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Daily photosynthetic course of calla lily plants

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ABSTRACT

The calla lily ornamental plant (*Zantedeschia aethiopica*) is grown and marketed in many countries. Studies on daily variation in photosynthesis are critical for understanding how a plant behaves in its growing environment. The objective of this study was to evaluate the daily photosynthetic course of calla lily plants grown in pots in a greenhouse under 50% shade. Gas exchange (*gs*, *A*, *E*, *Ci*, WUE, iWUE, and iCE) and chlorophyll indices (a, b, and total) were evaluated from 7:00 a.m. to 5:00 p.m. over three days. The values of all variables were greater at high temperatures (11:00 a.m. to 1:00 p.m.), except for *gs*, *Ci*, and chlorophyll b, which were higher at low temperatures (7:00 to 9:00 a.m.) Therefore, it is suggested that calla lily producers maintain the water status between 11:00 a.m. and 1:00 p.m. to optimize photosynthetic processes, and consequently, the growth and development of this plant. Correspondingly, irrigation of this crop should be performed prior to the interval mentioned above.

Keywords: Chlorophyll, Gas Exchange, Ornamental Plants, *Zantedeschia aethiopica*.

Curso diário fotossintético de plantas de copo-de-leite

RESUMO

A planta ornamental copo-de-leite (*Zantedeschia aethiopica*) é cultivada e comercializada em muitos países. Estudos sobre a variação diária da fotossíntese são fundamentais para entender como uma planta se comporta em seu ambiente de crescimento. O objetivo deste trabalho foi avaliar o curso diário fotossintético de plantas de copo-de-leite cultivadas em vasos em casa de vegetação sob 50% de sombreamento. As trocas gasosas (*gs*, *A*, *E*, *Ci*, WUE, iWUE e iCE) e os índices de clorofila (a, b e total) foram avaliados das 7h às 17h por três dias. Os valores de todas as variáveis foram maiores em temperaturas mais elevadas (11h às 13h), exceto para *gs*, *Ci* e clorofila b, que foram maiores em temperaturas mais baixas (7h às 9h). Com isso, sugere-se que os produtores de copo-de-leite mantenham o estado hídrico das plantas entre as 11h00 e as 13h00 para otimizar os processos fotossintéticos e, consequentemente, o crescimento e desenvolvimento desta planta. Da mesma forma, a irrigação desta cultura deve ser realizada antes do intervalo mencionado acima.

Palavras-chave: Clorofila, Trocas Gasosas, Plantas Ornamentais, *Zantedeschia aethiopica*.

1. Introduction

Calla lily (*Zantedeschia aethiopica* L. Spreng. (Araceae)) is native to temperate regions of Africa, cultivated in the temperate and tropical regions of Mexico, and commonly grown in Brazil. This plant is perennial, with white flowers in the shape of a cup, and a long, erect, and rigid stem. *Z. aethiopica* is used in floral therapies and toxic remedies, and its flowers and bulbs are cooked for consumption. In addition, calla lily plants can be grown in gardens or on a commercial scale as cut flowers and sold in high-value floral arrangements (Hlophe et al., 2015).

However, the productive and photosynthetic processes of this plant are still poorly understood. Calla lilies show improved flower formation after low temperatures, which is characteristic of the genus *Zantedeschia* and may be related to their region of origin. Vernalization and low production occur at high temperatures; therefore, the best production of this plant is in greenhouses and screened areas (Kippes et al., 2018).

Photosynthesis is responsible for energy entry into the biosphere, and identifying its limitations is fundamental to understanding the functioning of plants in the environment (Deans et al., 2019). In plant canopies, the response to light is highly dynamic, with fluctuations on the scale of seconds to minutes (Slattery et al., 2018). The study of the spatial distribution of light use in photosynthesis by plants such as calla lily can be useful for evaluating and improving the effectiveness of environmental control in greenhouses and screened environments (Murakami and Ibaraki, 2019).

Physiological factors affect the impact of rapid changes in photosynthetic photon flux density on plant carbon balance. The diffusion of CO_2 through the stomata and mesophyll can limit photosynthesis, with slow deactivation of photoprotective mechanisms when leaves enter the shade, reducing net carbon gain (Kromdijk et al., 2016). The slow induction of photosynthesis between the shady and sunny periods can also reduce carbon assimilation in plant canopies. RuBisCO activation is a critical constraint on photosynthetic induction during shade-sun transitions (Morales et al., 2018).

Plants perceive and respond rapidly to changes (even minor) in water status through a series of cellular, molecular, and physiological events that develop simultaneously (Pinheiro and Chaves, 2011). Changes in plant biological processes, particularly photosynthesis, can be evaluated through a daily photosynthetic course, such as those observed with *Annona squamosa* L. (Figueiredo et al., 2019) and *Olea europaea* L. (Haworth et al., 2018). Understanding the daily photosynthetic variation of calla lily can be useful for irrigation management of this plant, since it has a high sensitivity to water deficit. The maintenance of plant water status when the highest degree of photosynthesis occurs is essential for plant growth performance. Therefore, the objective of this study was to evaluate the daily photosynthetic course of calla lily plants grown in pots in a greenhouse under 50% shade.

2. Material and Methods

The experiment was performed at the Research and Extension Unit of the Floriculture Sector of the Department of Agronomy of the Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil. Ten calla lily plants were grown in 10 L pots in a greenhouse covered with a 50% shading net. These plants originated from bulbs collected from healthy plants that were cultivated under the same conditions as the experiment. The plants were subjected to cleaning, weed removal, flower pruning to avoid redirection of nutrients, and biweekly fertilization with Peters® fertilizer (N-P-K 20-20-20 + micronutrients) for three months.

The gas exchange of 10 calla lily plants was evaluated from 7:00 a.m. to 5:00 p.m. (every two hours) using an infrared gas analyzer (IRGA, model LCPro, ADC BioScientific Ltd.). Stomatal conductance (*gs*= mol H_2O m^{-2} s^{-1}), net photosynthesis (*A*= μmol CO_2 m^{-2} s^{-1}), transpiration rate (*E*= mmol H_2O m^{-2} s^{-1}), CO_2 internal concentration (*Ci*= μmol CO_2 mol air^{-1}), instantaneous water use efficiency (WUE= *A*/*E*), intrinsic water use efficiency (iWUE= *A*/*gs*), and intrinsic carboxylation efficiency (iCE= *A*/*Ci*) were evaluated. Chlorophyll a, b, and total indices, as well as the chlorophyll a/b ratio was measured using a non-destructive method with a portable electronic chlorophyllometer (ClorofiLOG®- model CFL 1030) and reported as Falker chlorophyll indices (FCI).

The experiment was performed in a completely randomized design with 10 replicates (one pot each) and two evaluations per leaf, each with a calla lily plant with healthy leaves and without flowers. The means and respective confidence intervals, obtained with the Microsoft Excel® program, were plotted in graphs using the SigmaPlot 10.0 program (Systat Software, Inc., San Jose, CA, USA). An analysis of canonical variables with confidence ellipses ($p \leq 0.01$) was performed to study the interrelationships between variables and factors using the candisc package (Friendly and Fox, 2017).

3. Results and Discussion

Stomatal conductance was greatest at 9:00 a.m. (*gs*- 0.82 mol H_2O m^{-2} s^{-1}) and decreased thereafter (Figure 1). The net photosynthesis was at a maximum at 11:00 a.m. (*A*- 15.77 μmol CO_2 m^{-2} s^{-1}) and consistent from 11:00 a.m. to 1:00 p.m.

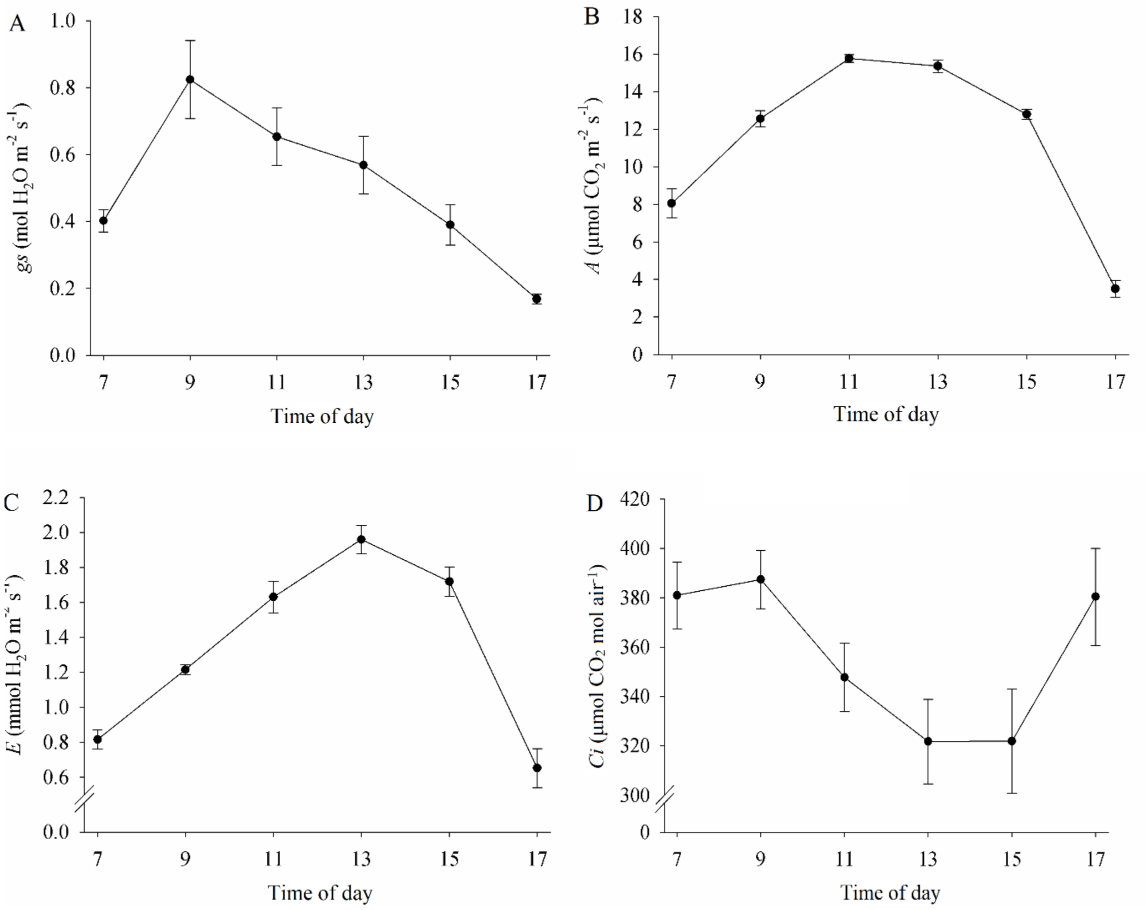

Figure 1. Stomatal conductance (*gs*– A), net photosynthesis (*A*– B), transpiration rate (*E*– C) and CO_2 internal concentration (*Ci*– D) of *Zantedeschia aethiopica* at each time of evaluation.

The transpiration rate was highest at 1:00 p.m. (*E*- 1.96 mmol H_2O m^{-2} s^{-1}) and decreased from this time forward. CO_2 internal concentration was lowest from 1:00 to 3:00 p.m. (*Ci*- 321.73 and 327.75 µmol CO_2 mol air^{-1}, respectively) and was inversely proportional to the net photosyntheis. The higher stomatal conductance and net photosynthesis at 9:00 and 11:00 a.m., respectively, are due to adequate environmental conditions, such as temperature, humidity, luminosity, and vapor pressure deficit, which optimize CO_2 entry through the stomata (Urban et al., 2017).

Furthermore, the higher net photosynthesis in the late morning reflects the high water potential of the leaves at this time (Costa and Marenco, 2007). The greater transpiration rate at 1:00 p.m. and the decrease thereafter confirmed a relationship with temperature, which was greater in the hours with higher values of this variable in the calla lily plants. Completely closed stomata under high-temperature conditions determine the minimum and unavoidable water losses to improve the chance of plants establishing themselves and surviving (Bueno et al., 2019).

The lowest CO_2 internal concentration from 1:00 to 3:00 p.m., which was inversely proportional to the net photosynthesis, was due to the utilization of this element by the plant in the process of photosynthesis. This behavior was due to CO_2 controlling the biochemical reactions of photosynthesis when it diffused into the leaves through the stomata towards the chloroplasts, whose reducing energy produced in this process was derived from solar energy (Wang et al., 2017), which was greater at 1:00 p.m.

The instantaneous water use efficiency was similar in the first few hours and decreased after 11:00 a.m. (Figure 2). The intrinsic water use efficiency was highest (iWUE- 35.57 µmol CO_2 m^{-2} s^{-1}/mol H_2O m^{-2} s^{-1}) at 3:00 p.m. The intrinsic carboxylation efficiency increased in the first few hours, reaching its maximum (iCE- 0.0478 µmol CO_2 m^{-2} s^{-1}/µmol CO_2 mol air^{-1}) at 1:00 p.m., with similar values between 11:00 a.m. and 3:00 p.m.

The instantaneous water use efficiency (WUE) was constant in the first few hours and decreased after 11:00 a.m., indicating that it is a determining factor in the cultivation of *Z. aethiopica* in tropical regions such as Brazil. The consistent values of this variable in the early hours of the day relate to the fact that the stomata were open, which improved water uptake, and increased the efficiency of its use (Schreel and Steppe, 2020). However, the higher temperatures throughout the day and changes in turgor pressure and gas exchange decreased the WUE (Bertolino et al., 2019).

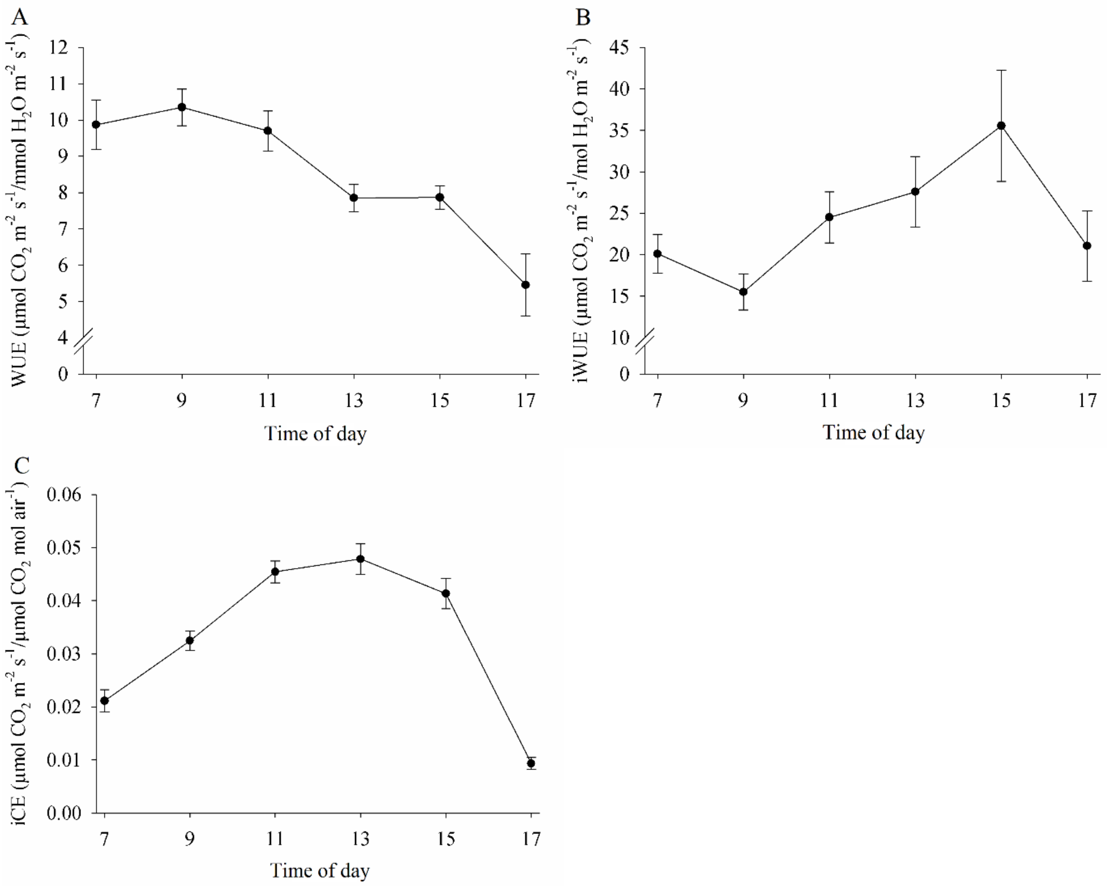

Figure 2. Instantaneous water use efficiency (WUE– A), intrinsic water use efficiency (iWUE– B) and intrinsic carboxylation efficiency (iCE– C) of *Zantedeschia aethiopica* at each time of evaluation.

Plants with reduced stomatal opening use less water to achieve a similar final yield (Dunn et al., 2019). The greater intrinsic water use efficiency at 3:00 p.m. is due to the sharp decrease in plant stomatal conductance at this time of the day in relation to the increase in temperature, which optimizes water use (Farooq et al., 2019). The iCE increased in the first hours remained similar between 11:00 a.m. and 3:00 p.m., and reached a maximum at 1:00 p.m. due to the use of *Ci* to perform *A* as a response to the increase in *gs* and luminosity. However, as *Ci* increased, *A* decreased, as they are inversely proportional processes (Osei-Bonsu et al., 2021).

Chlorophyll a reached the highest level (45.01 FCI) at 1:00 p.m., which was maintained until the end of the day (Figure 3). Total chlorophyll was greatest (64.86 FCI) at 3:00 p.m. and remained similar from that time forward. The chlorophyll a/b ratio was highest (2.35) at 1:00 p.m. and decreased thereafter. The components of the gas exchange and chlorophyll variables accounted for 95% of the variance (Figure 4A). The values of the gas exchange variables were higher at 11:00 a.m. and 1:00 p.m., except for *Ci*, which was higher at 7:00 a.m. These first two components accounted for up to 91.2% of the variance (Figure 4B). The values of the chlorophyll variables were greater at 1:00 p.m., except for Cb, which had a higher value at 7:00 p.m.

The highest chlorophyll a index occurred at 1:00 p.m. and continued until the end of the day due to the greater light irradiation at this time, causing greater light absorbance (Mamrutha et al., 2017). The lower chlorophyll b index at 1:00 p.m. is due to the difference in the absorption spectrum between chlorophylls a and b (Dias et al., 2018), which are absorbed differently at the same time. The consistent total chlorophyll value relates to its different absorbance, and the higher value at 1:00 p.m. was due to the greater amount of chlorophyll a than b.

The photosynthetic processes related to chlorophyll showed that calla lily plants are adapted to climatic conditions with the influence of irradiation on chlorophyll, which may be specific and vary with the adaptation of this plant to high irradiance (Padilla et al., 2019). The 95% explanation of the variance by the first two components (gas exchange and chlorophyll variables) and the higher values of the gas exchange variables at 11:00 a.m. and 1:00 p.m. (except for C*i*, which was greater at 7:00 a.m.) occurred because changes in ambient temperature were rapidly detected by cellular organelles.

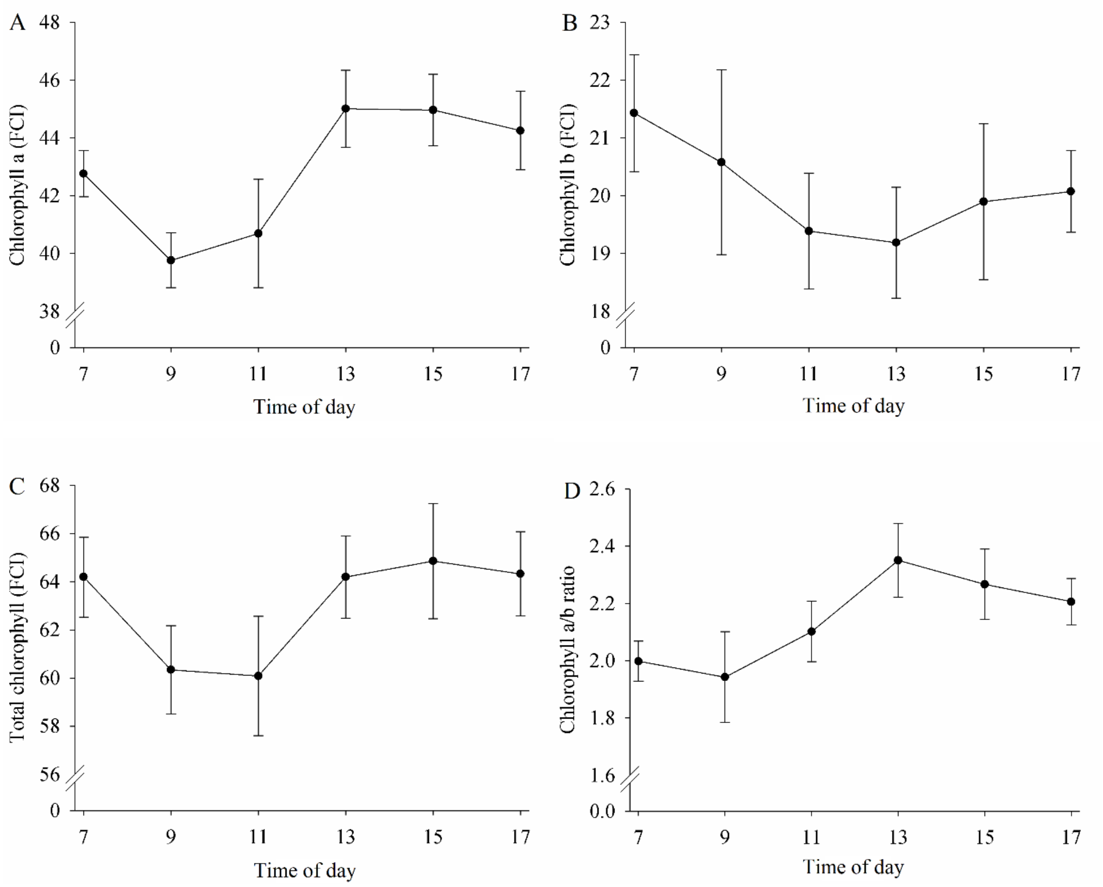

Figure 3. Chlorophyll a (A), chlorophyll b (B), total chlorophyll (C), and chlorophyll a/b ratio (D) of *Zantedeschia aethiopica* at each time of evaluation.

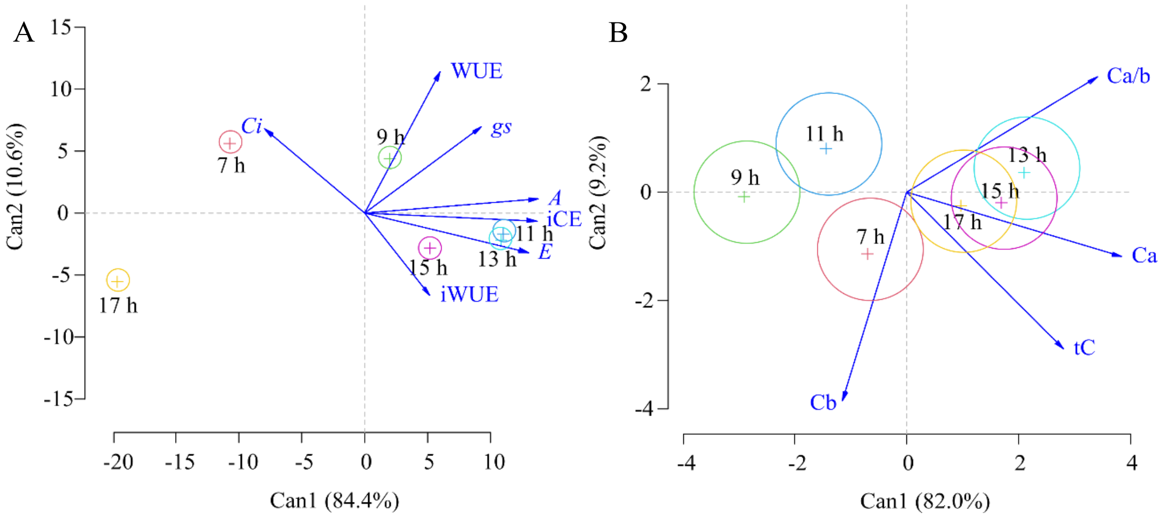

Figure 4. Canonical variable analysis with confidence ellipses between gas exchange (A) and chlorophyll (B) variables of *Zantedeschia aethiopica*.

Changes in ambient temperature were detected by cellular organelles, triggering specific pathways of biochemical and molecular responses at the cellular level that were integrated with temperature changes (Nievola et al., 2017)The highest *Ci* at 7:00 a.m. was due to CO_2 not being required for respiration in calla lily plants at night (Ogle et al., 2012). The relationship between photosynthesis and daytime light is proportional to the chlorophyll variables because they are involved in plant photosynthetic processes to convert light energy into chemical energy (Genesio et al., 2021).

4. Conclusions

The values of *A*, *E*, WUE, iWUE, iCE, total chlorophyll a and b, and chlorophyll a/b ratio were higher at higher temperatures (11:00 a.m. to 1:00 p.m.), while g*s*, C*i*, and chlorophyll b were greater at low temperatures (7:00 to 9:00 a.m.). Therefore, it is suggested to calla lily producers that the maintenance of water status between 11:00 a.m. and 1:00 p.m. is crucial to optimize photosynthetic processes, and consequently, the growth and development of this plant. Irrigation of this crop should be performed prior to the interval mentioned above.

Authors' Contribution

Marlon Gomes Dias, Toshik Iarley da Silva, Renata Ranielly Pedroza Cruz and Lucas Brêtas Barbosa contributed to the execution of the experiment, data collection, writing, interpretation and revision of the manuscript. José Cola Zanúncio and José Antonio Saraiva Grossi contributed to the writing, interpretation and revision of the manuscript.

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