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REGULAR ARTICLE

Do low-cost digital tools allow measuring the cladode area?

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Abstract

This study evaluated low-cost digital tools for estimating cladode area by mobile and fixed devices. We conducted the experiment at the Serra Talhada Academic Unit of the Federal Rural University of Pernambuco with pear cactus (*Nopalea cochenillifera* Salm-Dyck and *Opuntia stricta* (Haw.)). In this sense, we used four software to measure the cladode area: LAFore (fixed device), ImageJ (fixed device), Easy Leaf App (mobile device), and Petiole App (mobile device). We considered the LAFore software as a reference and used the following statistical parameters: linear regression, correlation coefficient (r), Willmott index (d), confidence index (c), and standard error of estimate (SEE). The software on fixed devices (ImageJ and LAFore) showed similar results, with performance considered excellent, and the Easy Leaf App showed a very good performance among mobile devices.

Keywords

Pear cactus; Linear Regression; Scanner.

Introduction

The Brazilian Northeast has an extensive region of semi-arid climate characterized by long periods of drought and, therefore, requires adequate nutritional management of livestock production systems. In this sense, pear cactus (*Opuntia ficus-indica* Mill and *Nopalea cochenillifera* Salm-Dyck), commonly known as cacto gigante and cacto miúdo, has been used for several decades to enable animal feed during critical periods of drought. These species have morphophysiological characteristics – crassulacean acid metabolism (CAM) – and uniformly distributed stomata, among others, that make them tolerant to prolonged droughts (Bispo et al., 2007). The leaf area is one of the most important constituent parts of a plant, as it is the area that intercepts solar rays, and provides the exchange of water and the transformation of light into energy. The photosynthetic process depends on the interception of solar radiation and its conversion into chemical energy. Therefore, the leaf area index (LAI) can be considered one of the indicative parameters of productivity (Favarin et al., 2002). However, the pear cactus has a different structure, as the modified stem, called cladode, carries out photosynthesis (Lucena et al., 2018) and hence the cladode area index (CIA) must be considered for this crop.

Despite the proliferation of pear cactus, there are few reports of practical and low-cost methods to measure the cladode area, standing out the studies by Silva et al. (2014), Pinheiro et al. (2015), and Lucena et al. (2018). In this sense, varied methods using different software to calculate the cladode area (CA) are essential to improve production management. Direct and indirect methods can measure CA. Direct methods are destructive and require the removal of the leaf or other structures, which may not be feasible due to the limited number of plants in the experimental plot (Maldaner et al., 2009). Indirect methods are non-destructive and provide accurate CA estimates from the beginning to the end of the plant cycle (Peksen, 2007). This study aimed to compare software on mobile and fixed devices to estimate cladode area and demonstrate the feasibility and accuracy for use in the field at a low cost.

Materials and methods

The study was conducted at the Federal Rural University of Pernambuco – Serra Talhada Academic Unit (UFRPE/UAST). The region is characterized by the BSw′h climate – semi-arid, hot, and dry – with annual precipitation of 657 mm year^{-1} and an average annual temperature of 25.8 °C (Alvares et al., 2013; Lins et al., 2017).

For this purpose, we developed the evaluation in two species of pear cactus: cochineal nopal cactus (*Nopalea cochenillifera* Salm-Dick) and erect pricklypear (*Opuntia stricta* (Haw.) Haw.) as shown in Figure 1. We collected cladodes of different orders from two plants, 26 from the first one (P1) and 19 from the second one (P2).

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Figure 1. Palm species used in the study.

The experiment used four different software to measure the cladode area (CA). Among fixed devices, we considered the LAFore "Leaf Area FOR Everyone by Veiko Lehsten," developed by the University of Oldenburg, Germany, and ImageJ, a program developed exclusively for computers by the US National Institute of Health, as presented by Schneider et al. (2012). Regarding mobile devices, we used the Easy Leaf App, Easy Leaf Area Free Application, developed by Easlon & Bloom (2014), and Petiole App, Petiole: Plant Leaf Area, Android system application, as presented by Tuyogon, (2020) and Singh et al. (2021).

The estimation of the area of each cladode in the fixed devices LAFore and ImageJ required the use of a commercial scanner (HP F4280), on which the images were processed for area estimation (Figure 2). However, this equipment was developed to obtain images of objects with thin thicknesses, such as sheets of paper, and, therefore, we made some adaptations, as presented by Silva et al. (2014). The digitization of cladodes was carried out in an illuminated environment, using a sheet of white A4 paper in place of the scanner cover, 200 dpi (dots per inch) resolution, and images saved in TIFF format. However, we used a ruler next to the cladode for collecting the image for ImageJ, as this program uses the informed dimension to estimate the leaf area.

The cladode area was estimated with the mobile device Xiaomi MiA3 smartphone on an Android system. Easy Leaf App requires that the collected image be made together with red paper with an area of 2x2 cm (4 cm^2), serving to calibrate the software and estimate the leaf area (Figure 2). Moreover, the Petiole App initially requires a calibration block, which can be for small, medium, and wide leaves (Singh et al., 2021). We considered the block of large leaves in this study. We used white A4 paper in both software as a background to contrast with the cladodes. Images were taken at a standard height of 50 cm above the surface of the paper and the plant.

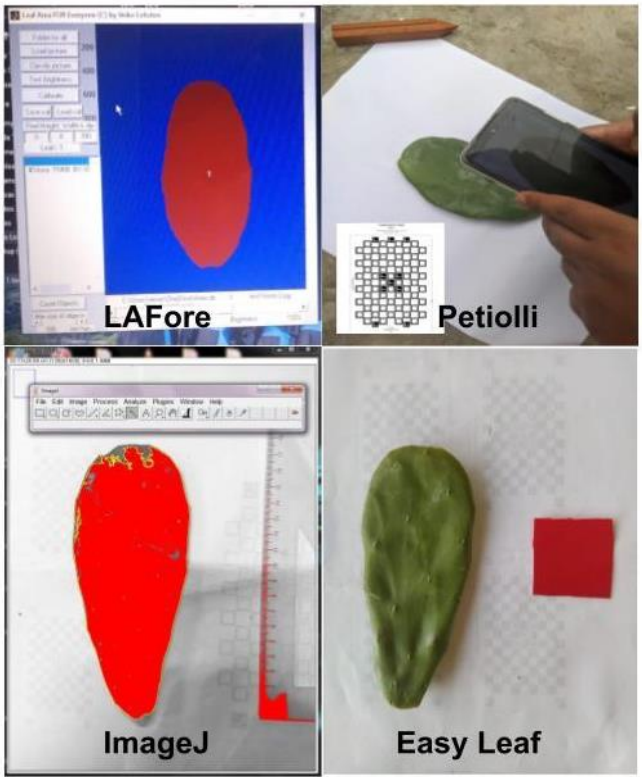

Figure 2. Estimation of cladode area with applications/programs.

The method used as a reference to estimate the cladode area was LAFore, as other studies have already evaluated this program in pear cacti (Silva et al., 2014; Pinheiro et al., 2015). We used the following statistical parameters to verify the software: linear regression, correlation coefficient (r), Willmott index (d), confidence index (c), and standard error of estimate (SEE) (Silva et al., 2014; Matos et al., 2017). In (Figure 3) below, we have a flowchart that briefly represents the project step by step.

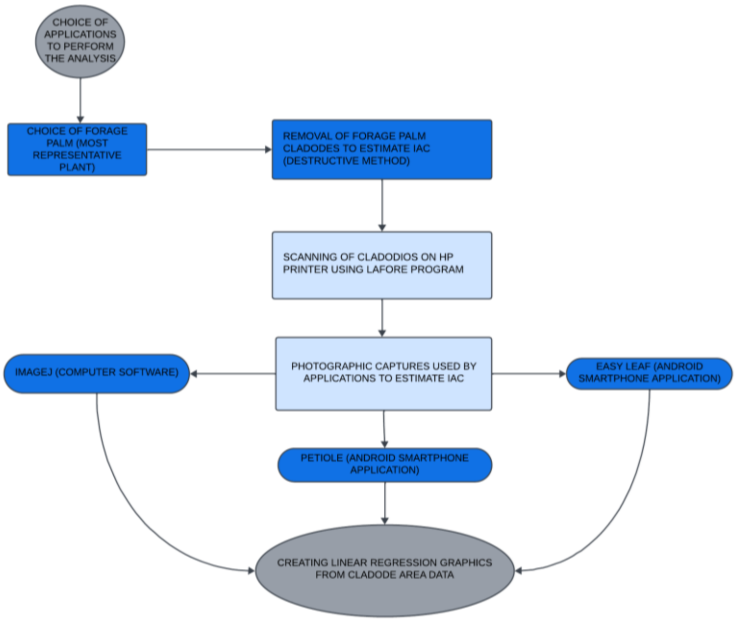

Figure 3. Work flowchart.

Results and discussion

The results show an association between the fixed devices ImageJ and LAFore with a mean regression inclination for the two plants (Figures 4A and 4B) of 0.848. In turn, the greatest association on the mobile device occurred with the Easy Leaf App and LAFore measures, with a mean regression inclination of 0.794. On the other hand, the Petiole App presents worse performance when compared to the reference program, with a mean inclination of 0.281. The coefficient of determination of the linear regressions, means of the two plants, was 0.882 for ImageJ and 0.869 for Easy Leaf App.

Table 1 shows the results of the statistics of fit to the reference program. ImageJ has a better fit than the Easy Leaf app. According to the classification by Camargo & Sentelhas (1997), ImageJ has a performance considered excellent, Easy Leaf App presented a very good, and Petiole App was classified as terrible, probably due to the framing of the image, since the calibration panels do not suit the height at which the photograph was being taken, this may be the application's limitation.

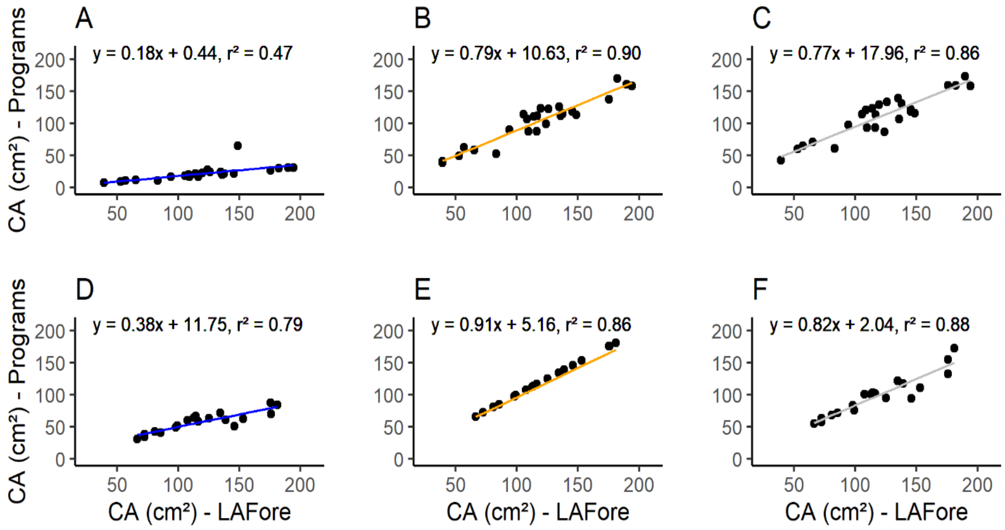

Figure 4. Scatter plots and linear regression trend line between programs (Petiole App, ImageJ, and Easy Leaf App) and the reference (LAFore): (A) Plant 1 (P1) – Petioli App; (B) Plant 1 (P1) – ImageJ; (C) Plant 1 (P1) – Easy Leaf App; (D) Plant 2 (P2) – Petioli App; (E) Plant 2 (P2) – ImageJ; (F) Plant 2 (P2) – Easy Leaf App.

Table 1. Statistical results of software comparison.

Statistics	ImageJ	Easy Leaf App	Petiole App
r	0.93	0.92	0.46
d	0.94	0.92	0.43
c	0.88	0.85	0.20
Performance	Excellent	Very good	Terrible
SEE	18.03	20.79	88.92

The ImageJ software presented an expected behavior, with results more consistent with the reference method, as the basic procedures are similar, such as the use of a scanner. Importantly, some studies have applied this program to estimate leaf area in *Schlumbergera truncata* and xerophytic succulents of Zygophyllaceae (Xu et al., 2020; Leytur et al., 2021). However, the predictive capacity of this program may have been reduced due to the image resolution, whose default is 300 dpi (Easlon & Bloom, 2014; Klingler et al., 2020).

The Easy Leaf App, on the other hand, is an integrated device that allows estimating more than one cladode at a time, depending on the framing used to obtain the image. Thus, the procedure can be sped up to obtain the cladode areas. However, its low quality does not allow for obtaining a large number of pixels with the same quality and reduces the ability to estimate the leaf area (Klingler et al., 2020).

Finally, the Petiole application did not allow an adequate area estimate, probably due to the image collection height of approximately 50 cm, as the recommended height range is between 5 and 25 cm. In this context, Singh et al. (2021) evaluated the effect of different heights (8, 12, and 16 cm) on estimating the leaf area of neem and rose with this application and compared it with the grid counting method. The authors found no significant differences between heights in the calibration, but they developed the estimates in the recommended height range.

Importantly, the software evaluated in this study is available in a free sharing format. Mobile devices are more practical because they only require the camera available on the equipment and handling is simpler since fixed devices need a scanner to generate the image and a desktop to process the software.

Conclusions

This study evaluated four software for estimating the cladode area in two pear cactus varieties, both in fixed and mobile devices. The software ImageJ and LAFore presented similar results on fixed devices. On the other hand, Easy Leaf App performed very well on a mobile device. Thus, they demonstrated excellent reliability and performance in estimating the cladode area with mobile and fixed devices.

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