinum* L.)[1]

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ABSTRACT

Chickpea is a winter legume with prospects for worldwide consumption growth, mainly demanded by Asian countries. Thus, studies on its growth, such as the leaf area (LA), are important to determine proper management practices for its cultivation. The objective of this work was to determine a mathematical model able to estimate the leaf area (LA) of chickpea in a non-destructive method. For this, a field experiment was carried out in the county of Santa Maria (RS), with five cultivars available in the national market. Several leaves of each cultivar were collected, and their greatest width (W) and longest length (L) were measured. With the aid of a scanner, these leaves were photocopied, and their LA (cm^2) was determined using software. With the power model, models relating to LA and its dimensions were determined. These models were tested using various statistics, with independent data. The results indicate that for the cultivars BRS Aleppo, BRS Kalifa, Jamu, and BRS Toro the best model is LA= $0{,}0940.(L)^{1.8483}$ and for the cultivar BRS Cícero the best model is LA = $0{,}1092.L^{2.1815}$.

Keywords: pulses; linear dimensions; mathematical models.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a legume, part of the pulses group, being the third most consumed after beans (*Phaseolus vulgaris* L.) and peas (*Pisum sativum* L.). Its main markets are countries located in the Middle East, Mediterranean, and Central Asia, and it is cultivated in different regions of the world, under the most varied climates (Hoskem *et al.*, 2017; Mohammed *et al.*, 2017). In comparison with other legumes such as soybean, it has a lower water requirement, close to 500 mm throughout its cycle (Desta *et al.*, 2015; Silva *et al.*, 2021). In Latin America it is cultivated as a winter crop, being a legume with high-quality protein (Manara & Ribeiro, 1992), which can be an alternative for cultivation after the summer crop.

They are herbaceous plants, with imparipinnate compound leaves, consisting of 9 to 19 leaflets (whole or serrated) (Nascimento *et al.*, 2016). The sum of the area of each leaf makes up the so-called leaf area of the plant, which is one of the most important growth parameters of agricultural crops, as it is directly related to the production of photoassimilates and, thus, productivity (Taiz *et al.*, 2017). Thus, the determination of the plant's leaf area is important to obtain agronomic efficiency indicators, such as photosynthetic capacity and growth potential (Zanon *et al.*, 2015), which will determine the crop yield.

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From the linear dimensions of the leaves, such as length (L), width (W), and the product of both (LxW), it is possible to define mathematical models that estimate the leaf area in a non-destructive way (Schwab *et al.*, 2014). Non-destructive methods, in addition to eliminating the need to eliminate plants or plots for evaluations, make research cheaper and more interesting, in the sense of making it possible to observe the development of the same plant, from the beginning to the end of the cycle of cultivation.

Given the perspective of increasing global demand for chickpea and the possibility of its cultivation in Brazil, due to its climate adaptability (Hoskem *et al.*, 2017), studies are needed to understand aspects related to its growth. Thus, the objective of this work is to present mathematical models that estimate, from the linear dimensions of the leaf, the leaf area of chickpea cultivars currently available in the Brazilian market.

MATERIAL AND METHODS

The field experiment was carried out in the municipality of Santa Maria (RS), located in the Horticulture area of the Universidade Federal de Santa Maria (UFSM) (latitude 29°43’23’’ S, longitude 53°43’15’’ W and altitude 95 m), in the year 2021. The local climate, according to the Köppen climate classification, is of the Cfa (subtropical) type, with hot summers and no defined dry season (Kuinchtner & Buriol, 2001). Soil classification, according to Streck *et al.* (2008), it is a transition between Argissolo Bruno Acinzentado Alítico úmbric and Argissolo Vermelho Distrófico arênico.

The experimental plots contained 4 lines 5 m long, spaced 0.5 m apart, making a total of 2 m² per plot. The sowing density was 10 seeds per linear meter. The experimental design used was a randomized block design, with four replications. The cultivars used were BRS Aleppo, BRS Kalifa, Jamu, BRS Cícero e BRS Toro. The sowing was carried out on April 7th, 2021 manually, at a depth of 5 cm. 7 days after sowing (DAS), the first fertilization was carried out with 25, 45, and 115 kg ha^{-1} of nitrogen (N), phosphorus (P), and potassium (K), this was complemented with two coverage fertilizations of N, with doses of 20 kg ha^{-1} of N at 33 and 92 DAS. The phytosanitary control was carried out according to the crop was demanding, based on the recommendations presented by Embrapa Hortaliças (Nascimento *et al.*, 2016).

To compose the dependent data for calibration of the mathematical models, 160 leaves were collected, at intervals of 21 days, throughout the crop development cycle. In each leaf collected, the dimensions of length (L) were measured, defined as the greatest distance between the insertion point of the leaf on the stem to the opposite end, and width (W), defined as the largest dimension perpendicular to the length axis (Figure 1). After performing the measurements, with the aid of a scanner, the leaves were photocopied and the individual area of each sheet (LA) was calculated using the *software Quant*®, version 1.0.2 (Vale *et al.*, 2003).

The relationship between leaf area (LA) and its linear dimensions (L, W, and LxW) was fitted to the potency model because, when compared to others, it is often the one that best fits the relationship between LA and linear dimensions, in different agricultural crops (Aquino *et al.*, 2011; Toebe *et al.*, 2012; Trachta *et al.*, 2020; Pohlmann *et al.*, 2021), as listed below:

$$LA = a \cdot (W)^b \quad (1)$$

$$LA = a \cdot (L)^b \quad (2)$$

$$LA = a \cdot (LxW)^b \quad (3)$$

Where LA is the leaf area (cm^2), W is the largest leaf width (cm), L is the longest leaf length (cm), *a* is the shape coefficient, and *b* is the power coefficient. These coefficients were estimated using the Excel® software.

To compose the independent data and test the equations listed above, another 160 leaves of each cultivar were collected. The statistics used in this work to evaluate the performance of the equations were: mean absolute error (MAE) - equation 4; the root mean square error (RMSE) - equation 5; the BIAS index - equation 6; the agreement index (d) - equation 7 and the modified agreement index (d1) - equation 8:

$$MAE=\frac{\sum_{i=1}^{N}|Si-Oi|}{N} \quad (4)$$

$$RMSE=\sum_{i=1}^{N}\frac{(Si-Oi)^2}{N} \quad (5)$$

$$BIAS=\frac{\sum_{i=1}^{N}Si-\sum_{i=1}^{N}Oi}{\sum_{i=1}^{N}Oi} \quad (6)$$

$$d=1-\left[\frac{\sum_{i=1}^{N}(Si-Oi)^2}{\sum_{i=1}^{N}(|Si'|+|Oi'|)^2}\right] \quad (7)$$

$$d1=1-\left[\frac{\sum_{i=1}^{N}|Si-Oi|}{\sum_{i=1}^{N}(|Si'|+|Oi'|)}\right] \quad (8)$$

In equations 4, 5, 6, 7, and 8, Si represents the estimated values, Oi the observed values, N the number of observations, Si'= Si - Mean of Oi, and Oi'= Oi - Mean Oi.

RESULTS AND DISCUSSIONS

The fitted equations for each model (Equations 1, 2, and 3, respectively) and those resulting from plotting the leaves area versus width (W), length (L), and product of length and width (LxW) data for each of the chickpea cultivars are shown in Figure 2. As noted by Schwab *et al.* (2014), when only one of the linear dimensions (L or W) is used to compose the model, the coefficient b presents a value greater than 1, indicating a non-linear relationship between the dimension in question and the LA. When the product between length and width of the sheet (LxW) is used in the model, the relationship is not visually clear, with coefficient b close to 1 and there is variation between the coefficient of determination (R^2).

To test the predictive capacity of equations 1, 2, and 3 for each cultivar, MAE, RMSE, BIAS index, d index, and d1 index were used, which are shown in Table 1. All statistics confirm that the model with the lowest predictive capacity to estimate the chickpea leaf area is the one that uses leaf width as a predictor (Equation 1). In this case, the MAE ranged from 0.2156 to 0.4534 cm²/leaf and RMSE ranged from 0.2934 to 0.6572 cm²/leaf, among cultivars. The statistics also showed that the models that use the leaf length (Equation 2) and the LxW product (Equation 3) have similar predictive capabilities, with MAE ranging from 0.1604 to 0.2844 cm²/leaf (for Equation 2) and MAE ranging from 0.1157 to 0.3162 cm²/leaf (for Equation 3) and RMSE ranging from 0.2232 to 0.4382 cm²/leaf and 0.1527 and 0.4352cm²/leaf, respectively for Equations 2 and 3. MAE and RMSE are tests that express the magnitude of the error produced by the model and, the closer to zero, the better the model (Janssen & Heuberger, 1995; Hallak & Pereira Filho, 2011).

In general, the BIAS index showed the worst performance (values furthest from zero) in the model that uses leaf width as a predictor (Equation 1), except for the cultivar BRS Cícero (Table 1). This result may be related to the different leaf shape of this cultivar in relation to the others used in the tests, as shown in Figure 1. The best BIAS performance (values closer to zero) occurred in the model that uses the leaf length (Equation 2), except, again, to cultivate BRS Cícero. This index shows the trends that a model has to overestimate or underestimate the LA values, compared to the observed values, and thus, the closer to zero, the smaller the error (Leite & Andrade, 2002).

The d and d1 indices showed the worst performances in the model that uses the leaf width as a predictor (Equation 1), for all cultivars. For the cultivars BRS Aleppo and BRS Cícero, the model with predictor L (Equation 2) showed better performance according to d and d1. As for

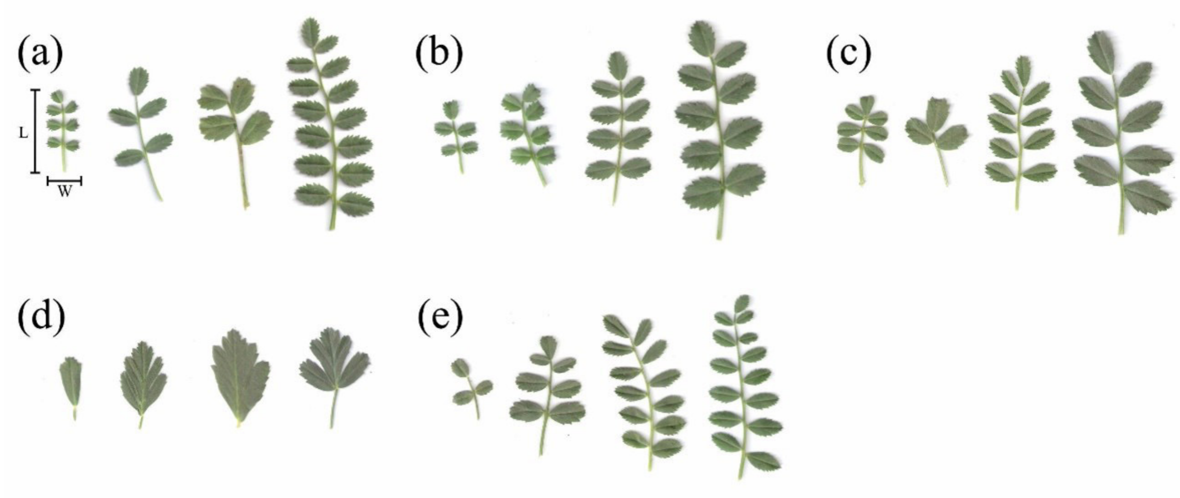

Figure 1: Copies of leaves of cultivars BRS Aleppo (a), BRS Kalifa (b), Jamu (c), BRS Cícero (d), and BRS Toro (e) with the linear dimensions of length (L) and width (W), with different leaf sizes and formats.

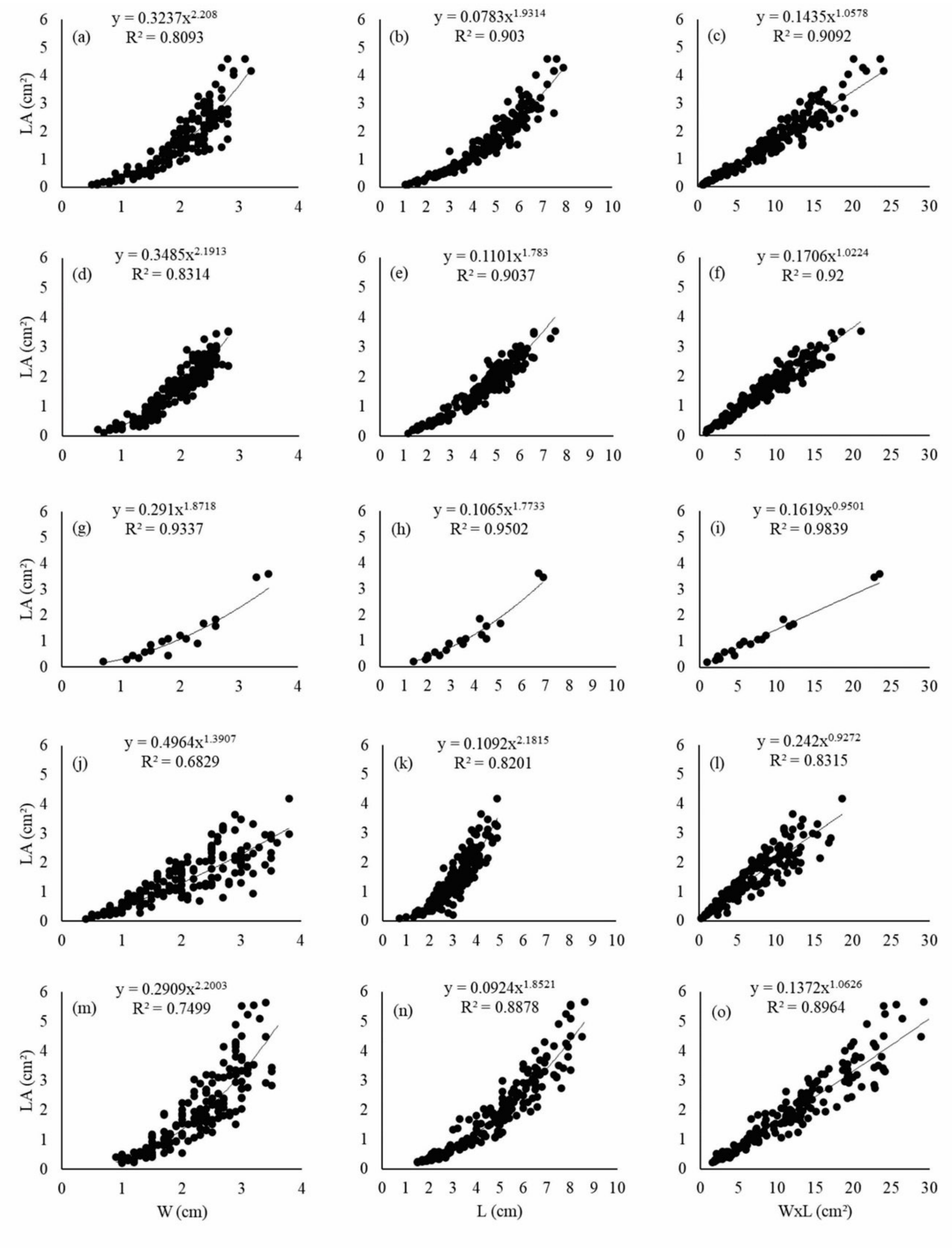

Figure 2: Relationship between chickpea leaf area (LA) and its linear dimensions of width (W), length (L), and product (LxW) for cultivars BRS Aleppo (a, b, c), BRS Kalifa (d, e, f), Jamu (g, h, i), BRS Cicero (j, k, l) and BRS Toro (m, n, o). The curve and fitted equation in each panel are templates indicated in equations 1, 2, and 3, respectively.

Table 1: Statistical performance of empirical models for estimating chickpea leaf area (LA) from its linear dimensions length (L) and width (W), with independent data

		Statistical Data*				
Model	**Cultivar**	**MAE**	**RMSE**	**BIAS**	**D**	**d1**
$LA = 0,3237.(W)^{0,2080}$	BRS Aleppo	0.4284	0.5620	-0.1054	0.8963	0.7180
$LA = 0,0783.(L)^{1,9314}$	BRS Aleppo	0.2431	0.3287	-0.0480	0.9682	0.8446
$LA = 0,1435.(W.L)^{1,0578}$	BRS Aleppo	0.2812	0.3709	-0.0762	0.9573	0.8161
$LA = 0,3485.(W)^{2,1913}$	BRS Kalifa	0.3280	0.4473	-0.0816	0.9487	0.7962
$LA = 0,1101.(L)^{1,7830}$	BRS Kalifa	0.1957	0.2692	-0.0352	0.9829	0.8811
$LA = 0,1706.(W.L)^{1,0224}$	BRS Kalifa	0.1913	0.2651	-0.0503	0.9832	0.8832
$LA = 0,2910.(W)^{1,8718}$	Jamu	0.2152	0.2934	-0.0514	0.9708	0.8377
$LA = 0,1065.(L)^{1,7733}$	Jamu	0.1604	0.2232	-0.0207	0.9848	0.8840
$LA = 0,1619.(W.L)^{0,9501}$	Jamu	0.1157	0.1527	-0.0252	0.9929	0.9146
$LA = 0,4964.(W)^{1,3907}$	BRS Cícero	0.4222	0.5738	0.0072	0.8568	0.6800
$LA = 0,1092.(L)^{2,1815}$	BRS Cícero	0.2591	0.3863	-0.0333	0.9432	0.8090
$LA = 0,2420.(W.L)^{0,9272}$	BRS Cícero	0.3162	0.4352	0.0074	0.9257	0.7685
$LA = 0,2909.(W)^{2,2003}$	BRS Toro	0.4534	0.6572	-0.1115	0.9363	0.7976
$LA = 0,0924.(L)^{1,8521}$	BRS Toro	0.2844	0.4382	-0.0827	0.9743	0.8771
$LA = 0,1372.(W.L)^{1,0626}$	BRS Toro	0.2780	0.4056	-0.0874	0.9779	0.8796

* MAE = mean absolute error (cm^2/leaf); RMSE = root mean square error (cm^2/leaf); BIAS = BIAS index; d = agreement index; d1 = modified agreement index.

the cultivar Jamu, the best performance of the d1 indices occurred for the model LxW (Equation 3), while for the cultivars BRS Kalifa and BRS Toro, the models with predictor L (Equation 2) and with predictor LxW (Equation 3) they present very similar performances, being, in this case, sensitive to the definition of the best model according to these indexes. The indices d (Equation 7) and d1 (Equation 8) are measures that vary from 0 (for no agreement) to 1 (perfect agreement), and the closer to 1, the smaller the error. By using a quadratic function in its equation, the index d allows for higher results and, thus, Willmott *et al.* (1985) suggested an adaptation to the model, making it more rigorous and calling it the d1 index.

The coefficient *a* of the models W (Equation 1), L (Equation 2), and LxW (Equation 3) was quite close for the cultivars BRS Aleppo (Figure 2a, b, c), BRS Kalifa (Figure 2d, e, f), Jamu (Figure 2g, h, i) and BRS Toro (Figure 2m, n, o), ranging from 0.2909 to 0.3485, from 0.0783 to 0.1101, and from 0.1372 to 0. 1706 respectively. For BRS Cícero (Figure 2j, k, l), the value of the coefficient a was higher than that presented by the others, being equal to 0.4964, 0.1092, and 0.2420 for the models with predictor L, W, and LxW, respectively. Due to the similarity of the leaf shape (Figure 1) and the small variation of the coefficient for the cultivars BRS Aleppo, BRS Kalifa, Jamu, and BRS Toro, Equations 1, 2, and 3 were adjusted for the data of the four cultivars (Figure 3) and then these models were tested with independent data for each cultivar (Table 2).

The adjusted models for all cultivars (except BRS Cícero), considering the linear dimensions of width (W), length (L), and its product (LxW), were $LA = 0,3269.(W^{2,1552})$, $LA= 0,0940.(L^{1,8482})$ and $LA = 0,1527.(WxL^{1,0380})$, with a R^2 of 0,7765, 0,8967 e 0,9037, respectively. When comparing the R^2 of the individual equations of each cultivar with the general equations, they present a similar performance to that equation from the cultivars BRS Aleppo, BRS Kalifa, and BRS Toro, while for the cultivar Jamu, its performance is slightly inferior. This can be explained by the fact that, for the cultivar Jamu, there was less data collection, due to the loss of some plots and, therefore, the superior performance of R^2, in this case, can be disregarded.

Comparing the coefficient of the individual models of each cultivar with the general models, these present intermediate values to those obtained with the cultivars, with

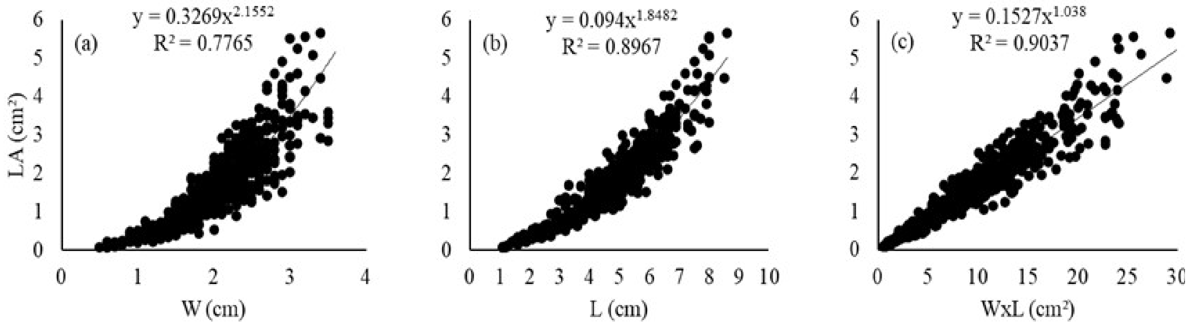

Figure 3: Relation between leaf area (LA) and its linear dimensions of width (W) (a), length (L) (b) and product (LxW) (c) of all cultivars, except for BRS Cícero. The curve and fitted equation in each panel are templates indicated in equations 1, 2, and 3, respectively.

values of 0.3269, 0.0940, and 0.1527 for equations 1, 2, and 3, respectively.

The use of general models for different cultivars facilitates work, as new cultivars are launched annually and, therefore, it is not necessary to perform new calibrations for each material available on the market. Results with general equations were found for crops such as soybean (Richter *et al.*, 2014), gladiolus (Schwab *et al.*, 2014), rice (Ribeiro *et al.*, 2019), cassava (Trachta *et al.*, 2020), and chia (Goergen *et al.*, 2021).

As in the individual models, the one that presented the lowest performance was the model that uses only the width (W) as a predictor (Equation 1). With MAE ranging from 0.3795 to 0.4432 cm²/leaf and RMSE ranging from 0.5281 to 0.6108 cm²/leaf, among cultivars. In addition, the model that uses the linear measure of length (L) (Equation 2) presented the best results for MAE and RMSE, except for the cultivar BRS Toro, where the model that uses LxW presented superior performance.

The BIAS index showed the worst performance in the model that uses only the leaf width as a predictor (Equation 1), except for the cultivar BRS Toro (Table 2). The best performance of BIAS occurred in the model that uses the leaf length (Equation 2), except, again, for the cultivar BRS Toro. Compared to other works, the BIAS index showed higher values, probably due to the morphology of the leaf, which is composed and has a variable number of leaflets, with the lowest values found in cultures with simple leaves, such as gladiolus, rice, and chia (Schwab *et al.*, 2014; Ribeiro *et al.*, 2019; Goergen *et al.*, 2021). Values close to those of this work were observed by Trachta *et al.* (2020), with the cassava crop, which, despite having simple leaves, presented values ranging from -0.3319 to 0.2286, which is probably explained by the morphology of the leaf, which is classified as simple palmatipartite.

The d and d1 indices presented the worst performances in the model that uses the leaf width (W) as a predictor (Equation 1) for all cultivars. For the cultivars BRS Aleppo and BRS Kalifa, the model with predictor L (Equation 2) showed better performance according to d and d1. As for the cultivar Jamu, the best performance of the index d occurred for the model that uses LxW as a predictor (Equation 3) and d1 for the model L (Equation 2), however, for both indexes, the values are very close. For the cultivar BRS Toro, the model with LxW predictor (Equation 3) showed the best performance, however, when compared to the statistics of the specific equations, the general equation shows better performance both in the model that uses L (Equation 2) and in the model that uses LxW (Equation 3) as a predictor. Analyzing works carried out with other cultures, the values of d1 indices are lower, possibly because they are composite leaves and smaller when compared to cultures such as rice (Ribeiro *et al.*, 2019), chia (Goergen *et al.*, 2021), gladiolus (Schwab *et al.*, 2014), cassava (Trachta *et al.*, 2020) and soybeans (Richter *et al.*, 2014).

The leaf area data calculated (cm^2) by the equations, compared to the observed leaf area (cm^2) by the software, are presented in Figure 4. The closer to the (solid) line the points are, the better the model's performance in estimating the simulated data. It can be observed that the coefficient of determination (R^2) of the model that uses only the length (L) (Equation 2) presents the best values, in the same way, that the statistics showed to be the most adequate model to estimate the leaf area of the crop. When using only one dimension to adjust the models, lower labor demand for data collection is required in the field, this is an important advantage since only one dimension needs to be measured (Maldaner *et al.*, 2009). Studies that suggest the

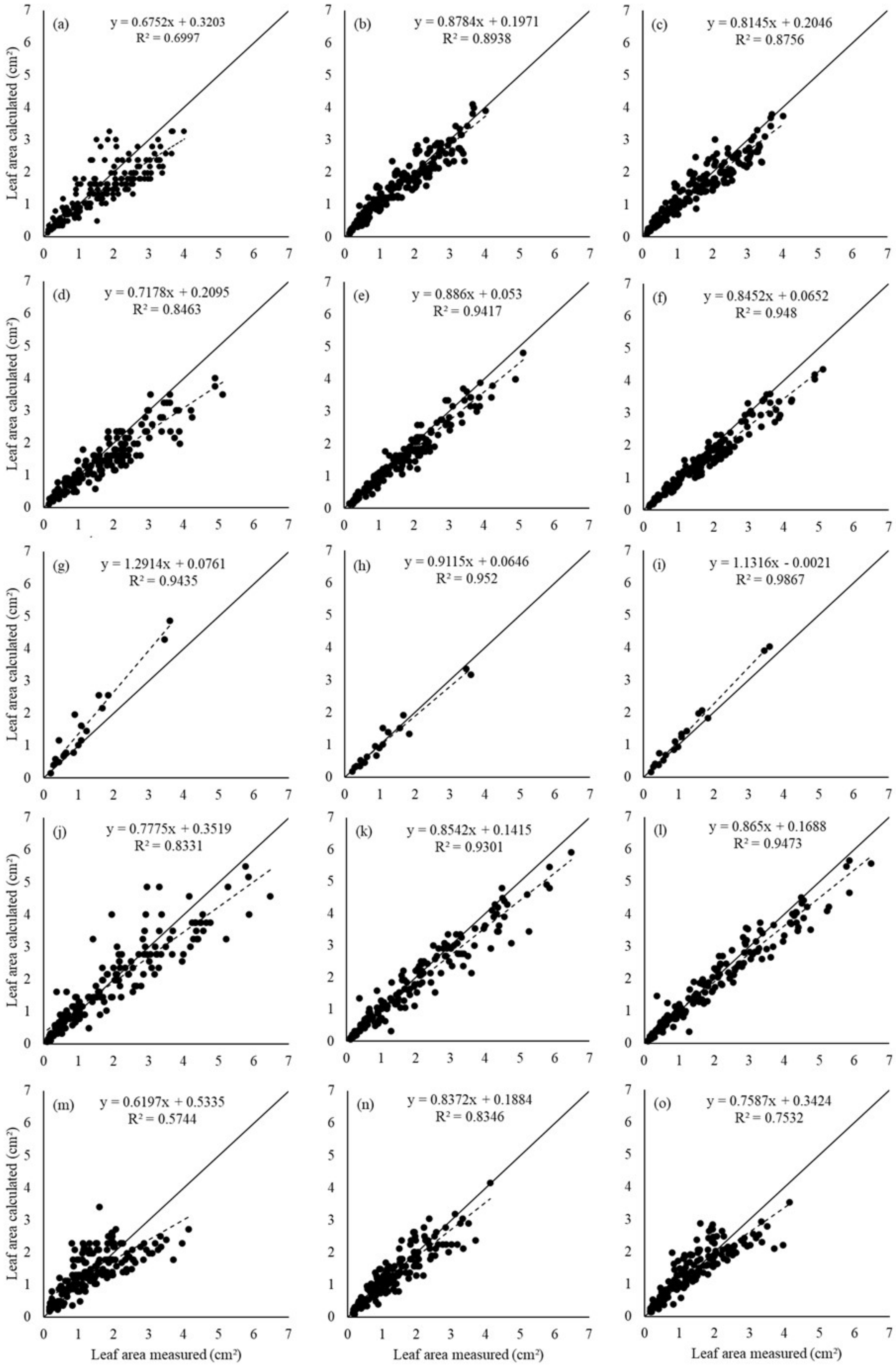

Figure 4: Chickpea leaf area calculated (cm^2) using the linear dimensions of width (W), length (L) and product (WxL), respectively, versus leaf area measured (cm^2) by the software, for the cultivars BRS Aleppo (a, b, c), BRS Kalifa (d, e, f), Jamu (g, h, i), BRS Toro (j, k, l) and BRS Cícero (m, n, o). The equations fitted in each panel are the models shown in Figure 3, except for the cultivar BRS Cícero, whose equations are shown in Figure 2.

Table 2: Statistical performance of empirical models for estimating chickpea leaf area (LA) from its linear dimensions length (L) and width (W), with independent data

		Statistical Data*				
Model	**Cultivar**	**MAE**	**RMSE**	**BIAS**	**D**	**d1**
LA= 0,3269.(W)^{2,1552}	BRS Aleppo	0.4432	0.5763	-0.1323	0.8871	0.7042
LA = 0,0940.(L)^{1,8482}	BRS Aleppo	0.2348	0.3168	-0.0031	0.9707	0.8504
LA = 0,1527.(W.L)^{1,0380}	BRS Aleppo	0.2734	0.3634	-0.0625	0.9590	0.8208
LA = 0,3269.(W)^{2,1552}	BRS Kalifa	0.3795	0.5281	-0.1622	0.9233	0.7609
LA = 0,0940.(L)^{1,8482}	BRS Kalifa	0.2144	0.3033	-0.0836	0.9779	0.8693
LA = 0,1527.(W.L)^{1,0380}	BRS Kalifa	0.2386	0.3384	-0.1175	0.9714	0.8526
LA = 0,3269.(W)^{2,1552}	Jamu	0.4323	0.5857	0.3562	0.9327	0.7341
LA = 0,0940.(.)^{1,8482}	Jamu	0.1552	0.2161	-0.0335	0.9861	0.8893
LA = 0,1527.(W.L)^{1,0380}	Jamu	0.1769	0.2339	0.1298	0.9869	0.8808
LA = 0,3269.(W)^{2,1552}	BRS Toro	0.4259	0.6108	-0.0419	0.9474	0.8127
LA = 0,0940.(L)^{1,8482}	BRS Toro	0.2790	0.4286	-0.0732	0.9756	0.8797
LA = 0,1527.(W.L)^{1,0380}	BRS Toro	0.2578	0.3706	-0.0484	0.9819	0.8889

* MAE = mean absolute error (cm^2/leaf); RMSE = root mean square error (cm^2/leaf); BIAS = BIAS index; d = agreement index; d1 = modified agreement index. The values in red and green represent the worst and the best results, respectively, of the statistics for each one of the cultivars.

use of only one of the dimensions (L or W) were found for sunflower (Maldaner *et al.*, 2009), canola (Cargnelutti Filho *et al.*, 2015), cassava (Trachta *et al.*, 2020) and beans (Pohlmann *et al.*, 2021).

CONCLUSIONS

It is possible to use the general model LA= 0,0940. L^{1,8482} to simulate the leaf area of the chickpea crop, for cultivars BRS Aleppo, BRS Kalifa, Jamu, BRS Toro, and other cultivars that have morphologically similar leaves. For the cultivar BRS Cícero, due to the morphological differences of its leaves, the most suitable model is LA= 0,1092.L^{2,1815}.

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