

Diurnal variations in physiological aspects of desert rose under different light intensities

Variações diurnas nos aspectos fisiológicos da rosa do deserto sob diferentes intensidades de luz

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ABSTRACT – Among the environmental factors influencing plant development, light is one of the most critical, directly affecting growth and physiological processes. Fluctuations in light intensity can significantly alter plant physiological mechanisms. This study aimed to evaluate the effects of different photosynthetically active radiation flux densities (PPFD) on the physiological responses of desert rose throughout the day. The experimental design was completely randomized, with treatments consisting of 18 photosynthetic photon flux densities (0, 25, 50, 75, 100, 125, 150, 175, 200, 400, 600, 800, 1,000, 1,200, 1,400, 1,600, 1,800, and 2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) and three evaluations throughout the day (8 a.m., 12 p.m., and 4 p.m.). Variations in gas exchange were analyzed, as were the flux densities that promote greater chlorophyll fluorescence and electron transport rate in desert rose plants. The results showed that physiological processes varied significantly with PPFD throughout the day. At 12 p.m., a PPFD between 1800 and 2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ favored the highest rates of CO_2 assimilation, stomatal conductance and transpiration. Chlorophyll fluorescence, especially maximum and variable, was also increased under high irradiance, while initial fluorescence was higher under low light availability. The results highlighted the influence of photon flux on photosynthetic efficiency, gas exchange and fluorescence parameters, demonstrating the importance of times of the day in CO_2 assimilation and stomatal opening.

RESUMO – Entre os fatores ambientais que influenciam o desenvolvimento vegetal, a luz está entre os mais relevantes, afetando o crescimento e os processos fisiológicos. Alterações na intensidade luminosa, sejam aumentos ou diminuições, podem alterar os mecanismos fisiológicos das plantas. Este estudo teve como objetivo avaliar os efeitos de diferentes densidades de fluxo de radiação fotossinteticamente ativa (PPFD) nas respostas fisiológicas da rosa-do-deserto (*Adenium obesum*) ao longo do dia. O delineamento experimental foi inteiramente casualizado, com tratamentos consistindo em 18 densidades de fluxo de fótons fotossintéticos (0, 25, 50, 75, 100, 125, 150, 175, 200, 400, 600, 800, 1.000, 1.200, 1.400, 1.600, 1.800 e 2.000 $\mu\text{mol m}^{-2} \text{s}^{-1}$) e três avaliações ao longo do dia (8h, 12h e 16h). Foram analisadas as variações nas trocas gasosas, bem como as densidades de fluxo que promovem maior fluorescência da clorofila e taxa de transporte de elétrons em plantas de rosa-do-deserto. Os resultados mostraram que os processos fisiológicos variaram significativamente com a PPFD ao longo do dia. Ao meio-dia, uma PPFD entre 1.800 e 2.000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ favoreceu as maiores taxas de assimilação de CO_2 , condutância estomática e transpiração. A fluorescência da clorofila, especialmente a máxima e a variável, também aumentou sob alta irradiância, enquanto a fluorescência inicial foi maior sob baixa disponibilidade de luz. Os resultados evidenciaram a influência do fluxo de fótons na eficiência fotossintética, trocas gasosas e parâmetros de fluorescência, demonstrando a importância dos horários do dia na assimilação de CO_2 e na abertura estomática.

Keywords: *Adenium obesum* (Forssk.) Roem. & Schult. Photosynthesis. Gas exchange. Abiotic stresses. Photon density.

Palavras-chave: *Adenium obesum* (Forssk.) Roem. & Schult. Fotossíntese. Trocas gasosas. Estresses abióticos. Densidade de fótons.

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INTRODUCTION

Plants are affected by adverse abiotic conditions, such as drought, high and low temperatures, light, and soil salinity, which can limit and impact growth and development (ŠAMEC et al., 2021). Abiotic stresses significantly reduce photosynthetic efficiency, negatively affecting chlorophyll production, photosynthetic apparatus function, and electron transport mechanisms. Therefore, understanding plant responses and behavior under harsh environmental conditions is crucial (ZHANG et al., 2022).

Changes in light intensity, whether increasing or decreasing, can significantly alter plant morphology and physiology. The intensity of luminosity, along with its duration and spectral quality, directly affects plant physiological processes, influencing photosynthetic efficiency and assimilate allocation (FENG et al., 2019).

The of photosynthetic photon flux density (PPFD) reflects the luminous intensity available for photosynthesis (POORTER et al., 2019). Thus, PPFD represents the amount of irradiance that reaches the leaf surface and its relationship with photosynthetic rate, as evidenced by the photosynthesis response curve (COELHO et al., 2023).

Abiotic factors, such as temperature, light intensity, humidity, and nutrient availability, directly influence plant physiological processes. Among these factors, light stands out as an essential element for carbon metabolism, being determinant for photosynthetic performance (SANTOS et al., 2025). In many ornamental species, the distribution and intensity of light throughout the day alter the photosynthetic dynamics, directly affecting the growth and functioning of vegetative structures. An example is the desert rose [*Adenium obesum* (Forssk.) Bite. & Schult.], whose flowering and development are strongly modulated by the luminosity of the environment (MCBRIDE et al., 2014).

The desert rose is a succulent herbaceous plant native to East Africa and belonging to the Apocynaceae family. It is well known for its exuberance, ornamental value, and medicinal use in the treatment of diseases (ALANAZI et al., 2021). In addition to medicinal use, this species is used as an ornamental plant due to its beauty, with flowers of varied colors and easy management, and can be cultivated under adverse climatic conditions in different regions of the world (SULEIMAN; BRIMA, 2021).

Thus, the objective of this research was to evaluate the effects of photosynthetically active photon flux density (PPFD), throughout the day (8 a.m., 12 p.m. and 4 p.m.), on gas exchange and chlorophyll *a* fluorescence parameters in desert rose plants.

MATERIAL AND METHODS

This study was conducted in a greenhouse located in the Didactic Garden of the Department of Agronomic and Forestry Sciences of the Federal Rural University of the Semiarid Region (UFERSA), in Mossoró, RN, Brazil. The region's climate is dry and hot, with a well-defined dry season and rainfall concentrated in the summer. According to the Köppen climate classification, the climate is BSh (ALVARES et al., 2013).

The experimental design was completely randomized with six replications (one plant per replicate), for a total of six plants evaluated. At the time of the experiment, the plants were in the vegetative stage, without flowers or fruits. They were grown in 5 L polyethylene pots filled with a 2:1 (v/v) mixture of soil and bovine manure. The plants were maintained in the greenhouse environment, where the physiological evaluations were carried out, and irrigated to keep the substrate at 80% of field capacity. The evaluations were carried out by establishing 18 photosynthetically active photon flux densities (PPFD) representing measurement intervals generated by the artificial light source coupled to the leaf chamber of the infrared gas analyzer (IRGA; model LI-6400XT, LI-COR, Lincoln, NE, USA) (0, 25, 50, 75, 100, 125, 150, 175, 200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, and 2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$), which were evaluated three times a day (8 a.m., 12 p.m., and 4 p.m.). At each PPFD level, data were recorded only after the gas exchange rates stabilized within the measuring chamber.

The internal (InT) and external (ExT) temperatures, as well as the internal (InRH) and external relative humidity (ExRH) of the greenhouse, were measured during the physiological evaluations, using a digital thermo-hygrometer (Minipa, model MT-241A). Photosynthetically active radiation (PAR) was quantified with a natural light sensor

connected to a portable infrared gas analyzer (IRGA).

Gas exchange analyses were performed using a portable infrared gas analyzer. The following physiological variables were evaluated: net CO_2 assimilation rate (A) ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$), stomatal conductance (g_s) ($\text{mol H}_2\text{O m}^{-2} \text{s}^{-1}$), transpiration rate (E) ($\text{mmol H}_2\text{O m}^{-2} \text{s}^{-1}$), internal CO_2 concentration (C_i) ($\mu\text{mol CO}_2 \text{ mol}^{-1}$), ratio between intercellular and atmospheric CO_2 concentrations (C_i/C_a) and vapor pressure deficit (VPD) (kPa). Measurements were performed under the following operating conditions in the measuring chamber: relative humidity between 50 and 60%, airflow of 300 $\mu\text{mol s}^{-1}$, CO_2 concentration set at 400 $\mu\text{mol mol}^{-1}$ and leaf chamber area of 2 cm^2 .

Chlorophyll *a* fluorescence analysis was performed using a fluorometer (LI-COR, model LI-6400-40 LCF) coupled to the IRGA. Initial fluorescence (F_o'), maximum fluorescence (F_m'), variable fluorescence (F_v'), potential quantum yield of PSII (F_v'/F_m'), ratio between variable and initial fluorescence (F_v'/F_o'), effective quantum efficiency of PSII (ΦPSII), photochemical quenching (q_P), non-photochemical quenching (q_N) and electron transport rate (ETR) were determined in leaves subjected to a saturating flash of actinic irradiation and a pulse of light in the far red region.

Gas exchange and chlorophyll *a* fluorescence were evaluated on four leaves per plant, located in the middle third of the plant, which were well-developed, healthy, and free of pests or diseases. The response curves of gas exchange and chlorophyll fluorescence to PPFD were estimated in increments of 200 - 2,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at intervals of 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$. The response curve of A as a function of PPFD was adjusted for a rectangular hyperbolic function:

$$A = \frac{A_{\text{max}} * Q}{a + Q}$$

where:

A - Net CO_2 assimilation rate;

Q - Flux density of photosynthetically active photons;

A_{max} - maximum rate of photosynthesis; and

a - Coefficient of fit of the equation.

The data were subjected to nonlinear regression analysis using a rectangular hyperbola, and the significance of the regression models was evaluated using the F-test. Pearson's correlation and principal component analysis (PCA) were also performed to evaluate the relationships between environmental variables (PAR, InT, ExT, InRH, and ExRH) and physiological variables (A , g_s , E , C_i , C_i/C_a , VPD, F_o' , F_m' , F_v' , F_v'/F_m' , F_v'/F_o' , ΦPSII , q_P , q_N , and ETR). Statistical analyses were performed using R v.4.1.1 software (R DEVELOPMENT CORE TEAM, 2024).

RESULTS AND DISCUSSION

The abiotic factors analyzed varied across the different times of evaluation throughout the day (Figure 1). The highest PAR was observed at 12 p.m. (524.28 $\mu\text{mol m}^{-2} \text{s}^{-1}$) and the lowest at 4 p.m. (80.67 $\mu\text{mol m}^{-2} \text{s}^{-1}$) (Figure 1). A similar behavior was observed in relation to internal and external air temperature, which reached the highest values at 12 p.m.

[35.83 °C (InT) and 32.89 °C (ExT)] (Figure 1). On the other hand, the internal and external relative humidity showed an inverse pattern, being lower, with maximum values observed at 4 p.m. [83.56% (InRH) and 76.49% (ExRH)] and at 8 a.m. [74.36% (InRH) and 70.13% (ExRH)] (Figure 1). This

variation is critical because the increase in vapor pressure deficit (VPD) throughout the day results from the combination of high temperature and low relative humidity, which creates a stronger vapor pressure gradient (DONG et al., 2024).

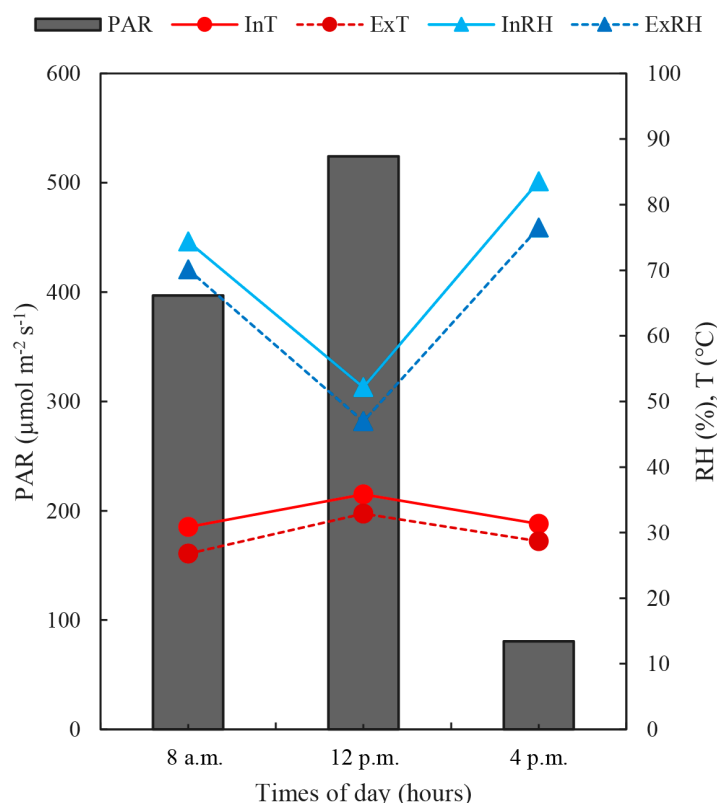


Figure 1. Photosynthetically active radiation (PAR), internal (InT) and external (ExT) air temperature, and internal (InRH) and external (ExRH) relative humidity as a function of time of the day.

As the temperature and PAR increased, the relative humidity (InRH and ExRH) decreased (Figure 1). The decrease in relative humidity, both internal and external, throughout the day can be attributed to increases in PAR and air temperature, as observed by Ribeiro and Coêlho (2021).

The highest CO_2 assimilation (A) value ($14.10 \mu\text{mol m}^{-2} \text{s}^{-1}$) was recorded at 12 p.m., under a PPFD of $2000 \mu\text{mol m}^{-2} \text{s}^{-1}$ (Figure 2B). Typically, photosynthesis increases with PPFD only up to an optimal light-saturation point, beyond which excessive light can act as a photosynthetic inhibitor. However, the results indicate that the high experimental irradiances favored CO_2 assimilation, demonstrating that high PPFD values stimulate photosynthetic mechanisms that maximize photon absorption and light-use efficiency, characterizing an adaptive strategy of *A. obesum* in high-light environments (COÊLHO et al., 2023).

At 8 a.m. and 4 p.m., the A values were reduced compared to those observed at 12 p.m. (Figures 2A and 2C). Stomatal conductance (gs) followed a similar trend, showing the highest value when the PPFD reached $1800 \mu\text{mol m}^{-2} \text{s}^{-1}$, recorded at 12 p.m. (Figure 2E). The regulation of gs occurs through guard cells, which adjust stomatal opening and closure in response to environmental stimuli, especially light

intensity, which, in general, favors stomatal opening at high irradiances (DANG et al., 2024).

In the evaluations at 8 a.m. and 4 p.m., gs increased to $2000 \mu\text{mol m}^{-2} \text{s}^{-1}$, with reductions of 6.25% and 50%, respectively, compared with that observed at 12 p.m. (Figures 2D and 2F). It is important to note that, in addition to light, temperature also directly influences this process, since under higher conditions there is a tendency to increase gas exchange, favoring evaporative cooling and contributing to the thermal acclimatization of the plant, as long as water availability is adequate, which helps in thermal protection under extreme temperature conditions (URBAN et al., 2017; FAUSET et al., 2019).

The transpiration rate (E) showed similar behavior across the three times evaluated (Figures 3A, 3B and 3C). The highest E value was observed at 12 p.m., coinciding with the highest temperature of the day, reaching $4.52 \text{ mmol m}^{-2} \text{s}^{-1}$ at a PPFD of $2,000 \mu\text{mol m}^{-2} \text{s}^{-1}$ (Figure 3B). The increase in PPFD led to higher transpiration rates, without signs of stomatal closure, as both A and gs reached their maximum values at 12 p.m., coinciding with the highest transpiration rates.

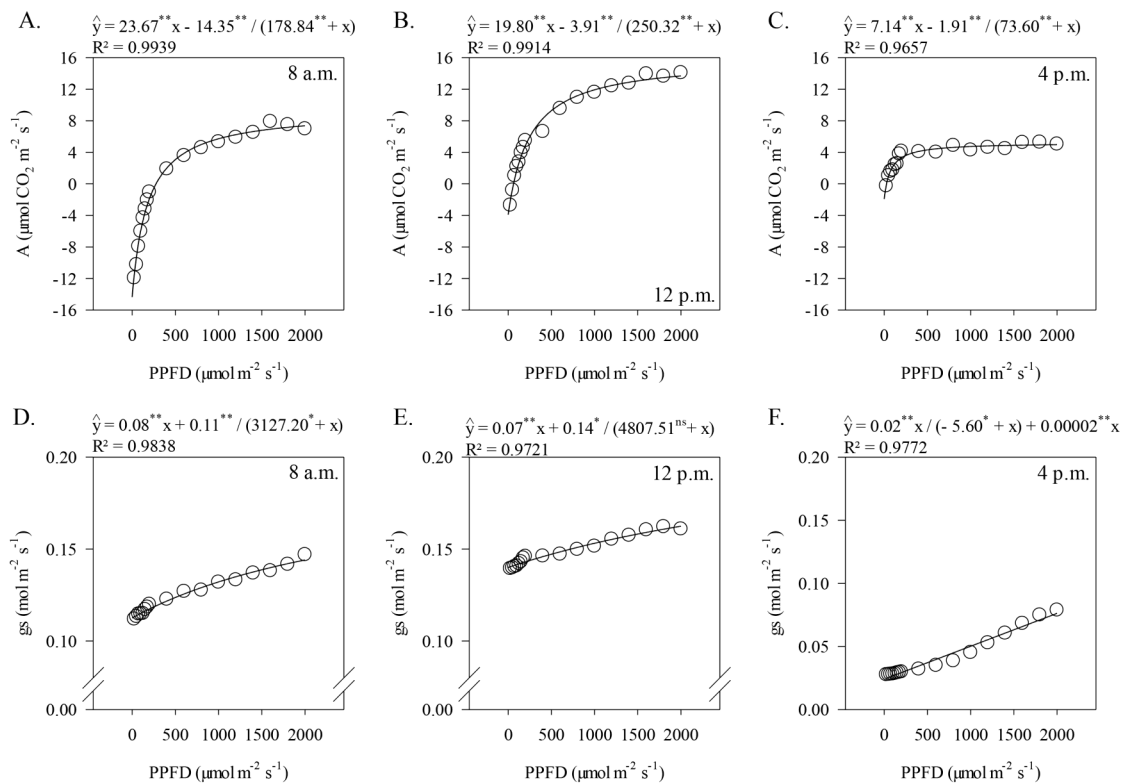


Figure 2. CO₂ assimilation rate (A) and stomatal conductance (gs) in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1%; *: significant at 5%; ns: not significant by the F test.

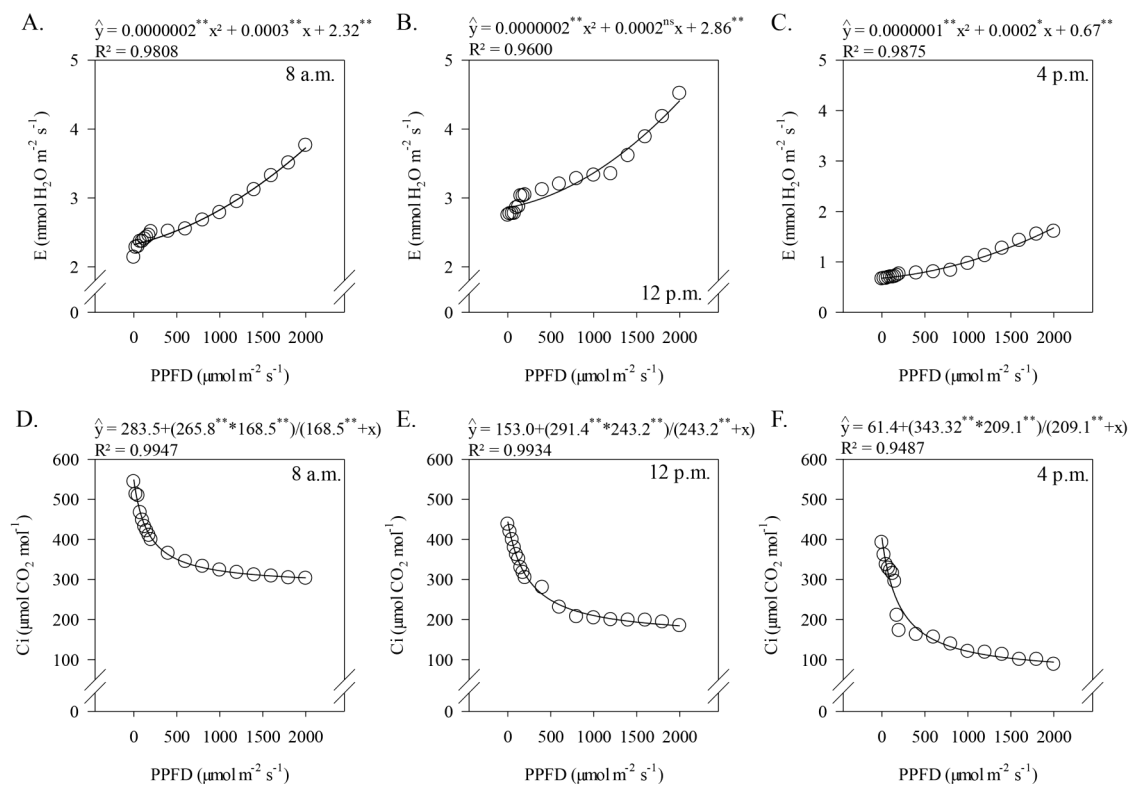


Figure 3. Transpiration (E) and internal CO₂ concentration (Ci) in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1%; *: significant at 5%; ns: not significant by the F test.

At 8 a.m. and 4 p.m., the maximum values of E were lower, representing reductions of 16.15% and 64.38%, respectively, compared with those recorded at 12 p.m. This result indicates that, during the hottest part of the day, *A. obesum* plants kept their stomata open to facilitate leaf cooling through water vapor loss. Given that high temperatures reduce relative humidity and increase vapor pressure deficit (VPD), it is plausible that the steeper VPD gradient stimulated the observed transpiration. However, although high VPD values may favor transpiration and leaf cooling, when the physiological threshold is exceeded, partial stomatal closure and reduced photosynthesis can occur (YU et al., 2023; BINSTOCK; MANANDHAR; MCADAM, 2024). Thus, the results suggest that stomatal regulation and transpiration in *A. obesum* act in an integrated manner, balancing gas exchange and thermal regulation.

Concomitantly, the internal CO_2 concentration (C_i) decreased as irradiance increased (Figures 3D, 3E and 3F). The decrease in C_i observed throughout the day indicates that, under high irradiance, the rate of CO_2 consumption by photosynthesis exceeds its diffusion into the leaf interior, resulting in lower C_i (BALIGAR et al., 2021). This behavior, particularly the association between low C_i values and high A

and g_s values (Figure 2), indicates greater carbon fixation by the enzyme RuBisCO (FAUSET et al., 2019).

Conversely, the increase in C_i in the early hours of the day (and at lower PPFD levels) may be related to lower initial photosynthetic demand, which favors the accumulation of CO_2 in the intercellular spaces (WANG; DANG, 2023). Additionally, the reduction in C_i under high PPFD is not solely due to lower stomatal conductance, but also to an increase in CO_2 demand imposed by photosynthesis (BALIGAR et al., 2021). These results reinforce the ability of *A. obesum* to adjust carbon assimilation in response to light fluctuations.

The vapor pressure deficit (VPD) reached the highest values at 12 p.m. (Figure 4), reaching a maximum value of 3.46 kPa when the PPFD reached $2000 \mu\text{mol m}^{-2} \text{s}^{-1}$ (Figure 4B). The increase in VPD throughout the day is due to the combination of high temperature and low relative humidity, which contribute to a higher vapor pressure gradient (DONG et al., 2024). Although high VPD values may favor transpiration and leaf cooling, when the physiological threshold is exceeded, partial stomatal closure and reduced photosynthesis occur (BINSTOCK; MANANDHAR; MCADAM, 2024).

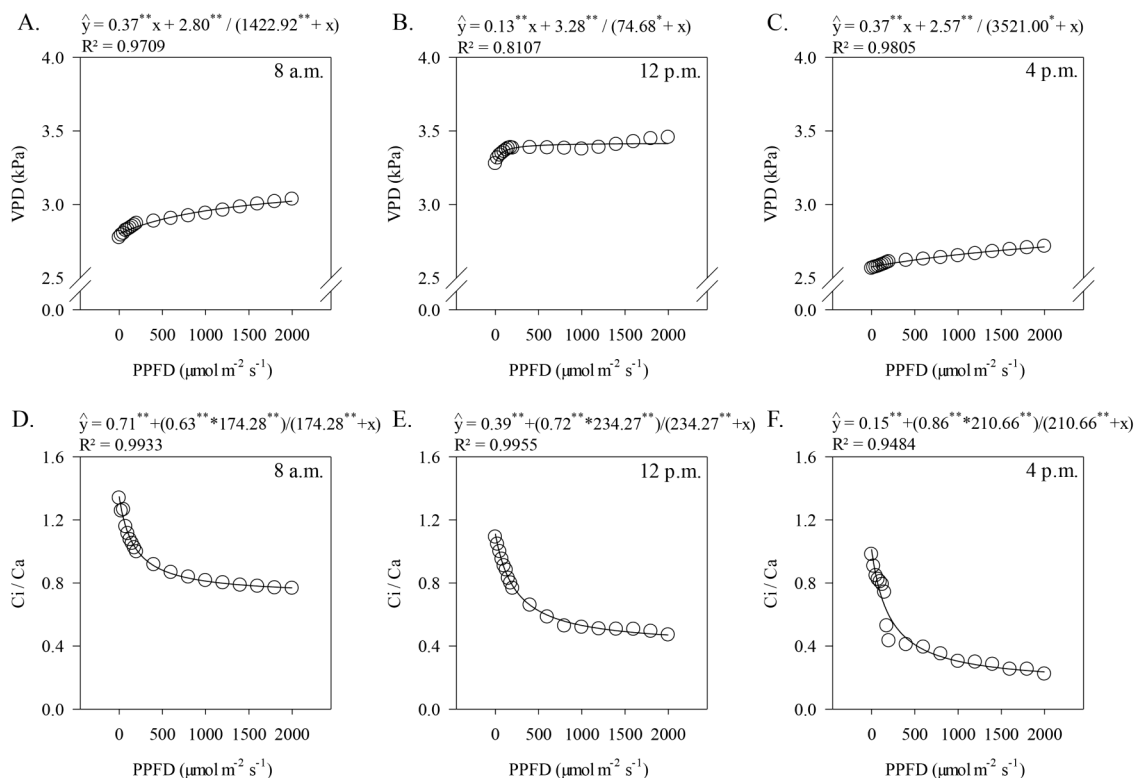


Figure 4. Vapor pressure deficit (VPD) and internal and external carbon ratio (C_i/C_a) in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1%; *: significant at 5% by the F test.

For the relationship between the internal and external carbon of the leaf (C_i/C_a), the highest value (1.33) was obtained at 8 a.m., when the PPFD reached $0 \mu\text{mol m}^{-2} \text{s}^{-1}$ (Figure 4D). This value decreased as the PPFD increased. This behavior indicates that, under high irradiance, greater CO_2 assimilation leads to a decrease in internal concentration

(C_i) and, consequently, in the C_i/C_a ratio.

Mechanistically, when the stomata partially close, CO_2 input is limited, reducing its availability in the mesophyll and decreasing this ratio (BEAUCLAIRE; VANDEN BRANDE; LONGDOZ, 2024). However, the reduction in C_i under high PPFD is not solely due to lower stomatal conductance, but

also to an increase in CO₂ demand imposed by photosynthesis (BALIGAR et al., 2021). Thus, under higher light intensity, greater photosynthetic activity increases the consumption of internal CO₂, resulting in lower values of C_i and, therefore, of C_i/C_a.

Regarding chlorophyll fluorescence parameters, the maximum fluorescence (F_m') values increased as the PPFD

increased (Figures 5A, 5B and 5C). This increase under high irradiance indicates greater efficiency in the capture and use of light energy by photosystem II (PSII), favoring electron transport and the production of NADPH and ATP, which are essential for carbon assimilation (RIBEIRO et al., 2022; RIBEIRO et al., 2024).

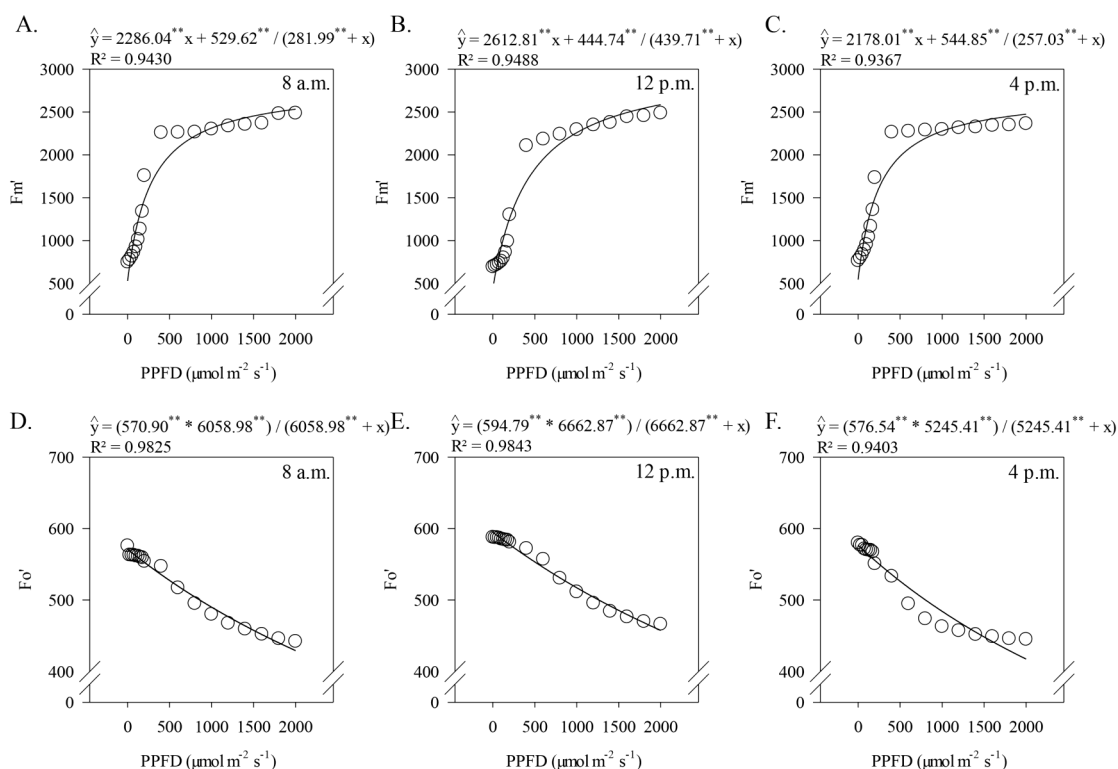


Figure 5. Maximum fluorescence (F_m') and initial fluorescence (F_o') in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1% by the F test.

On the other hand, initial fluorescence (F_o') showed the opposite trend, with the highest values obtained at a PPFD of 0 μmol m⁻² s⁻¹ in all hours analyzed, with the highest value (587.71 electrons quantum⁻¹) observed at 12 p.m. (Figures 5D, 5E and 5F). Higher values under low irradiance indicate reduced QA accumulation and limitations in electron transport (SWOCZYNA et al., 2022). This behavior suggests the presence of partially inhibited reaction centers, which reduce photochemical efficiency and photosynthetic performance.

Variable fluorescence (F_v') showed trends similar to that of the potential quantum yield of PSII (F_v'/F_m') (Figure 6), with higher values with increasing PPFD, reaching maximum values at all evaluation times when PPFD reached 2000 μmol m⁻² s⁻¹. This parameter, obtained by the difference between F_m' and F_o', reflects the ability of the photosynthetic tissue to adapt to variations in luminosity, representing the maximum potential for electron transport in the photochemical stage (SOUZA et al., 2019).

The highest values of F_v' and F_v'/F_m' were recorded at 8 a.m. (Figures 6A and 6D). Higher F_v' values under high PPFD indicate greater electron transport capacity and carbon

assimilation, as long as photoinhibition does not occur (LI et al., 2023). Similar trends were observed at 12 p.m. and 4 p.m. (Figures 6B, 6C, 6E, and 6F). Conversely, the reduction in the F_v'/F_m' ratio under low irradiance suggests a limitation of chlorophyll excitation and a consequent reduction in the efficiency of light absorption and utilization (GUIDI; LO PICCOLO; LANDI, 2019).

The ratio between variable and initial fluorescence (F_v'/F_o') reached the highest values with the PPFD of 2000 μmol m⁻² s⁻¹ (Figures 7A, 7B and 7C). Biologically, the increase in the F_v'/F_o' ratio with the increase in PPFD indicates a greater capacity of the PSII to transfer energy (NOOR et al., 2022; SANTOS et al., 2025). Following the same trend, the effective quantum efficiency of the PSII (ΦPSII) increased according to the highest PPFD values, with the maximum values of 0.794, 0.785, and 0.770, at the evaluation moments of 4 p.m., 8 a.m., and 12 p.m., respectively, with the PPFD of 2000 μmol m⁻² s⁻¹ (Figures 7D, 7E and 7F). This behavior corroborates the high capacity of *A. obesum* to maintain photosynthetic function even under high light intensities.

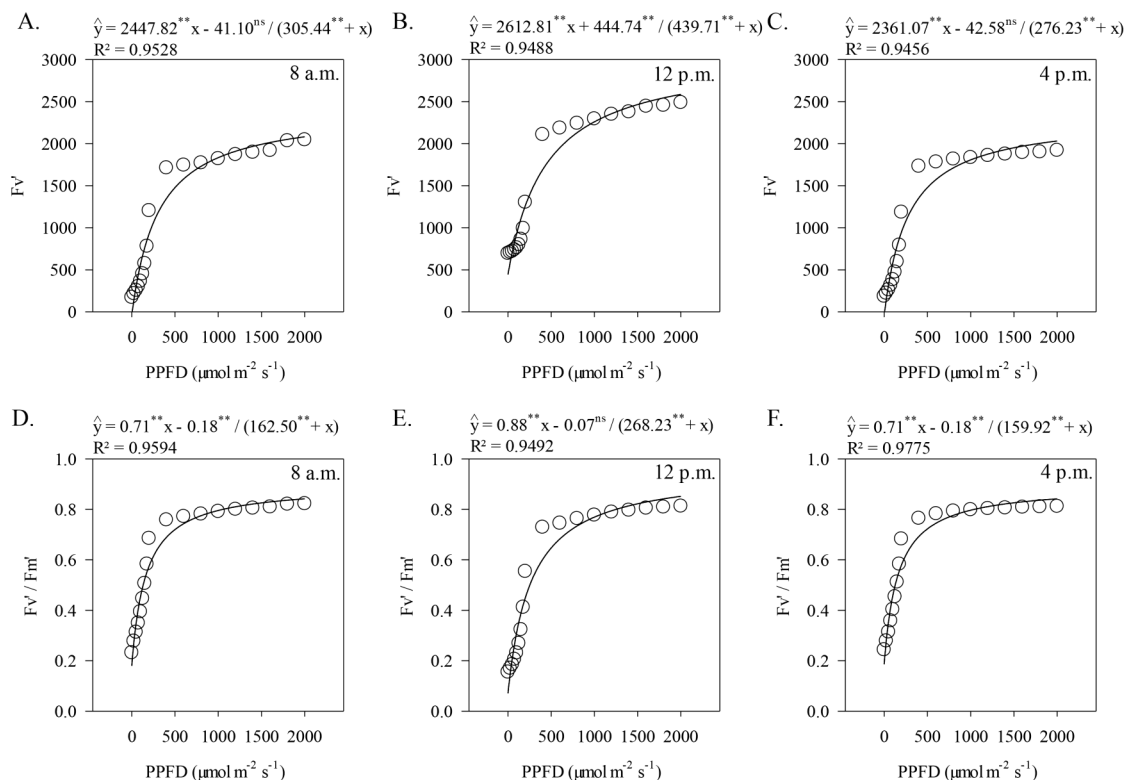


Figure 6. Variable fluorescence (Fv) and potential quantum yield of PSII (Fv/Fm') in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1%; ns: not significant by the F test.

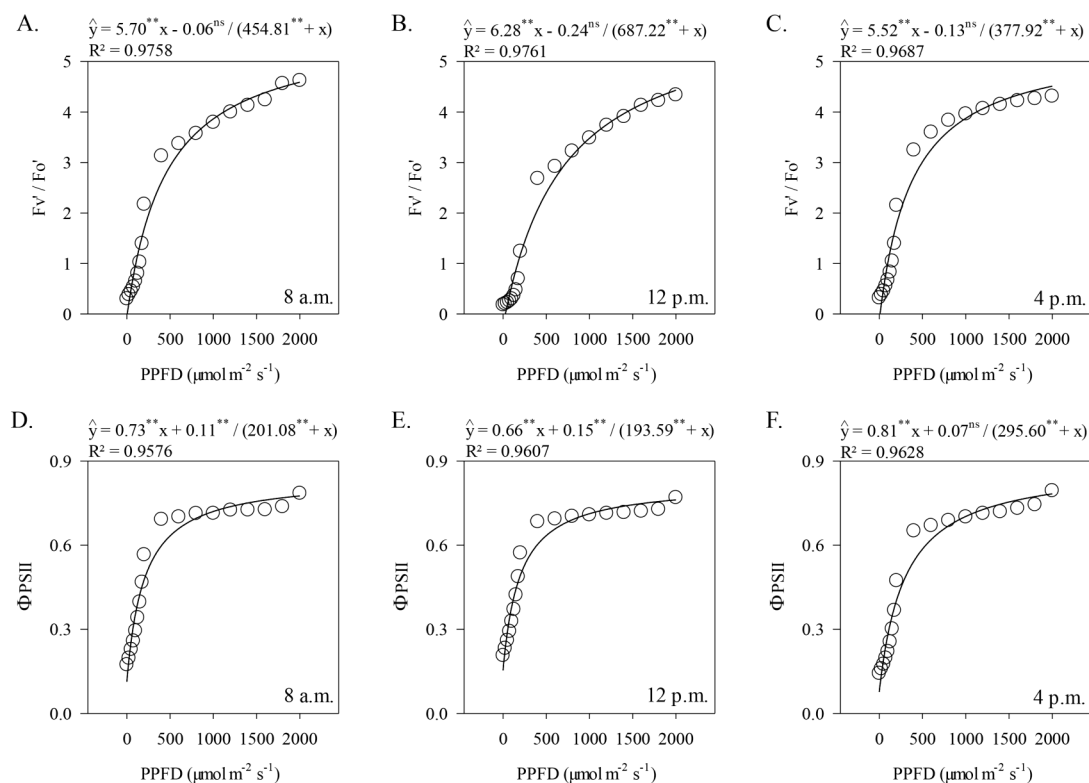


Figure 7. Ratio between variable and initial fluorescence (Fv/F0') and effective quantum efficiency of PSII (ΦPSII) in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1%; ns: not significant by the F test.

Regarding the dissipation coefficients, photochemical quenching (qP) increased with PPFD, reaching its highest values at 2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at all times evaluated. The maximum value of qP (1.025) was observed at 4 p.m., followed by 12 p.m. (1.015) and 8 a.m. (1.011) (Figures 8A,

8B and 8C). The increase in qP at high luminous intensities indicates a higher proportion of PSII reaction centers in the oxidized state, reflecting a higher flux of electrons to photosystem I (TOPCHIIY et al., 2020).

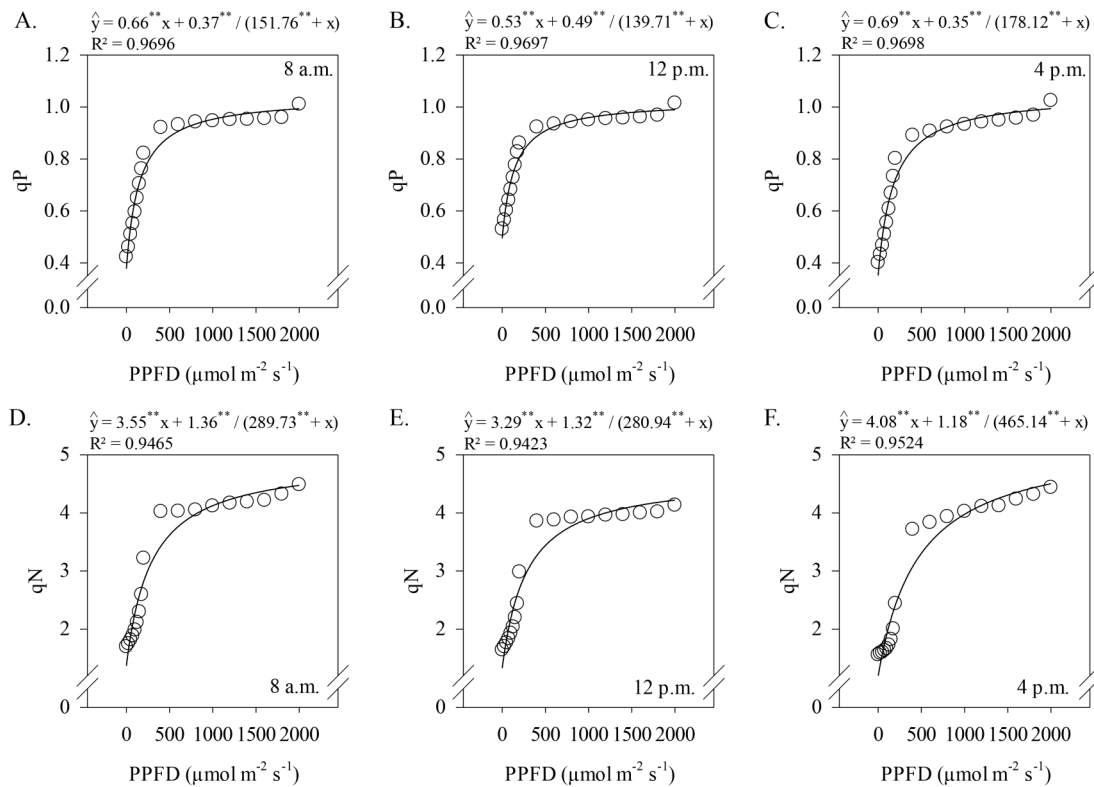


Figure 8. Photochemical dissipation (qP) and non-photochemical dissipation (qN) in *A. obesum* as a function of PPFD at (A, D) 8 a.m., (B, E) 12 p.m., and (C, F) 4 p.m. **: significant at 1% by the F test.

The increase in qN is associated with the dissipation of excess energy as heat, a fundamental mechanism to prevent photo-oxidative damage and photoinhibition (LAI et al., 2022). Therefore, the simultaneous increase in qP and qN suggests that *A. obesum* employs an efficient dual strategy: it maximizes the photochemical use of energy (high qP) while safely dissipating excess energy (high qN), ensuring high

photosynthetic performance without photoinhibition during the hottest hours of the day.

The electron transport rate (ETR) reached its highest value ($183.04 \mu\text{mol m}^{-2} \text{s}^{-1}$) at 12 p.m., when the PPFD was $1800 \mu\text{mol m}^{-2} \text{s}^{-1}$, and showed a tendency to stabilize or slightly decrease with increasing PPFD beyond this point (Figure 9).

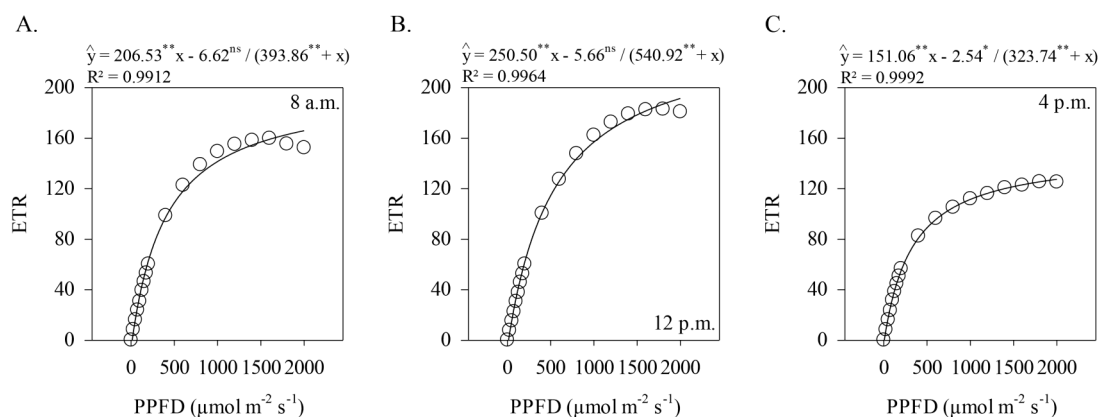


Figure 9. Electron transport rate (ETR) in *A. obesum* as a function of PPFD at (A) 8 a.m., (B) 12 p.m., and (C) 4 p.m. **: significant at 1%; *: significant at 5%; ns: not significant by the F test.

The high ETR values observed, especially at noon, reflect the efficiency of photosystem II in supplying electrons for ATP and NADPH production, which are energy substrates required for the Calvin cycle (RIBEIRO et al., 2022). This behavior is consistent with the high rates of CO₂ assimilation (A) observed at the same time (Figure 2). Furthermore, the maintenance of high ETR, associated with high thermal dissipation (qN), confirms that *A. obesum* possesses a robust photoprotective system, capable of processing high light energy fluxes without compromising the integrity of the photosynthetic apparatus, which directly explains the absence of photoinhibition in this study. The efficient diversion of excess excitation energy as heat (qN) prevents over-reduction

of Photosystem II, serving as a vital survival strategy under extreme irradiances.

To synthesize the interaction between environmental and physiological variables, a Pearson's correlation analysis was performed (Figure 10). The results indicate that abiotic factors, particularly PAR and VPD, significantly influence the physiological responses of desert rose plants. PAR showed positive correlations with gas exchange variables, such as stomatal conductance (gs) and transpiration (E), but showed negative or weak correlations with chlorophyll fluorescence variables (Fm', Fv', Fv/Fm', Fv/F0') and strong negative correlations with relative humidity variables (lnRH and ExRH) (Figure 10).

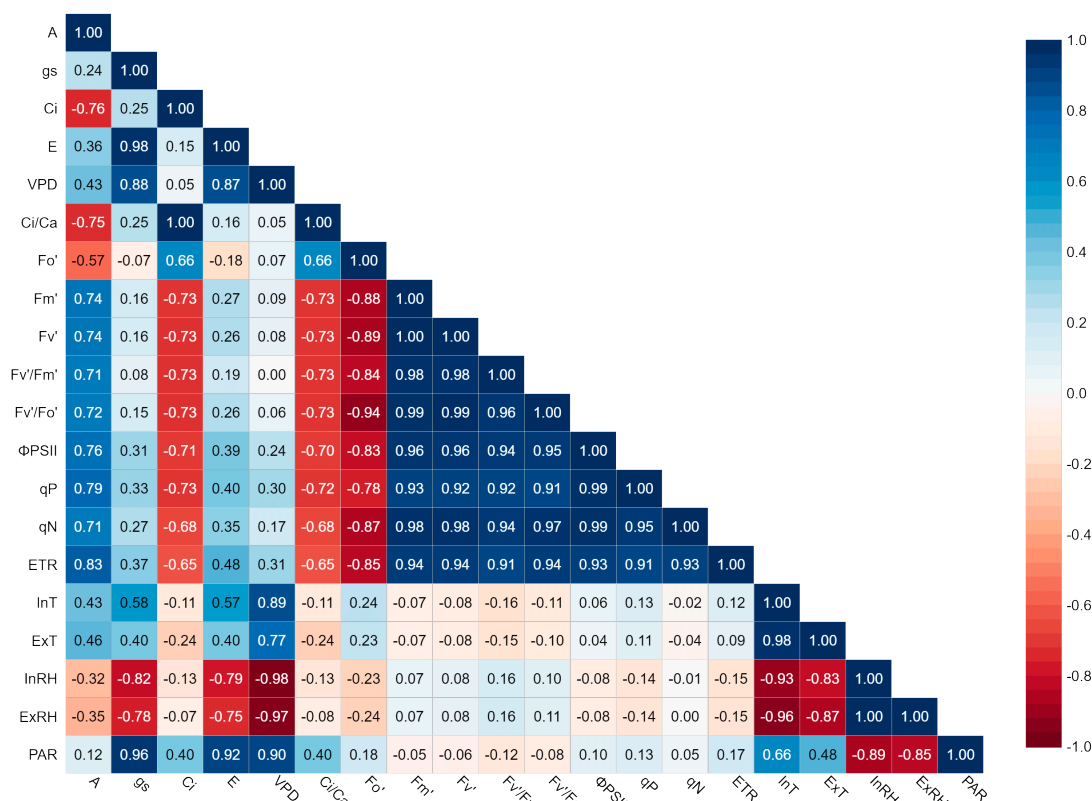


Figure 10. Pearson's correlation between ecophysiological and climatic variables in *A. obesum* plants.

Net CO₂ assimilation rate (A) was positively correlated with fluorescence parameters such as Fm' (0.74), Fv' (0.74), and photochemical quenching (qP) (0.79). This strong correlation indicates that the photochemical efficiency of PSII was directly associated with higher CO₂ assimilation rates, confirming that the energy harvested was effectively used for carbon fixation. Furthermore, the positive relationship between A and non-photochemical quenching (qN) (0.71) suggests that heat-dissipation mechanisms contributed to preventing photo-oxidative damage under high irradiance, allowing photosynthesis to continue efficiently. It was also observed that VPD showed a strong positive correlation with leaf temperature (lnT) (0.89), reinforcing the combined role of radiation and evaporative demand in leaf heating. These results demonstrate that the interaction between gas exchange variables and chlorophyll fluorescence is determinant in modulating photosynthetic efficiency throughout the day, reflecting the desert rose's ability to adjust its photosynthetic

apparatus and photoprotective mechanisms in response to environmental variations.

CONCLUSIONS

The flux density of photosynthetically active photons and the environmental variations throughout the day exerted a marked influence on the physiological processes of the desert rose. The highest temperature, recorded at 12 p.m., associated with a PPFD between 1800 and 2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$, favored gas exchange, resulting in higher values of stomatal conductance (gs), CO₂ assimilation (A), transpiration rate (E) and vapor pressure deficit (VPD). In addition, chlorophyll *a* fluorescence benefited from PPFD of 2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$, except for initial fluorescence, which had higher values under PPFD of 0 $\mu\text{mol m}^{-2} \text{s}^{-1}$.

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